Cost Based Reliability Enhancement in a Power System by Appropriate Planning using Novel Evolutionary Technique

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Certificate from the Supervisor

This is to certify that the thesis entitled "**Cost Based Reliability Enhancement in a Power System by Appropriate Planning using Novel Evolutionary Technique**" submitted by Vivekananda Haldar, who got his name registered on 17th August, 2010 for the award of Ph.D. (Engg.) degree of Jadavpur University is absolutely based upon his own work under the supervision of Dr. Niladri Chakraborty, Professor, Department of Power Engineering, Jadavpur University and that neither his thesis nor any part of the thesis has been submitted for any degree/diploma or any other academic award anywhere before.

....

Signature of the supervisor and date with office seal

Dedicated

to

My Parents

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Nomenclature

λ^{fl}	**Failure rate**
λ_i^{fl}	**Failure rate of ith load point**
λ_i	**Failure rate of ith component**
λ_{avg}^{fl}	**Average failure rate**
r_i	**Outage time of ith component**
r_{avg}	**Average outage time**
An_{avg}^{out}	**Average annual outage time**
An_i^{out}	**Annual outage time of ith load point**
$R(t)$	**Reliability at time *t***
$N_s(t)$	**Surviving population at time *t***
N_o	**Original population**
$N_f(t)$	**Population fails after a certain time *t***
N_i^{cus}	**Number of customers at ith load bus**
nl	**Total number of load bus**
La_i	**Load connected at ith bus**
PIC^{ini}	**Power interruption cost without DG and capacitor placement**
PIC^{it}	**Power interruption cost after DG and capacitor allocation**
$loss^{ini}$	**Real power loss without DG and capacitor placement**
$loss^{it}$	**Real power loss after DG and capacitor placement**
$cost^{it}$	**Calculated total cost value after DG and capacitor allocation**
C_i	**Composite customer damage function at ith load bus**
nb	**Total number of buses in the considered radial distribution system**
i, j	**Bus index**
nc	**Total number of capacitor installed at load buses**
ng	**Total number of DG allocated at load buses**
λ_{i-new}^{fl}	**New failure rate of ith branch after DG and capacitor placement**
λ_{i-line}^{fl}	**Failure rate of ith branch without DG and capacitor allocation**
λ_{i-min}^{fl}	**Minimum failure rate of ith branch**
α	**Ratio of currents after and before capacitor and DG placement**
I_{new}	**Value of current after DG and capacitor placement**
I_{old}	**Value of current without DG and capacitor allocation**
DG_i	**Distributed generation allocated at ith bus**
K_i	**Capital cost of DG unit installed at ith bus**
V^{min}	**Minimum p.u voltage**
V^{max}	**Maximum p.u voltage**
V_i	**Voltage at ith bus in p.u**

Q_j^L	**Reactive power load at *j*th bus**
DG^{limit}	**Maximum allowable DG value**
$F(x)$	**Multi objective function**
x	**Decision variable**
$f_1(x), f_2(x), f_3(x), f_4(x), f_5(x)$	**Singular objective functions**
W_i	**Pseudo weight value of ith conflicting objective**
f_i^{max}	**Obtained maximum value of *i*th conflicting objective**
f_i^{min}	**Obtained minimum value of *i*th conflicting objective**
f_i	**Value of ith conflicting objective**
M	**Total number of conflicting objectives in a solution**
Wt_j^{chosen}	**Chosen weight value of *j*th conflicting objective**
$dev(j)$	**Deviation value of *j*th conflicting objective**
dev^{total}	**Total deviation value for decision making**
K_P	**Dollar conversion constant for loss**
$Eloss$	**Energy loss**
$T_{lifetime}$	**Life time of the considered project**
K_j	**Dollar conversion constant for capacitor installation**
K_i	**Capital cost considered for DG placement**
S_{cost}	**Combined cost after capacitor allocation**
Q_j	**Value of capacitor installed at *j*th bus**
PIC	**Power interruption cost or reliability worth**
α_i	**Ratio of current before and after capacitor allocation**
$Inew^i$	**Current flowing in ith branch after reactive power compensation**
$Iold^i$	**Current flowing in ith branch before capacitor placement**
λ^{new}	**New failure rate after capacitor allocation**
λ^{uncomp}	**Failure rate without reactive power compensation**
λ^{comp}	**Failure rate of electric line after full reactive power compensation**
$E, loss$	**Real power loss or energy loss**
$T, Cost$	**Total cost**
Cap_j	**Value of capacitor installed at *j*th bus**
$diff$	**difference between maximum and minimum limit of solution variable**
$longrange$	**a set of discrete values in** $longrange$
$shortrange$	**a set of discrete values in** $shortrange$
$p1_l, p2_l, p3_l$	**constant terms for** $longrange$ **formulation**
$p1_s, p2_s, p3_s$	**constant terms for** $shortrange$ **formulation**
$vshortrange$	**a set of discrete values in very short range**

$diff$	**difference between maximum and minimum limit of solution variable**
i, k, j	**index terms**
$slope, vs$	**electrical image slope, short distance interval value**
$xnew$,	**calculated solution value after evolution,**
x^{min}, x^{max}	**minimum and maximum limit of solution domain**
$elec^{pulse}$	**value of electric pulse for generation of new electrical wave**
$capu, capl$	**capacitor upper limit, capacitor lower limit**
$capint$,	**initial capacitor value,**
$caphover$	**capacitor value when the conceptual electro-fish is hovering and searching**
$rand, floor, fix, randperm, randn$ **and** $length$	**standard MATLAB® 7.0 library functions**
$rand^{i}$,	**random value for** ***i*** **th individual amongst population,**
$rand_{j}^{i}$	**random value for** ***i*** **th individual and** ***j*** **th variable**
$prob^{div}$, $prob^{sel}$	**probability of divergence, probability of selection**
$prob^{rng}$	**probability of range**
$x_{best}^{t}, x_{worst}^{t}$	**best found variable value at** ***t*** **th iteration, worst found variable value at** ***t*** **th iteration**
$ch1$ **and** $ch2$	**minimum and maximum value of objective function for the first iteration**
$g1, g2$	**constant terms for distance calculation**
cap^{run}	**running capacitor value**
$toggle$	**toggle switch or changeover switch**
$\sigma(x_i)$	**symbol for standard deviation function**
$slope^{const}$	**a constant value for** $elec^{pulse}$ **generation**
$s, m1$ **and** $m2$	**array of random index terms concerning to the length of** $longrange, shortrange$ **and** $vshortrange$
$n, h1$ **and** $h2$	**selected random value from** $s, m1$ **and** $m2$
$c2$ **and** $c3$	**values concerning to** $shortrange$ **and** $vshortrange$
PS, BS	**Population Space, Belief Space**
$PSI, PSII$	PS **for distributed generator penetration,** PS **for capacitor allocation**
SK, HK	**Situation Knowledge, History Knowledge**
$SKI, SKII$	SK **for** PSI, SK **for** $PSII$
$HKI, HKII$	HK **for** PSI, HK **for** $PSII$
$PPI, PPII$	**Population Pool for DG penetration, population pool for**

	capacitor allocation.
f_{eff}	BS **effective factor**
fI_{eff} **and** fII_{eff}	BS**'s** f_{eff} **for** PSI **and** $PSII$
$Blfbst$	BS**'s best individual**
$BlfbstI$ **and** $BlfbstII$	$Blfbst$ **for** PSI **and** $PSII$

List of abbreviations

rcGA	**Real coded genetic algorithm**
PSO	**Particle swarm optimization**
MCA	**Modified cultural algorithm**
FEO	**Fish electrolocation optimization**
DG	**Distributed generation**
SAIFI	**System average interruption frequency index**
SAIDI	**System average interruption duration index**
CAIDI	**Customer average interruption duration index**
ASUI	**Average service unavailability index**
ASAI	**Average service availability index**
AENS	**Average energy not supplied**
CBRI	**Cost based reliability index**
LOLE	**Loss of load expectation**
LOEE	**Loss of energy expectation**
IEEE	**Institute of electrical and electronics engineers**
EDN	**Electrical distribution network**
FTN	**Feeder terminal node**
SOAP	**Simple object access protocol**
SCADA	**Supervisory control and data acquisition**
HTTP	**Hyper text type protocol**
XML	**Extensible markup language**
ACS	**Automatic control system**
LRS	**Loop restoration scheme**
PV	**Photovoltaic**
EUP	**Expected unserved power**
TVWF	**Time varying weight factor**
TVFR	**Time varying failure rate**
TVRT	**Time varying restoration time**
WHPS	**Wind hydro pumped storage**
UPFC	**Unified power flow controller**
SM	**System minutes**
SRAT	**Sag and reliability assessment tool**
DC	**Direct current**
AC	**Alternating current**
IGA	**Improved genetic algorithm**
IEAR	**Interrupted energy assessment rate**
ECOST	**Expected interruption cost**
AAM	**Average or aggregated model**
PDM	**Probabilistic distribution model**

RBF	**Radial basis function**
OLS	**Orthogonal least squares**
VBRP	**Value based reliability planning**
SAMBA	**Self adaptive modified bat algorithm**
ISFLA	**Improved shuffled frog leaping algorithm**
CAPSO	**Coordinated aggregation based particle swarm optimization**
DSTATCOM	**Distributed static compensator**
FACTS	**Flexible alternating current transmission system**
HVDC	**High voltage direct current**
VSC	**Voltage source controller**
DVR	**Dynamic voltage restorer**
DUPS	**Dynamic uninterruptible power supply**
CDF	**Customer damage functions**
SCDF	**Sector customer damage function**
CCDF	**Composite customer damage function**
TOPSIS	**Technique for order preference by similarity to ideal solution**

Abstract

Cost based reliability enhancement in a power system is a critical and complex combinatorial optimization problem. This enhancement is much necessary when deregulated business environment is developing very fast particularly in microgrid sector. Actually these business domains these days may be very small in size say in the range of a few megawatts or in moderate form in the range of a few tens of megawatts. Whatsoever be the size the reliability of a power system especially of a microgrid type radial distribution system can be enhanced by incorporating distributed generators and applying shunt capacitors at suitable locations as line losses will be substantially reduced by such incorporation. Reliability can also be improved by performing network reconfiguration. Obviously these activities have economical implications. Here in this work reliability has been found to be increased economically by incorporating shunt capacitors and distributed generators at the proper locations in a microgrid type radial distribution system. Appropriate planning has been performed for selecting proper value and location for capacitor as well as distributed generation (DG). Distributed generations have been incorporated considering these are catering 10%, 15% and 20% of the total active power load. Study has also been performed considering DG integration at 50% of total real power load keeping a futuristic plan in mind. Standard thirty four bus and sixty nine bus microgrid type radial distribution systems have been chosen for simulation. On the other hand, reliability indices' studies have been performed considering two common reinforcement schemes. One is applying only disconnects or isolator between two buses and the other one is based on introducing lateral protection with disconnects. These reinforcement schemes have been chosen to make the microgrid radial distribution system realistic. Furthermore, those schemes have been considered to study any kind of contingencies leading to failure of distribution line. It is well known that failure of electric line can be reduced by decreasing the real power loss of it. Distributed generator integration reduces the real power loss by decreasing the loading effect of electric line thereby improving reliability. On the other hand, reactive power compensation by shunt capacitor has the objective of reducing real power loss. This also helps to reduce failure rate of electric line improving reliability. Here distribution system reliability indices viz. *system average interruption frequency index* (SAIFI), *system average interruption duration index* (SAIDI), *customer average interruption duration index* (CAIDI), *average system unavailability/ availability index* (ASUI/ASAI), *average energy not supplied* (AENS) and a newly developed *cost based reliability index* (CBRI) have been thoroughly investigated in connection to the microgrid radial distributed system. To perform reliability improvement vis. a vis. cost minimization, single objective optimization study has been exercised. Additionally a few important reliability indices viz. SAIFI, SAIDI and AENS have been found to be improved while performing minimization. The total cost, loss, SAIFI, SAIDI and AENS are generally conflicting objectives. It is also observed that single objective optimization can't always give the clear picture of the problem under question. Therefore the stated five conflicting objectives have been studied in multi-objective environment having either two or five objectives competing with each other. The selection of the appropriate solution has been done providing equal importance to five conflicting objectives for thirty four bus microgrid type radial distribution system. On the other hand, for sixty nine bus microgrid type radial distribution system unequal weightage values for objectives have been considered for different customers to observe variance in solutions between these two microgrid based radial systems. The total number of customers has been selected based on realistic distribution system data for sixty nine bus microgrid type radial distribution system.

On the other hand, for 34 bus microgrid type system lump sum values of loads has been assigned to buses for selection of number of customer. Actually the number of customers is related to different reliability indices. Justification for choosing different weight values for various customers viz. rural, urban, hospital, office/building, industrial, commercial etc has been provided. Load enhancement has been exercised in 69 bus microgrid type radial distribution system to have a reflection of futuristic load growth. Studies related to cost reduction, energy loss minimization and improvements of SAIFI, SAIDI and AENS have been performed in this enhanced load model considering the deregulated business environment. In the soft computing front, two novel algorithms have been mathematically developed. This is the significant thing of this research work.

To have the optimal solution for single objective as well as multi-objective environment soft computing methods especially novel evolutionary techniques have been developed inspired from natural phenomena. Fish's electro location phenomenon has been considered to be taken as the concept for algorithm. Elephant nose fish *Gnathonemus petersii* and shark fish's active and passive electro location have been mathematically mimicked as fish electrolocation optimization (FEO) as novel evolutionary technique. On the other hand, a well established algorithm called cultural algorithm has been effectively modified to apply in this cost based reliability enhancement problem. The said modification to original cultural algorithm evolved as a modified cultural algorithm which has given the desired strength and potential to solve the mentioned critical and complex combinatorial optimization problem. The interesting thing in this work is to study the competitiveness amongst the newly developed and chosen evolutionary techniques for achieving the highest cost based reliability enhancement. Comparative studies have been performed amongst particle swarm optimization (PSO), real coded genetic algorithm (rcGA), fish electrolocation optimization (FEO) and modified cultural algorithm (MCA). It has been observed that total cost has been reduced from its initial value i.e. without DG and capacitor connectivity after suitably placing capacitors and distributed generators by the application of rcGA, PSO, MCA and FEO techniques in 34 bus microgrid type radial distribution system. The best total cost values have been achieved by FEO technique at a maximum of 10% and 20% DG penetration considering reinforcement scheme as disconnects with lateral protection. Reliability improvements have been conceived by the application of four considered algorithms after performing minimization of SAIFI, SAIDI and AENS. The SAIFI value has been observed to be reduced from 5.240010 interruption/customer yr to 5.052301 interruption/customer yr by the implementation of FEO technique after suitably placing DG and capacitor at a maximum of 10% DG penetration in 34 bus microgrid type distribution system. The least AENS value has been obtained by FEO technique at 1.956178 kWh/customer yr amongst all the chosen algorithms considering DG penetration up to 20% in 34 bus microgrid type distribution system. The best outcomes related to real power loss minimization, total cost reduction and improvement of SAIDI and AENS have been achieved by MCA technique considering a maximum of 50% DG penetration in 34 bus microgrid type system. Five and eleven pareto-optimal solutions have been obtained by the implementation of MCA and FEO techniques after performing multi-objective optimization in 34 bus microgrid type system considering five conflicting objectives and a maximum of 50% DG penetration. On the other hand, fifteen and twenty one non-dominated solutions have been achieved by the application of FEO and MCA techniques after performing multi-objective optimization in 69 bus microgrid type distribution system considering five conflicting objectives and DG penetration up to 50%. Finally total cost, energy loss, SAIFI, SAIDI and AENS have been observed to be reduced from intial values i.e. without placing DG and capacitor by the application of rcGA, PSO, MCA and FEO techniques in enhanced load 69 bus microgrid type system considering a maximum of 20% DG penetration. The results showed that reliability improvement as well as cost reduction and loss minimization have been successfully achieved by appropriate planning considering optimal capacitor allocations and DG integrations for present and futuristic situations.

Chapter 1

Introduction

Now-a-days electricity is an essential commodity like food, shelter and clothing. Electrical power is mainly generated in power plants. This may be generated from non-renewable or renewable energy sources. Non-renewable energy sources are fossil fuel based such as coal, oil and gas. Renewable energy sources are wind, hydro, solar, biomass, geothermal, tidal etc based systems. However, in most of the cases after generation from power plant the electrical power is transmitted through transmission lines and transformers. Transmission system therefore comes after generating stations. Transmission and sub-transmission substations work as voltage modifier before distribution system. Sometimes in those stations the voltage is stepped down for supply power to the large and industrial consumers. After feeding power to those big consumers the voltage is again stepped down in distribution system. Office, shopping mall, commercial buildings, government institution and residential buildings fall mainly under the distribution system. Adequate power supply with standard voltage and frequency is necessary in this regard to these customers. Every consumer, whether large or small, requires electrical power for twenty four hours which has to be safe and secure. Reliability of power system especially in distribution system is important in this case. Faults in distribution system for lines and cables carrying excess current may lead to overheating of these equipments. This may cause breakdown and reduce reliability of supply. This can be improved by performing optimal capacitor allocation, distributed generation integration, proper protection equipment and switch selection, network reconfiguration etc. Customer behaviour, fault occurrence and also social and political phenomena can influence the nature of load change in the distribution system where mainly domestic customer resides. The newly developed restructured power scenario is important to be understood in this regard.

1.1 Restructured power scenario

Deregulation is prevailing in the electrical power industry. Previously the power system was regulated by single authority such as government. Generation, transmission and distribution were connected to the end users through monopolistic business. Earlier there was no evidence of multiple generation, transmission and distribution companies in the power system network. Now-a-days the system has been changed. There are more than one generation, transmission and distribution companies. Reliable and economic power is must for sustainable business purpose as the business has become competitive. Most of the consumers reside in distribution network as end utility users. They want not only uninterrupted power but also crave for standard voltage and frequency. Sag or dip in the voltage of the overhead line or underground cable causes damage of electrical appliances. Power electronics based voltage control can improve the voltage profile. FACTS devices are significant for that purpose. On the other hand high voltage transmission reduces the real power loss and enhances the voltage profile. HVDC transmission is important to study in that regard. Power producing and distribution companies should therefore consider all the technical aspects i.e. power, voltage, frequency etc available in standard value for business sustainability. Cost is now connected to all these technical aspects in totality.

It is quite obvious fact that fossil fuel will be exhausted in near future. The non-conventional or renewable energy sources are therefore the in thing for the present scenario. Integration of distributed energy sources (DER) considering solar, wind, biomass, tidal, geothermal etc are therefore important to understand as the system is now becoming hybrid interconnected one. These stated renewable sources can be utilized to provide electrical power in the competitive environment. On the other hand, distributed generation (DG) integration to the interconnected power system or grid for loss minimization has now becoming important for business sustainability. Before going to that detail, interconnected power system or the conventional grid has to be revisited once again quickly for proper perception.

1.1.1 Interconnected power system or grid

An electrical power system is comprised of generating system, transmission system, sub-transmission system, and distribution system. The generation and transmission structure are considered as bulk power supply providing system. The sub-transmission and distribution system are the ultimate means to feed electrical power to the consumers [1].

Reliable electric power systems provide uninterrupted power to the consumer. Generation system must generate sufficient power to meet customer demand. Transmission system must transmit large amount of power over extensive distances without overheating or endangering the stability of the system. Distribution system must deliver electrical energy according to each consumer's demand. Electric power system consists of several subsystems. These are Generation subsystems, Transmission subsystems and Distribution subsystems. Generation subsystems include generation plants and generation substations. Generation plants generate electrical energy from another form of energy such as fossil fuels, nuclear fuels, or hydro power. In a turbo-generator set, prime mover turns the generator that produces voltage. Generation substations connect generation plants to transmission cables through a step-up transformer which increments voltage up to transmission level. Transmission systems transmit electricity over extensive distances from generation substation to transmission or distribution substation. Transmission switching stations works as nodes in transmission systems which permit transmission line connection to be reconfigured. Transmission substations are transmission switching stations with suitable transformers which step down voltage level to sub-transmission levels. Sub-transmission systems transmit electrical power from transmission substation to distribution substations. Distribution substations are nodes for ending and reconfiguring sub-transmission line plus transformers which step down voltage to primary distribution levels. Primary distribution systems deliver electrical power from distribution substations to distribution transformers. Distribution transformers step down primary distribution voltage to utilization voltage. Secondary distribution systems transport electrical power from distribution transformers to consumer service points. These days apart from conventional fossil fuel based generation system, renewable based generation systems are coming up very fast. Many a times, these renewable based systems got connected to the conventional systems producing hybrid generation systems.

1.1.1.1 Generation system

Typical generation plants comprises of one or more generating units which convert mainly mechanical energy into electrical energy by moving a prime mover coupled to an alternator. Prime movers are mainly driven by steam generated in a boiler fired by coal, oil, natural gas, or nuclear fuel. Others may be driven by non-thermal resources e.g., hydro electric dams and wind farms. Apart from conventional generation DER based generation are also available for providing electrical power to the load.

The ability of generation units to provide all of the electrical power demanded by consumers is referred to as system adequacy. Three conditions must be satisfied to ensure system adequacy. First, available generation capacity must be greater than demanded load plus system losses. The system must be able to transmit demanded electrical power to consumers without overloading equipment. Finally the consumers must be served within an acceptable voltage range.
System adequacy estimation is probabilistic in nature. Each generator can have three kind of probability [1]. The first one is a probability of being available. The next one is a probability of being available with a decreased capacity. The third one is a probability of being unavailable. This permits the probability of all generators state combinations to be enumerated. To carry out an adequacy evaluation, each generation state combination is compared to hourly system loads for a whole year. If available generation cannot provide demanded load or constraints are violated, the system is considered as inadequate and the load must be restrained. Tendencies are also noticed now-a-days to generate electricity very close to the load centre by distributed generators of small and medium size. Generators, conventional or renewable based are connected to generator substations. Generation substations step up voltage to transmission levels by transformers.

1.1.1.2 Transmission system

Transmission systems transmit electrical power over long distances from bulk power generation system to sub-transmission or distribution substations. Mainly transmission lines are overhead. There is also a growing trend to use underground transmission cable (oil-filled, SF_6 filled, extruded dielectric and possibly superconducting) [1].
Transmission lines are interconnected at transmission switching stations and transmission sub-stations to increase flexibility and improve reliability. It improves overall performance, but makes the system susceptible to cascading failures.

1.1.1.3 Distribution system

Distribution systems deliver electric power from bulk power systems i.e. generation and transmission system to utility customers. Distribution substations receive electrical power from sub-transmission lines. It then steps down voltages with power transformers. These transformers provide electric power to primary distribution system which is made up of many distribution feeders. Feeders are consisted of a main 3 phase trunk, 2 phase and single phase laterals, feeder interconnections, and distribution transformers [1]. Voltage is stepped down to utility levels by distribution transformers which supply secondary mains or service drops.
However the conventional distribution system starts with distribution substation. A distribution substation is consisted of many different types of interconnecting components. These are high voltage disconnect switches, high voltage bus-rigid conductor, high voltage circuit breaker switches, circuit switchers, voltage and current transformers, power transformers, auto transformers, medium voltage switchgear, protective relays etc. Apart from these, there is SCADA (supervisory control and data acquisition) system in distribution substation. This actually is concerned with the substation automation. Generally, substation automation allows circuit breakers, transformers and feeders to be remotely operated. The closing and opening of circuit breakers are remotely performed by this system. This system works also as communication links to automated equipments situated on feeders.
There is also gas insulated substation available these days in distribution system. Gas insulated substation (GIS) includes high voltage bus, switches and breakers [1]. The specialty is that the

breakers are in containers filled with SF_6 gas. It reduces the substation space requirement. It also protects equipments from failure. These are sold in modular unit.

Again mobile substation is also another kind of substation in this regard. When there is a loss of multiple power transformers, then these substations are used to replace permanent substations. Multiple substations are supported by a mobile substation.

Primary distribution systems supply electrical power from distribution substations to distribution transformer. It is consisted of feeders. There is a breaker at the starting position of a feeder coming out of distribution substation. A concrete duct bank or feeder gate-away is utilized to allow exit of many feeders [1]. They terminate closely near a pole. There after underground cable is moved to an over head three phase main trunk. The main trunk is connected to the feeder service territory. It may be utilized for connection to other feeders through normally open tie points. Underground main trunks are costly. It is common in urban areas. It is costlier than overhead construction. Feeder's service territory is mostly covered with the lateral taps off. Single phase, two phase or three phase connections are common provisions of lateral taps. Fuses, reclosers or automatic sectionalizers are utilized for protection of laterals. These laterals are generally connected directly to the main trunk. Pad mount and pole-mounted distribution transformers are utilized to serve customers by underground and overhead lateral respectively.

Many types of components are available in the feeders. Those components play an interconnected role for distribution system. Overhead equipment is economical and easy to commission. Its maintenance is also easy. But it is open to ambient and exposed to weather. Its aesthetic characteristic is poor. Poles, overhead lines, sectionalizing switches, fuse cutouts, reclosers, sectionalizers, capacitors, voltage regulators and pole-mounted transformers are the components related to overhead equipment [1].

Underground system has now been considered as increasingly popular with the decrease of cost difference between overhead and underground system. Aesthetic has become an important criteria to public. They prefer underground system. Statutes and laws regarding this underground system are becoming more familiar. Riser pole, cable, underground residential distribution cable, cable termination, cable splice, load break elbow and pad mounted distribution transformer are the components concerning to underground distribution system [1].

Customer service entrances are connected to distribution transformers by secondary systems. Secondary systems can be complex like a secondary network. Secondary mains, service drop and secondary network are part of secondary system.

Apart from all the above discussed descriptions regarding conventional power system, new concepts having inherent strength of automation such as smart grid, microgrid etc. are coming up very fast in the power system's conceptual framework dealing mainly with the distribution side.

1.1.2 Distribution automation

Feeder automation is considered controlled by SCADA i.e. supervisory control and data acquisition system. It also incorporates locally controlled devices on feeders. Automatic reconfiguration, capacitor control, automatic meter reading, intelligent electronic devices, remote terminal units, faulted circuit indicators and many other functions are there in feeder automation. Distribution automation can significantly reduce the outage time by using sophisticated control unit. This improves distribution system reliability. On the other hand, distribution system reliability can be enhanced by incorporating distributed generation in the grid near the load centre.

1.1.3 Distributed generation integration

Distributed generation helps to cut the excess loading effect of electric lines or cables. Distributed generation integration helps in reducing the line current carrying capacity and indirectly reduces the real power loss and improves the voltage profile of the electric lines and cables. This also helps to improve power system reliability by reducing the failure rate of electric line. It has been emphasized later in Chapter 4. The energy resources of distributed generation are solar, wind, biomass, geothermal, tidal etc. The energy supply issue with renewable as a source has a significant impact on power system reliability as the energy resources are intermittent in nature. Solar energy works in the day time especially when the sky is clear and the temperature is high. Wind energy is also fluctuating in nature as the wind speed is not consistent with time. Sometime it's more and sometimes it's less which causes the mismatch with the power grid frequency. So, some technical problems are there that develop with the integration of distributed generation. But the engineers, scientists and researchers are working on this topic to integrate distributed generation to the conventional grid or infinite bus or hybrid grid. However, reactive power compensation is an engineering scheme which indirectly reduces the real power loss and improves reliability.

1.1.4 Reactive power compensation

Reactive power compensating devices such as capacitor injects reactive power to the grid and improves the voltage profile. With this real power loss decreases as the voltage profile improves. This helps to improve the system reliability. Capacitor can be of many types according to its installation and control. It can be series capacitor, shunt capacitor on the basis of its installation. It can be of thyristor controlled series capacitor (TCSC) etc on the basis of power electronics based control. Thyristor controlled reactor is another type of the reactive power compensating devices. So far we have discussed those compensating devices which inject reactive power to the grid. There can be other reactive power compensating devices which can both withdraw and inject imaginary power to the grid. Static var compensator, static synchronous compensator, dynamic var compensator, unified power flow controller are some of the examples of such issues. So, reactive power compensation helps to improve voltage profile as it is known to all that '*Q*' and '*V*' are closely coupled. It has a great impact on power system reliability. Apart from this reactive power compensation, new concepts are coming in the restructured power scenario as discussed earlier in this chapter. These are smart grid, microgrid etc.

1.1.5 Smart grid

Smart grid is the assimilation of a communication network, an electric grid, hardware and software to control, monitor and supervise the distribution, creation, storage and consumption of electrical energy [2]. The smartgrid of future will be interactive, self-healing; distributed and be in touch with every device. However, this smartgrid can increase grid reliability by integrating utility infrastructure, electric vehicles, distributed generation, homes, buildings, energy storage and smart devices. It can also increase energy efficiency by the incorporation of renewable sources. This smartgrid has also the capability to satify customer while decreasing the operating and capital costs. On the other hand, smart grid can also be represented as the use of computational ability, sensors and communications in some form to augment the overall functionality of the electric power delivery system [3]. This allows several functions in a power system to minimize energy usage, ensure reliability, reduce cost, mitigate environmental impact and manage assets. Nevertheless, there can be a combination of distributed energy resources, conventional grid run by thermal power plant or nuclear power plant and plug-in-vehicle or hybrid vehicle in a smartgrid. On the other hand, the excess amount of energy coming out from the conventional plant can be pushed back to the pumped storage plant during the off peak hour such that in time of scarcity of power supply that electrical energy can be utilized. This can be accomplished by smart operation. Again in the day time or peak hours it is possible to have power electronics based switching for smart and intelligent control of solar electrical energy. Say for example at the day time solar roof top panel may give ample electrical energy so that the electricity supply can be cut from the main grid and the household or building or complex can have electric supply from solar roof top panel. Excess solar power can be stored in battery which can also be utilized when the conventional power cut occurs. Biomass, geothermal, tidal, small hydro and wind are other sources of energy which can be integrated to the conventional grid intelligently as regard operation is concerned so that the whole system can be considered as a smart grid. However, microgrid is also an upcoming concept not yet implemented in a larger scale in different countries for efficient and reliable power supply.

1.1.6 Microgrid

Microgrid is a small scale low voltage supply network [4]. This is developed to provide electrical power for a small community such as a suburban locality or a housing estate. This can even supply electric loads for a district, an industrial site or a municipal region. The microgrids are active distribution network as bidirectional power flows in this system due to the incorporation of distributed generations (DG). The distributed generators may be of conventional in nature or renewable or non-conventional distributed energy sources based integrated together to provide electricity supply at distribution voltage level. The generators or microsources are connected with power electronic interface and controllers to provide the required flexibility for autonomous system as well as linked with the main grid. This is also required to maintain a specified power quality and energy output from operational point of view. This control flexibility also allows the microgrid to become a single controlled unit to the main utility power system for satisfying the reliability and security needs.There are some differences between conventional power network and microgrid. Microsources or distributed generators are of smaller capacity in comparison to the large generators in the conventional power plant connected to main grid. There is no need of transformer to step down voltage level in the microgrid. Power developed at distribution voltage level by the DG unit can be directly fed to the utility distribution network. These DG units are commissioned very near to the electrical loads in the microgrid such that power can be supplied with standard voltage and frequency profile and also with negligible line loss. The microgrid can be very effective for providing power to remote areas where main grid fails to supply power either due to unavailability for topological issues or frequent disruption due to severe weather conditions and man made disturbances. The major advantage of a microgrid is that it can be operated for a single aggregated load and can be presented as a controlled entity within the power system. Its easy controllability and conformity with the grid rules and maintaining a certain level of reliability and security are also the eminent characteristics of microgrid. The microgrid is also beneficial from the customer point of view. It can satify the customers by locally meeting their electrical loads. These microgrids can also enhance the local reliability, decrease the real power loss of electric line and provide uninterruptible power with standard voltage and frequency. Microgrids are also beneficial from the environmental point of view as it can reduce global warming by decreasing carbon emission through utrilization of solar, wind etc as DG sources. There are some limitations which are low energy content of fuel such as biomass, intermittent and climate dependent nature of distributed energy sources and lack of standards for operating the microgrid in synchronism with conventional power system. But this microgrid has to be designed and developed for better future and clean energy and also to enhance reliability. In this regard, whatever is the size of the grid or utility the power supply must be reliable to satisfy customers.

1.2 Reliable power supply

Reliable power supply means uninterruptible power supply with standard voltage and frequency. In recent scenario, the power system has been restructured. It runs in deregulated mode. There are plenty of power companies in the market. They are having competition with each other to provide economic and reliable power to the consumers. Mainly in the distribution sector, the utility companies are getting enormous challenges to supply reliable power. Disruption or stoppage of supply occurs due to failure of power system equipment and lines or cables. This causes less reliable power supply to the customer. To secure reliable power supply the power engineers, scientists and researchers are performing research investigations. They are trying to perform better than the earlier conditions. On the other hand, the power companies should supply reliable power as per the Electricity Act prevailing in different countries. Voltage and frequency should be maintained as per that said electricity norm. This is due to the fact that utility appliances have been manufactured considering that norm as standard. On the other hand, the fossil fuel will be exhausted in near future. Non conventional energy resources such as wind, solar, biomass, geothermal etc. are the in thing in this situation. But power quality issues are there. The solar energy source is intermittent energy source. It generates for twelve hours in a sunny day. Wind source is also dispersed. Biomass is much localized. These are unreliable energy sources. We can’t compromise with the standard voltage and frequency. But we have to accommodate this distributed generation into the healthy grid for our better future. Engineers and scientists are performing examination to augment the performance of the non-conventional energy resources. They are doing it to make those energy sources reliable. It’s now a challenge in this competitive energy market to supply reliable power economically.

1.3 Novelty and contribution of the thesis

Simultaneous optimal capacitor allocations and distributed generation integrations have been performed here to observe the reliability improvement as well as cost and loss reduction in microgrid type radial distribution systems. Appropriate planning schemes have been designed in single as well as multi objective situations. Cost reduction has been performed considering two operational policies in a 34 bus microgrid type radial distribution system. One reinforcement scheme by applying only disconnects or isolator between two buses has been considered. The other one is incorporating fuse gear protection as lateral protection at the ‘T’ junction point between lateral and main feeder. These two reinforcement schemes have been observed as common practice therefore considered for making the distribution system realistic. These two segregated studies related to reliability are hardly found in the literature. A new reliability index named CBRI has been developed in this work. This is linked with the power interruption cost or reliability worth. If this index value is high then it signifies that the power interruption cost is low. The newly developed index has been assessed in single objective environments. Furthermore, this reliability index has been studied with other reliability indices and also with total cost and loss in multi-objective environments. Cost incorporated customer based capacitor allocations and DG integrations have been performed for rural, industrial, urban, hospital, commercial and office customers. This has been performed considering realistic customer chart in 69 bus microgrid type radial distribution system of having about 4 MW total active load. This small scale system has been enhanced to near about 40 MW considering futuristic load growth and suitable capacitor and DG placements have been exercised for cost reduction, loss minimization and reliability improvements.

In the evolutionary computation front, two novel algorithms named modified cultural algorithm (MCA) and fish electrolocation optimization (FEO) have been developed from nature inspired phenomena. Modified cultural algorithm is a modified version of original cultural algorithm (CA). Pouplation space and belief space are the two main ingredients of CA with communication protocol. These have been newly designed for population evaluation in MCA. On the other hand, situation knowledge and history knowledge have been considered amongst all the knowledge sources of belief space in the modified CA. Four newly developed mathematical operators have been incorporated in the situation knowledge influence which are addition, replacement, unchanged and multiplication. Furthermore, a new plan or concept has been developed for the history knowledge effect for population upgradation. Modified cultural algorithm mimics the progression of civilization whereas fish electrolocation optimization conceptualizes the active and passive electro location phenomena of elephant nose fish and shark, respectively. Fish electrolocation optimization is mathematically developed on the basis of a conceptual electro fish which toggles between active and passive electro location governed by several probability and ranges. Randomization and localization have been considered in FEO to reach near the global optima considering electrical capacitance value of the projected electric image in the fish's body. However, these techniques have been newly developed to implement as optimization tool for optimal DG integrations and capacitor allocations in microgrid type radial distribution systems. Comparative studies have been executed amongst fish electrolocation optimization, modified cultural algorithm, real coded genetic algorithm and particle swarm optimization for cost based reliability enhancement in microgrid type radial distribution systems.

1.4 Outline of the thesis

The whole work has been illustrated in eight chapters. Chapter 1 mainly deals with the introduction section. Here, conventional grid, restructured power scenario and distribution automation have been briefly stated. Concept about reactive power compensation, smart grid, microgrid, distributed generation integration and reliable power supply has also been addressed with the illustration of novelty and contribution of the thesis.

Chapter 2 explicitly states about the literature review considered for the determining the rationale of the whole work. The contribution of several researchers performed especially for the power distribution system reliability issues have been discussed thoroughly. At last concluding comments have been made on the basis of studies attempted by different groups after analyzing the extensive literature review.

Power distribution system reliability and economic worth of reliability is the topic of Chapter 3. Mathematical expression concerning to the basic reliability has been described. Discussions on power distribution reliability assessment procedures have been made. Distribution system reliability indices have been considered here with the newly developed cost based reliability index. Economic implications related to reliability issues have been stated with the illustration of customer damge function.

Chapter 4 discusses the objective function formulation part of the work. Distributed generation integrations to the microgrid type distribution system and capacitor placements to the load buses have been considered as the engineering schemes for simulation studies related to cost and reliability. Mathematical expression of cost for individual capacitor placement has been developed. Multi-objective optimization has also been considered here choosing five conflicting objectives. Decision making part has also been illustrated. Especially implementation of TOPSIS method has been discussed. Microgrid type radial distribution system studies considering two reinforcement schemes have been considered.

The necessity of soft computing technique’s implementation especially the evolutionary computation techniques are the prime issues of Chapter 5. In this chapter a brief about the important evolutionary techniques has been illustrated. Finally the literature review concerning to the application of evolutionary techniques on critical and complex optimization problem related to power system has been presented. Lastly, proposed and developed evolutionary techniques are defined in this chapter.

Chapter 6 mainly deals with the newly developed modified cultural algorithm (MCA) and fish electrolocation optimization (FEO). On the other hand, application procedures of real coded genetic algorithm (rcGA) and particle swarm optimization (PSO) have been illustrated for optimal capacitor allocations and DG integrations to observe cost reduction and reliability improvements. However, modified cultural algorithm has been mathematically generated from the original cultural algorithm. Inherent parameters and implementation procedure of this algorithm has been discussed. Flowcharts have been developed for both single and multi objective optimization problems. Fish electrolocation optimization has also been illustrated theoretically and mathematically in this chapter. The technique has been developed by mimicking the active and passive electrolocation phenomena of elephant nose fish and shark. The implementation procedure of FEO for simultaneous DG integration and capacitor placement to observe cost based reliability enhancement has also been discussed.

Chapter 7 tells about the simulation work performed here. Analysis of the obtained results for cost based reliability enhancement in different situations has been discussed in this chapter. The effectiveness of the proposed FEO and MCA has been observed here in comparison to the considered real coded genetic algorithm (rcGA) and particle swarm optimization (PSO) in single objective situations. That’s why multi-objective optimizations considering two and five conflicting objectives have been performed by MCA and FEO. Cost incorporated customer based capacitor allocations and DG integrations have been exercised for rural, urban, commercial, industrial, office and hospital customer. In addition, enhanced load type microgrid distribution system has been designed considering futuristic load growth and appropriate capacitor and DG placements to observe cost reduction and reliability improvements.

Finally Chapter 8 concludes the whole work. What so far has been developed, studied and simulated has been briefly notified. Further study or scope for future work has also been stated depicting the assumptions and considerations of the present work.

Lastly a list of references considered for the present work has been written with an appendix section.

However, reliability related state of the art issues are needed to be considered before going into the details of objective function formulation. This is due to the reason that these reliability studies are necessary for problem identification purpose. These have been illustrated in the next chapter.

Chapter 2

Trends of reliability based power system analysis

Several research works have been analyzed to comprehend the reliability of a power system from different aspects. Reliability planning has also been investigated in a power system network. Economic implications of power system reliability are also analysed for business sustainability. Shunt capacitor placement, distributed generation integration, switch allocation etc are mainly considered as the schemes to improve the reliability of power distribution system network. In this chapter these above mentioned issues have been discussed such that the audience can have a clear view of the previously researched topics in one go.

2.1 Reliability assessments of power system

Reliability assessment methods and programs handling are vital issues for both power systems planning and testing. The evaluation methods can be suitable for finding weak points in the reliability appraisal. The computation time is one of the major burden of the developed methods particularly from the simulation view point. This time is required to solve a large number of credible contingencies or outage states. Reliability study along with reliability evaluation on conventional system especially on distribution system is important to understand studies related to reliability enhancement on microgrid type radial distribution systems.

2.1.1 Distribution system

Most of the utility customers such as rural, urban, commercial, hospital, industrial etc are available in the distribution system. Reliable power supply is significant to these customers in distribution system. Several methods have been considered by different groups to assess reliability of power distribution system.

2.1.1.1 Analytical methods for finding distribution system reliability

Reliability evaluation is utmost necessary when deregulation is prevailing in the power market. An analytical method had been proposed by Bono et al. to find out distribution system reliability [5]. The work of Bono et al. established the rule of employing the breakdown modes and effects of fault tree analysis methods based on the IEEE Gold Book. The investigation provided a foundation for knowledgeable resolutions when the chosen systems planned to enhance system availability. The systematic methods were demonstrated utilizing two easy distribution schemes. It showed how the methods might be employed to systems which were more intricate. In another work, Kjolle et al. proposed an analytical approach for distribution system reliability assessment [6]. Here, the considered approach developed a reliability model which connected component failures to load point outages. On the other hand, an analytical technique was proposed by Bae et al. to evaluate the reliability of the distribution system with distributed generation [7]. Here, explicit expressions were presented to analyze the reliability of distributed generation. The proposed technique incorporated the standby mode, peaking mode and mix operation modes. In that attempt, the reliability indices were compared with Monte Carlo simulations (MCS) utilizing the hourly load model. It was found that the proposed technique is almost comparable to MCS and more accurate than the method utilizing peak load model. The proposed technique showed the DG's characteristic properly though investigative approaches require special knowledge for reliability assessment purpose.

2.1.1.2 Investigative approaches for reliability estimation

Reliability assessment can be performed utilizing validation technique. In this regard, Brown et al. studied distribution system reliability with default data method [8]. This distribution system reliability evaluation was useful to foretell the disruption profile of a utility based on system topology and component reliability data. Unluckily, numerous distribution systems did not have adequate historical reliability data to carry out such an evaluation. Brown et al. were not certain that other sources of data could be made representative of the exacting system. As a result, these utilities did not integrate distribution system reliability evaluation into their design procedure and sacrifice its noteworthy advantages. A way of achieving comprehensive knowledge in a reliability model was presented by Brown et al. with the development of a corroboration technique. This technique involuntarily found out suitable evades component of reliability data which would envisage reliability indices having equivalence to some historical data values. The result was an authenticated base case from which incremental design improvements could be investigated. Nevertheless, characteristic function based approach is very useful for reliability assessment of distribution system like the discussed validation technique. Carpaneto et al. performed evaluation of the probability density functions of distribution system reliability indices with a characteristic function based approach [9]. Here, characteristic function based approach was proposed to handle the random events like the occurrence of a fault. The proposed method provided a fast and simple computation of probability distributions. It also provided moments for local and global reliability indices. The study was performed for large real urban distribution system. However, quantitative reliability study is also another approach which had been investigated in distribution system. In this regard, Rigler et al. executed quantitative reliability analysis of distribution systems [10]. Here, the effect of repair times was studied on the action of the distribution network in an isolated rural community utilizing a strategy tool. This was developed purposely to aid in the economic and strategic assessment of capital savings and technical improvements in distribution networks. Rigler et al. on the other hand inspected the effect on system availability caused by changing the repair times. The sensitivity of the results was estimated for a variety of networks with varied characteristics and changeable reliability data. Nevertheless, fuzzy logic and algorithmic approaches can be very effective for reliability estimation.

2.1.1.3 Fuzzy logic and algorithmic approach for reliability appraisal

Soft computing based fuzzy logic technique can be implemented for reliability assessment. Reliability evaluation of distribution system was performed by Jaipradidtham for pricing services in bilateral contract electricity markets applying fuzzy logic method [11]. Here, a method was proposed to assess the reliability of reorganized distribution system. The sufficiency evaluation of a deregulated power system was performed by using time sequential Monte Carlo simulation. This was done to evaluate customer load point reliability in bilateral treaty electricity markets. The agreements amid market players were established in a financial power market. The example of such thing was the reliability network equivalents of deregulated power system. Its work was to find out the reliability at each load point for a given time period. Fuzzy logic number was applied to form all apprehensive uncertainties. This consisted of the load demand and reserves necessitated in each market and prices cleared in every market. Load flow computation was utilized to assess the amount of load served. The idea of non-uniform reliability was also proposed here. This was sensitive to system security. Furthermore, long term investment of the distribution system by considering both system reliability enhancement and reliability worth in term of benefit to cost ratio were also investigated. The reliability assessment algorithm can be appropriate for assessing reasonably complex medium voltage radial electrical distribution networks (EDNs) with multiple sub-feeders. In this regard, Xie et al. proposed reliability assessment technique for complex medium voltage electrical distribution systems on the basis of shortest path [12]. Here, a forward-search technique was implemented to identify the feeder section controlled by a breaker. Techniques for searching for the shortest paths from any node to the energy source and between any two nodes were developed by employing graph theory and taking into account the structural characteristics of the EDNs. It was easy to imply a detached section based on the descriptions of feeder terminal node (FTN) and the shortest path from a stoppage element to FTNs. A classification of the nodes was achieved following the mentioned incident. The reliability indices of the feeders, buses and system were enumerated based on the nodal categorization. The developed algorithm had been studied on numerous test systems. The results illustrated the efficiency and applicability of the technique. Again reliability evaluation of distribution system was performed by Goswami et al. [13]. In that attempt, reliability analysis algorithm had been presented for radially operated electrical distribution systems. However, distribution network based concept was considered to assess reliability of power distribution system.

2.1.1.4 Distribution network based reliability assessments

Reliability assessment with an enhanced distribution model can be very effective in the restructured power scenario. Anbalagan et al. studied an enhanced distribution model for reliability evaluation of power distribution system [14]. The most important factor in designing and planning of distribution systems was reliability assessment. The distribution systems should be operated in an economic manner with minimal interruption of customer loads. Here, the main aim was development of interoperable services for power distribution systems reliability evaluation. This was performed by using simple object access protocol (SOAP) communication. In this communication the reliability data were attached within the SOAP message. Power system reliability service provider and reliability service requester were the two components of the proposed XML based SOAP with attachment model. Standards such as HTTP, XML and Simple Object Access Protocol (SOAP) were the basis for the enhancement of interoperability regarding the power system reliability services. Extensible markup language (XML) was considered for representation of the data related to power systems reliability analysis. This was executed for exchanging the reliability data among the users and service providers. SOAP messages were considered for configuration of the calling sequences of reliability evaluation services along with required data. Flexible loosely coupled as well as high-efficient integration architecture was presented by the proposed model for distribution system reliability evaluation in the deregulating and competitive electric market. It had inbuilt features such as scalable and reliable environment for power systems reliability analysis. Reliability network equivalent approach is also important for the reliability evaluation of power distribution network. Reliability network equivalent approach was presented by Billinton et al. for distribution system reliability evaluation [15]. Here, a common feeder was defined and an uncomplicated set of equations were used. The fundamental general feeder equations and the reliability network equivalent approach offered a realistic method for weighing up the reliability of intricate radial distribution systems. The process was demonstrated by applying it to a relatively straightforward but realistic system.

The reliability assessment of distribution system was discussed so far by various approaches and techniques. However, distributed energy resources form the basis of distributed generations which eventually helps to develop a microgrid system. Reliability evaluation in microgrid system is important to study as this small type of system can be a prototype system from the business perspective.

2.1.2 Microgrid system

The concept of microgrid has come as an important engineering scheme. The paradigm shift from the conventional power system to microgrid has occurred due to the loss of fossil fuel and cravings for clean and green energy. In this regard, Burgio et al. did reliability studies of a novel integrated configuration for microgrids [16]. The microgrid was consisted of photovoltaic plant, wind plant and a storage system. Here, the aim was to enhance reliability of load supply by investigating network congestion adapting the above said micro grid configuration. The reliability enhancement study was performed considering the randomness of renewable sources namely sun and wind. Furthermore, the randomness of the power required by the load was also taken to be considered. The reliability estimation was performed in terms of the number of critical load interruptions. This estimation was exercised by Monte Carlo simulation method over a certain period of time. However, reliability evaluation of consumers in a microgrid is important to be understood as this microgrid type system is very significant from the deregulated business perspective. Bae et al. performed reliability evaluation of customers in a microgrid [17]. An analytical technique was proposed to assess the reliability of customers in a microgrid including distributed generations (DGs). Operators of the microgrid were in charge for a reliable energy supply to their customers. The reinstallation procedures of DGs were reordered when system outages occurs. The earlier study had presented the analytical method to assess the reliability of customers in the distribution system where one operator owned all DGs. The proposed technique incorporated fuses and photovoltaic (PV) systems. A concept impact factor was introduced which was adjusted to acquire the interruption cost. Equations were also simplified to consider more than one component in a bus section having a DG connection. Case studies in Billinton Test System Bus 4 confirmed the accuracy of the presented method which was analogous to that of Monte Carlo Simulation. The pattern of system was divided into several micro grids. This altered the protection scheme and reliability of customers in the micro grids.

Protection system is an inevitable part of the power system network. The reliability study related to protection scheme of a power distribution network is also important as regards this research work is concerned. This is due to the reason that lateral protection with disconnects has been considered as a reinforcement scheme in microgrid type radial distribution systems discussed in later chapters.

2.1.3 Schemes related to protection and reliability

It is known from recent studies that the protective devices' hidden failures have a great impact on the power distribution system reliability. In this regard, Wang et al. studied optimal locations for protection system enhancement to evaluate the impact on power system reliability [18]. Here, the definitions of vulnerability and reliability of protection system were provided. This was performed to numerically characterize the said impact on reliability. A random search algorithm based on system heuristic was developed for fast rare event simulation of consecutive relaying malfunctions in bulk power distribution systems. An economical system upgrading strategy was also proposed here. This system could best improve the protection system reliability under limited financial budget. It was also evidenced that Yang et al. studied effects of protection system hidden failures on bulk power system reliability [19]. Here, a breaker oriented bulk power system network model had been developed to incorporate detailed system substation configurations. On the other hand, significance of automatic control system on the distribution system reliability is also important to be understood as regard as reliable service is concerned. Impacts of automatic control system of loop restoration scheme were studied by Kazemi et al. on the distribution system reliability [20]. The loop restoration scheme was discussed as special feeder automation scheme to enhance distribution system reliability. Two common types of automatic control system (ACS) of loop restoration scheme (LRS) were proposed and utilized. It was noticed that fruitful operation of automatic control system was dependent on the protection and automatic control functions of switching devices of loop restoration scheme. Automatic control functions of switching devices, fuse of lateral distributors on reliability indices and the impacts of failure protection were also illustrated. Quantitative evaluation of the impacts of two common types of ACS of LRS was performed on the distribution system reliability [20]. Like automatic control system consideration, switch placement impact for reliability improvement is also important to be comprehended as regard as reliable power supply is concerned. Switches such as recloser, sectionalizers etc have to be placed suitably in a power distribution system network for technical reasons and also to have reliability benefits. Mao et al. again performed switch placement to improve system reliability for radial distribution system with distributed generation [21]. Switch placement schemes were proposed along with the distributed generator under fault condition to enhance the system reliability. Here, customer priority was also given importance. Graph based algorithms had been developed to locate switches for multi-objective non differentiable optimization problem. The proposed algorithms could be implemented for unbalance distribution network. However, simulation based study was performed on 394 bus distribution system incorporating priority customers and single or multiple distributed generators.

It is quite obvious that performance of the equipment will decay after its useful life period. Conventional power distribution system is comprised of several equipments such as electric lines, cables, breakers, transformers etc. Reliable services will be achieved if the health conditions of these equipments are taken care of with the progress of time.

2.1.4 Importance of maintenance on reliability

Maintenance is important for healthy operation of power system equipments. It is due to the fact that the power companies want utility system to run in an uninterruptible mode. But sudden failure or short circuit may occur anywhere in the network which is the cause of decrease in service reliability. To have reliable power supply power engineers must do maintenance of power equipments viz. transformer, circuit breaker, lines, fuse gear, cables etc as stated earlier on regular basis. In this regard, retirement of aged equipment draws special attention for reliability consideration.

2.1.4.1 Retirement of aged equipment

Aged equipment retirement decision is vital for power system reliability. The early retirement of aged equipment and buying of new equipment does waste of capital cost. On the other hand, delay in retirement does fatal error and might cause severe damage to the system. In that case it is detrimental also and the damage cost is more. Hajagos was concerned more about the system with much aged equipments [22]. Here, the transmission and distribution system planning was studied to increase system reliability and power quality. On the other hand, Li et al. proposed a probabilistic approach to determine the retirement of aged equipment [23]. Here, the basic idea was to compare the capital saving and expected damage cost due to delay in retirement of aged equipment. In that attempt, weibull distribution was used to model the unavailability due to the ending of life failure of aged equipment. This approach did evaluation of the expected damage cost caused by the ending of life failure. Here, economic comparison analysis was performed between the system risk cost and capital saving. Severe weather condition is also another type of contingency which has major impact on service reliability.

2.1.5 Impact of weather conditions

There are many causes of faults and outages in electric power system. These lead to poor system reliability. One of the major and significant causes of poor system reliability is lightning or severe weather condition.

2.1.5.1 Lightning storms

Two major contributing factors important for the reliability evaluation are momentary interruptions and storms. Lightning storms can be very dangerous to uproot power apparatuses which have major impact to service reliability. Distribution system reliability assessment was performed by Balijepalli et al. due to lightning storms [24]. Predictive evaluation of distribution reliability indices was utilized to identify poor reliability areas. This had been done so that suitable changes in system design could be implemented. Here, a Monte Carlo simulation for assessing distribution system reliability under lightning storm condition was proposed. The simulation results from a practical distribution system showed the significance of detailed modeling of storm characteristic. Furthermore, simulation of the system response in evaluating distribution system reliability during lightning storms was also performed. On the other hand, Brown et al. performed distribution system reliability assessment for momentary interruptions and storms [25]. Here, Monte Carlo simulation methods were proposed to determine the impact of every stated phenomenon. Reliability of an existing utility distribution system was evaluated by the said methods. Furthermore, these methods were utilized to explore the reliability impact of distribution automation.

2.1.5.2 Weather based reliability evaluation

Weather based issues are very crucial in respect of reliability assessment. In this regard, Billinton et al. performed weather based distribution system reliability evaluation [26]. It was discussed that the weather environment could severely impact the performance of an overhead distribution system. Electric utility’s operational ability was also mentioned. Billinton et al. identified that the likelihood of system failure had increased due to enhancement of line failure rates during bad weather periods. Here, an approach was proposed to evaluate distribution system reliability in different weather conditions. The weather conditions were normal, adverse and extreme. These were demonstrated utilizing a practical distribution system. Reliability indices were assessed in three different weather states. A series of sensitivity studies were also proposed. Application of adverse and extreme adverse weather for modeling in transmission and distribution system was studied for reliability evaluation [27]. Billinton et al. discussed about the significant impact of physical environment on the resulting reliability of the transmission and distribution system network. Weather conditions in the reliability analysis were included for transmission and distribution system. A series of weather models was proposed with the idea of implementation to

realistic system. The traditional approach to predictive reliability evaluation utilizing single and two state weather models was briefly demonstrated. A three state weather model was proposed to include failures occurring in major adverse weather conditions. It was observed from the study that the weather effects needed to be incorporated into the reliability analysis. Otherwise the results achieved without incorporating the weather effects could be quite misleading and optimistic. Time varying weather conditions and restoration resources had been incorporated by Wang et al. for performing reliability cost/worth assessment of distribution system [28]. Here, a time sequential simulation technique was proposed to incorporate the effects of weather conditions. This was also proposed to incorporate the effects of restoration resources in reliability cost/worth evaluation of distribution system. Time varying weight factors (TVWF) were established for illustration of the impacts of restoration times of weather, component failure rates and available refurbishment resources. Time varying failure rate (TVFR) was created for each component. Time varying restoration time (TVRT) was also developed in this regard. It was observed from the test distribution systems that TVFR and TVRT had significant impact on the interruption costs of frequency-sensitive customers and indices for all customers, respectively.
These are significant as deregulation has changed the plan of reliability management of a power distribution system.

2.1.6 Other approaches of power distribution system reliability evaluation

Restructured power scenario is creating pressure amongst the power companies to supply economic and reliable power to the customers. Hence reliability assessment of a power system especially on a distribution system is necessary. Brown et al. assessed the reliability of distribution systems [29]. This evaluation had been performed for financial success and customer satisfaction. Hierarchical Markov modeling had been used by Brown et al. for distribution system reliability assessment [30]. Here, hirarchical Markov modeling method was proposed to perform predictive distribution system reliability evaluation. In another study, Gilligan et al. proposed a method for estimating the reliability of the distribution circuit [31]. Here, the expected reliability performance was discussed for primary distribution circuits. This could be estimated by a direct evaluation of the configuration and exposure of the circuit. On the other hand, Koner et al. developed distribution voltage sag and reliability assessment tool [32]. Here, a user friendly sag and reliability assessment tool (SRAT) had been presented. This was developed on the basis of existing impedance data, protection characteristics and a model of failure probability. The said tool was applied to an Australian distribution network to illustrate the application of this model. In another work, Zhang et al. proposed a boundary analysis method for reliability and economic assessment of distribution system [33]. The presented method had been implemented to real life distribution reinforcement projects. Bulk power system reliability assessment was performed by Yang et al. considering protection system hidden failures [34]. Here, a systematic methodology had been proposed on the basis of a breaker oriented system network model.
Reliability assessment and study related to distribution system, protection scheme and microgrid system have been discussed so far. Further discussion can be done on each system and scheme especially for distribution system. But impact of recent technologies on reliability is very important to be understood as regard as disruption of customer load is concerned. This has been briefly described in the next section.

2.2 Impact of recent technologies on reliability

Service reliability is an important issue for discussion when deregulation is prevailing in the power market. Several approaches such as reactive power compensation, distributed generation integration etc affect power system reliability and these have grave impact on it.

2.2.1 Effect of reactive power compensation

Failures concerning to reactive power sources such as synchronous condenser and compensator has major impact on system reliability. Reliability evaluation of reactive power sources is important in this regard. Reliability assessment of power system was executed considering reactive power sources by Wang et al. [35]. Here, a technique had been proposed to evaluate the system and load point reliability indices. This had been exercised considering reactive power shortages caused by failures of reactive power sources. In this attempt, the reliability indices due to real power shortage had been separated from those of reactive power shortage. Here, two reliability indices were presented on the basis of reactive power shortage. These indices were implemented on the modified IEEE 30 bus system. The nodes with low voltage were chosen as the reactive power injection point. The calculation of reactive power shortage was performed at those points of injection. The results had provided significant information for system planners and operators for reactive power management. The information was regarding optimal locations for installation of new reactive power sources and the procedures to nullify voltage violations. Reactive power plays an important role in power system reliability. The reactive power limits of generator had been considered as the fixed maximum and minimum values in conventional power system reliability evaluation. But considerations of failures of reactive power sources are hardly found in the literature. Qin et al. studied reactive power aspects in reliability assessment of power systems [36]. New reliability indices were proposed in this attempt to represent the effect of reactive power shortage. The *P-Q* curve was studied for determination of reactive power limits. Reactive power injection technique was proposed to resolve reactive power shortage and location. Reactive power compensation can also be performed by installing shunt capacitors. Capacitor allocation at suitable position indirectly reduces real power loss and improves voltage profile which in turn does reliability enhancement. Sallam et al. studied shunt capacitor effect on electrical distribution system reliability [37]. Here, shunt capacitors were used as compensators. Security and reliability of a transmission line as well as power flow can be improved by the usage of shunt capacitor. The shunt capacitor improves the load carrying capability by controlling the reactive power flow. Here state space method was used to evaluate the reliability indices by the application of shunt capacitor. Reliability indices were found for the compensated and uncompensated system with different success criteria. The importance of using shunt capacitor incorporation was illustrated through numerical example. This was exercised on the basis of Markov process. It was found that with the usage of shunt capacitor as compensator the reliability was improved.

Reliability can also be improved by integrating distributed generation considering non-conventional energy sources such as sun, wind etc into the grid.

2.2.2 Impacts of distributed generation (DG) as non-conventional energy sources

Reliability study after incorporating non-conventional energy sources as DG units into the grid is necessary as fossil fuels are depleting day by day. Non-conventional energy sources such as solar photovoltaic, wind, biomass, etc can be integrated into the grid. This incorporation has the capability to provide clean and green energy.

2.2.2.1 Wind energy related issues

Special attention has been drawn to the wind based distributed generation. It is due to the controlling of harmful emission substances from thermal power plants. Wind energy as distributed generation source can be integrated into the conventional power system network for reliability reasons. Caralis et al. studied the value of wind energy on the reliability of autonomous power systems [38]. This was studied in the Greek islands. The islands' autonomous power systems were based on expensive oil. It experienced high variation of demand during the time period between summer and winter. Wind energy was an additional source of nonconventional energy to the autonomous power systems. Wind energy had not been utilized solely due to the technical reasons to the autonomous power system. But this wind energy had been utilized with pumped storage plant to cater the load demand. This combined usage of energy resources viz. combined wind hydro pumped storage (WHPS) had been considered as a mean to utilize the abundant wind potential. The effect of wind energy had been studied on the reliability of autonomous power system. The combined wind hydro pumped storage (WHPS) had been assessed for reliability improvement of the system. The results showed that the wind hydro pumped storage system contributed effectively to wind capacity credit. This was found out instead of the required large wind installed capacity. A trend has been seen where limiting the cost of energy of conventional power producers and encouraging the independent power producers are done. Quantitative assessment of wind based DG on distribution system reliability is important to be understood as regard as grid operation is concerned. In this regard, Atwa et al. performed reliability evaluation with renewable distributed generation for distribution system [39]. Here, a probabilistic technique was presented to estimate the distribution system reliability. The reliability assessment was performed with segmentation concept and a novel constrained grey predictor technique. The later one was utilized to evaluate wind speed profile. A comparative study of the wind speed profile has been performed amongst proposed technique and common weibull probability density function. This had been executed to check the validity of the proposed technique. A probabilistic technique had been utilized to correlate the stochastic behavior of the load and DG's power output. This had been exercised to enumerate the probability of generation to satisfy the load during islanding mode of operation. Reliability modeling is necessary when intermittent and non-intermittent energy sources are considered for integration into the conventional grid. Andrade et al. discussed about the modeling of reliability aspects of distributed generation connected to distribution system [40]. Here, three different models were presented. The first model is based on analytical method and is implementable to DG units of non-intermittent energy sources. The second model was created considering the uncertainty of generation connected to wind generation. This model was created on the basis of Markov process. The last model chose some aspects of two said models and did aggregation of load variation curve in a sequential Monte Carlo simulation method. The said three models give a good representation of the power supplied by the DG units mainly for sources which are of intermittent in nature such as wind.

Solar photovoltaic plant can also provide electricity like wind generator. This distributed generation considering solar energy is only available during day time in sunny weather. Though the solar power is intermittent and only available when the sky is clear but this has to be accommodated into the grid for clean energy and better future.

2.2.2.2 Reliability improvements using photovoltaic inverter

Solar photovoltaic cell develops DC power. This has to be converted into AC for use in a power system network through inverter system. Solar photovoltaic system can be an effective energy source for reliability benefits in industrial environment where power consumption is huge in comparison to other types of customers. Geibel studied multifunctional photovoltaic inverter system for power quality and reliability improvement in industrial environment [41]. With the improvement of power quality and reliability, a few technical benefits had also been achieved. These were peak shaving, reactive power compensation and provision of ancillary services. This multifunctional photovoltaic system was considered to be economical or less expensive in several countries. Distributed energy system had been considered to study improvement of power quality and reliability with multifunctional photovoltaic (PV) inverters [42]. Here, several approaches were proposed regarding multifunctional inverter system. These approaches included not only power quality and reliability improvement but also reactive power compensation, peak shaving etc. This additional benefit was offered by the distributed energy resources as surplus value to the customer. Reliability improvement of distribution system was performed by Sritakaew et al. using photo voltaic (PV) grid connected system [43]. Experiments were conducted to check the output characteristics of the photo voltaic system. Investigation was done to conceptualize the effect of the PV grid connected system with the usage of experimentally measured data. This was done to improve the electrical power system reliability. It was observed from the simulated results that the action of the tie switch, loading level of tie switch and system losses could be decremented with suitable installation of the photo voltaic system. On the other hand, Marinopoulos et al. performed installation of photovoltaic systems in Greece and studied their contribution in the reliability of the distribution network [44]. Here, incorporation of photovoltaic (PV) system was performed with the aim to enhance the power system reliability. The estimated power production of that PV system was compared to the data related to load shedding. The reliability of the distribution system was improved with the assumption that some portion of unsupplied power could be provided by the accessed power generation of PV units. Distribution system reliability indices such as system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI) and customer average interruption duration index (CAIDI) were studied. Finally the improvement was expressed as financial terms with the reduction of disruption costs. There are also other approaches involving DG which had been considered to assess reliability of a power system network.

2.2.2.3 Other approaches involving distributed generation

Incorporation of distributed generation in the distribution system converts the system from passive to active mode. It not only decreases line loading but also improves service reliability. Chowdhury et al. performed reliability modeling of distributed generation for conventional distribution system planning and analysis [45]. Here, a reliability model was presented for determining the DG equivalence to a distribution facility in the new competitive environment. On the other hand, Greatbanks et al. presented optimization with distributed generation for reliability and security of power system [46]. Here, genetic algorithm was employed to solve for optimal recloser positions when distributed generators were placed in a securely optimal manner. In another work, Popovic et al. [47] studied placement of distributed generator and recloser for distribution network security and reliability. In that attempt, optimal allocations of distributed generators and reclosers were determined by sensitivity analysis of the power flow equations. On the other hand, reliability impact of distributed generation was analyzed by Brown et al. [48]. Here, both positive and negative impacts of DG on reliability were analyzed using predictive reliability assessment tool. In another attempt, Waseem et al. studied reliability benefits of distributed generation as back up source [49]. Here, the value of distributed generation as a back up source was quantified for reliability improvement of a residential distribution network. The reliability improvement was measured by reliability indices viz. SAIDI, CAIDI and ENS.

Like distributed generation integration into the grid, outages and major events have to accounted for reliability reasons.

2.2.3 Outages and major event impacts

Reliability can be enhanced in a power system network if concerns are raised for outages and major events. Burke used outage data to improve reliability [50]. Here, sophisticated outage management systems had been utilized to improve system performance by establishing accurate failure rates and outage times. Identification was also performed for specific areas which developed poor system reliability indices. On the other hand, Christie performed statistical classification of major event days in distribution system reliability [51]. Here, major event day in distribution reliability had been defined in terms of average frequency of occurrence. Nontechnical people like regulators could easily understand the definition. This was fair to employ on system of any size. In that attempt, two possible methods of applying the definition were illustrated. This was discussed utilizing bootstrap method, an example of real utility data and fitting a probability distribution. Several practical issues had also been illustrated and resolved. These were calculating normal annual reliability with major event days removed, how to handle zero outage days and types of probability distribution connected to the events. However, outage of power system apparatuses is necessarily performed when a maintenance work has been scheduled. This type of problem in a typical power system is considered as the outage planning of the power system network. In this regard, Kawahara et al. proposed a supporting expert system for outage planning of electric power facilities retaining high power supply reliability [52]. The outage planning problem belonged to a class of combinatorial problem. In that attempt, a supporting expert system for the outage planning had been proposed. This retained high power supply reliability. Some issues of the outage planning were presented here. Three security indices had also been introduced.

Electricity price is very important as regard as business is concerned. Customer wants uninterruptible power supply with standard voltage and frequency considering economic factors. Deregulation is also creating pressure to provide economic power with utmost reliability. But reliability improvements can be achieved after monetary investments. On the other hand, power interruption cost or reliability worth is also another factor which consideres several issues for reliability evaluation.

2.3 Financial aspects of power system reliability

2.3.1 Reliability worth estimation

Power interruption cost or reliability worth has to be considered for economic reasons. Goel et al. performed prediction of customer load point service reliability worth estimates in an electric power system [53]. Here, three different methods for assessing system customer load point reliability worth factors were presented. The interrupted energy assessment rates (IEAR) was designated as the load point reliability worth factors. The developed IEAR could be used for several purposes. A reliability test system was utilized for illustration of customer damage function in association with customer reliability indices. Again, Goel et al. studied nodal price volatility reduction and reliability enhancement of restructured power systems considering demand price elasticity [54]. Here, demand and price correlations were represented utilizing the demand-price elasticity matrix. It consisted of self/cross elasticity coefficients. Simulation based study was performed on the IEEE reliability test system to illustrate the developed techniques. It was observed from the simulation results that the demand price elasticity decreased the nodal price volatility. Furthermore, it had been noticed that the demand price elasticity improved both the system reliability and nodal reliabilities of restructured power systems. On the other hand, overall distribution system reliability worth was assessed by Ou et al. using Monte Carlo simulation technique [55]. Here, a series of simulation studying the impacts of various probability distributions was presented. Load point expected cost (ECOST) and interrupted energy assessment rate (IEAR) were studied on the basis of restoration time. The impacts of different radial system had been analyzed. The radial distribution systems operation philosophies were also included. Different kinds of failures had been studied. Electric power utilities and planners could have good references from these simulation studies. The planners could have it for decision making. In another work, artificial intelligence had been considered by Bouhouras et al. for performing cost/worth assessment of reliability improvement in distribution networks [56]. Here, the implementation of an artificial intelligence system was performed in an urban distribution network. The network was capable to locate an isolated short circuit fault in the feeder. This could accomplish the quick restoration of electric supply to the customers. This work illustrated the benefits of the project. These benefits were supply reliability improvement and distribution network loss reduction via network reconfiguration. Dispersed customer cost data had been considered to find out reliability worth of distribution system after performing network reinforcement [57]. Two cost models were proposed. These models could be utilized in reliability cost analysis. These were an average or aggregate model and a probability distribution model. Illustration had been provided for a time sequential simulation technique for distribution system reliability cost/worth evaluation. The evaluation had been performed utilizing the two developed cost models and incorporating time varying loads. The method was utilized to evaluate the reliability worth of installing disconnect switches, lateral fuses and alternate supplies in a test distribution system. However, simultaneous consideration of reliability and cost is necessary for appropriate planning.

2.3.2 Power system reliability and associated costs

Power system reliability and financial issues should be simultaneously considered for making profit in deregulated power market. In this regard, joint analysis of power system reliability and market price was performed by Chongqing et al. considering the uncertainties of load forecasts [58]. Here, a novel model and algorithm for joint analysis of power system reliability and market price were proposed. This was performed considering the uncertainties of load forecast. The market simulation and reliability assessment results helped to analyze the system reliability indices and probability distribution function of price. A stochastic load model was chosen to illustrate the uncertainty of the future system load. In that attempt, units' uncertain bids and output were included with the probability of forecasting load in the algorithm. Two numerical samples were investigated here in details to show the effectiveness of the proposed model and algorithm. A simple system containing four units was examined thoroughly. The system reliability indices had also been illustrated. These were demonstrated considering uncertain load forecasting. On the other hand, an IEEE reliability test system consisting of 32 units was considered for simulation of real electricity market. The expectant unit output and its income were studied in this regard. Some instructive conclusions were yielded. The study results showed that the model was effective. In another work, Brown et al. studied automated primary distribution system design for reliability and cost optimization [59]. An economic criterion was proposed for the design stage. Comparison had been exercised amongst several automated design methods. Brown et al. identified the best suited algorithm for distribution system reliability and cost optimization. Electricity price is a very significant factor for the rural customers. On the other hand, reliability in several situations is poor in rural distribution system. In this regard, Wang et al. studied time sequential simulation technique for rural distribution system reliability cost/worth evaluation including wind generation as alternative supply [60]. A time sequential simulation technique was proposed for the reliability cost worth assessment of a distribution system including wind turbine generator. Variable wind speed and forced outage rate were considered in presenting a three state model of a wind turbine generator. A test rural distribution system had been considered for illustration purpose of the proposed method. However, there are other financial issues related to reliability which are always of major concern for business sustainability.

2.3.3 Other economical aspects of reliability

Reliability cost is a crucial part which should be accounted for performing appropriate power system planning. Kjolle et al. studied economic aspect of reliability in distribution system planning [61]. Here, reliability had been considered as an integrated part of cost minimization problem. It was studied that the economic evaluation of reliability was of great importance in distribution system automation and design. On the other hand, Lin et al. performed distribution system planning with evolutionary programming and considered the cost of reliability [62]. Reliability cost for optimal distribution system planning was considered here. The cost model was developed as a linear function of line flows for assessing the outages. Evolutionary programming was implemented to solve the very complicated problem. Again, Lin et al. have done distribution system reliability worth analysis with the customer cost model based on radial basis function neural network [63]. Here, two interruption cost models were proposed. These cost models included an average or aggregated model (AAM) and a probabilistic distribution model (PDM). These models were proposed by utilizing the radial basis function (RBF) neural network with orthogonal least squares (OLS) learning method. It had been observed that the two cost models resulted in very different interruption costs. It was noticed that PDM might be more practical in modeling the system. In another work, Moya et al. studied long term marginal cost of reliability and inter zone reliability transfer in power system [64]. Here, the topological problem was solved by using radial sub networks to consider the presence of loops in the grid. On the other hand, supply reliability cost allocation was performed by Niioka et al. under deregulated generation market [65]. Expected unserved energy (EUP) was applied in the proposed method. This EUP was implemented to assess the system supply reliability and reliability cost for the system. A test system was utilized to show the effectiveness of the proposed method. In another study, Hui et al. implemented power system security and reliability considering risk under environment of electricity market [66]. Two approaches were proposed here. This was presented to implement system security and reliability. The first approach was based on the maximization of social effect. The other approach was based on the maximization of power grid companies' economic benefit. The benefit was under the prerequisite of ensuring the economic benefit of power grid company's users. It was discussed that the presented two techniques provided new

thinking under market environment. On the other hand, Sullivan et al. estimated the value of service reliability improvements [67]. The work of that research group showed how the use of crude interruption cost estimation techniques could substantially impact the estimated value of service improvements.
Economic benefits are necessary for business sustainability but appropriate planning is must to achieve financial gain. Reliability planning thus becomes a coveted approach in a power system network to satisfy customer as well as to make profit for company.

2.4 Reliability studies related with planning issue

Monopolistic business has been changed to deregulated power busness. Power engineers, researchers and scientists are striving to find better engineering option to provide reliable and economic power to the customers. Appropriate planning which will enhance reliability as well as reduce cost is very significant for business sustainability. Here, a few planning approaches related to power system reliability have been discussed to understand the matter in a better way.

2.4.1 Planning related to costs for reliability analysis

Reliability estimation for power system planning is important as regard as economy is concerned. Bhowmik et al. performed a new power distribution system planning through reliability evaluation technique [68]. Here, a cost function was minimized by an algorithm. This algorithm was developed to find an optimal solution for a large scale radial distribution system. Three stage iterative solutions considering substation optimization, feeder optimization and outage cost optimization were presented in that attempt. On the other hand, power distribution system planning was studied with reliability modeling and optimization [69]. Here, a new approach was proposed for the systemized optimization of power distribution system. Outage costs and costs of switching devices along with the nonlinear cost of investment, maintenance and energy losses of both the substations and feeders were incorporated in the objective function. Optimization had been performed by the planning software for a power distribution system of a developing city. In another work, deregulated power system planning was performed by Billinton et al. using a reliability network equivalent technique [70]. Here, a technique was developed on the basis of reliability cost-worth considerations. The technique could be utilized to make utility planning. Operating decisions could also be made. Generation and transmission facilities were represented with the introduction of the concept of a service provider. Reliability equivalence method was utilized to find out a representative service provider. This method was also utilized to create equivalent elements. In another attempt, reliability worth was determined for distribution system planning [71]. Here, concerns were raised for the evaluation of the reliability worth index which could be utilized to make decisions in distribution system planning and design. Interrupted energy assessment rate (IEAR) was chosen as reliability worth index. Three fundamentally different methods were studied for evaluating distribution system reliability indices. These methods were tested on a small but comprehensive test system. However, value based reliability planning is also necessary for proper economic assessment.

2.4.2 Procedures involving value based reliability

Reliability planning considering customer value is significant when deregulation is prevailing in the power market. Chowdhury et al. dealt with current practices and customer value based distribution system reliability planning [72]. Here, a brief overview had been illustrated related to current deterministic planning practices in utility distribution system. A probabilistic customer value based approach was also described here. This approach was attained for alternating feed requirements planning for overhead distribution system. In another attempt, Chowdhury et al. again performed value based distribution system reliability planning [73]. Concerns were raised here with the value based evaluation of proposed modifications to an existing industrial distribution network. The assessment was performed to minimize the cost of interruption to both the utility and its industrial customers. A series of case studies of an actual industrial load area were presented. This load area was supplied by two feeder circuits. These circuits were originated from two alternate substations. Variance in reliability performance indices and their impact on the cost of load point interruptions were discussed in detail. On the other hand, Longo et al. performed evaluation of distribution system enhancements using value based reliability planning procedures [74]. The application of value based reliability planning (VBRP) method was illustrated here. This method was applied to the problem of distribution substation capacity enhancement. Operating cost of various alternatives and relative investment were considered in the traditional approach. The VBRP did enhancement of the traditional approach with the addition of reliability valuation. Transformer failures and accelerated aging from increased stress on remaining transformers were given importance in this regard.

Reliability improvement is necessary like reliability planning in the deregulated business environment. Reliability enhancement can be achieved by suitable incorporation of distributed generation, capacitor etc into the power system network.

2.5 Reliability enhancements of a power system network

2.5.1 Incorporating capacitor

Service reliability can be enhanced by proper capacitor allocation in a power system network. Capacitor installation indirectly reduces the real power loss of the system. As the real power loss reduces it decreases the heating effect of electric line. In this way the failure rate also decreases. This in turn improves service reliability. Reactive power compensation by capacitor is significant in transmission system where disruption in power supply can cause wide area blackout. Billinton et al. studied thyristor controlled series capacitor (TCSC) installation for reliability enhancement [75]. Here, TCSC had been employed to adjust the natural power sharing of two different parallel transmission lines. It enabled the maximum transmission capacity for utilization. Comparative studies had been performed to show the impact of reliability indices by the application of TCSC. In that attempt, a reliability model of multi-module had been formulated and included in the transmission system. To measure the impact of TCSC incorporation, reliability indices such as LOLE, LOEE, UPM and SM were used. The incremental peak load factor had been shown for different load factors. This was shown as a penalty in the load carrying capability when TCSC was not employed. Here, the worth of incorporation of TCSC had been shown as incremental customer interruption cost. However this should be compared with capital, operating and maintenance costs when TCSC had been employed in the decision making process. Reliability enhancement had also been performed in sub transmission system using a thyristor controlled series capacitor [76]. Here, TCSC was incorporated in a system to adjust the transmission infeed impedances. This in turn did increment in transmission system capacity without the increment of the system fault current level. In that attempt, a multi module reliability model had been developed and incorporated that into the transmission system. Two kinds of performance indices were also presented to investigate the impact of TCSC on the sub-transmission system reliability. The results showed that delivery point and system indices had been improved significantly after incorporation of TCSC. On the other hand, distribution system

reliability enhancement was optimally performed by allocating capacitor [77]. Here, two objective functions were proposed for reliability enhancement. The first one had been considered as the sum of reliability worth and capacitor installation cost. The later one had been chosen as the addition of real power loss cost to the first one. Particle Swarm Optimization technique was used to find out the optimal solution in capacitor placement problem. A nine section feeder had been taken for implementation of the soft computing technique. Considerable savings had been found out in annual cost due to the increase in reliability. It had also been observed that with the incorporation of additional capacitors, the reliability worth reduces. This reduction also pushed the solution point away from the optimal solution point.
Like capacitor allocation, distributed generation integration is also another approach which can be opted to achieve reliability benefits in a power system network.

2.5.2 Integrating distributed generation in power network

Distributed generation incorporation in the distribution circuit can improve reliability of a power system network. Reliability enhancement was performed by optimal placement of DGs in distribution system with time varying load using Genetic Algorithm [78]. Here, annual load duration curve had been considered with four load levels having different weighting factor. Customer oriented reliability indices SAIDI, SAIFI, CAIDI, ASUI and load and energy oriented reliability index ENS had been considered separately as objective function for Genetic Algorithm implementation. It was observed that individual DG placement and network reconfiguration did reliability improvement. But utilizing both the scheme reliability had been observed to be improved significantly. On the other hand, Borges et al. performed optimal distributed generation allocation for voltage, loss and reliability improvement [79]. Here, a methodology had been proposed for optimal sitting of distributed generators. In another study, Dezaki et al. performed optimized allocation of DGs based on loading effect to improve system reliability [80]. Here, a novel method was presented to optimize the allocation of DGs based on decreasing failure due to the enhancement of loading effects. Reliability enhancement by DG penetration was studied by Hlatshwayo et al. [81]. In that attempt, reliability improvement had been compared with analytical and Monte Carlo simulation techniques for DG placement at different load points. On the other hand, reliability improvement and loss reduction both were studied by Hosseinzadeh et al. [82]. Here, a multi-objective formulation for optimal placement of DG sources was presented to minimize the cost of loss and energy not supplied. Intentional islanding of distributed generation had also been studied for reliability enhancement [83]. Here, the coordination requirements for intentional islanding were investigated to augment DG/utility reliability in providing uninterruptible power to the connected loads. In another attempt, Okuyama et al. performed reliability improvement by information exchange between dispersed generations [84]. Here, reliability improvement was studied considering online information in distribution system which was isolated from the upper system. However, distributed generation can be of various types such as solar, biomass, wind etc. In this regard wind power generation as DG source had been considered for reliability augmentation by several research groups [85-86]. Rohrig et al. studied improvement of the power system reliability by prediction of wind power generation [85]. Prediction of wind power generation was necessary for the utilization and control of electric power system. The concept of wind farm cluster was introduced here. It was assumed that the wind farm cluster manager would assist the transmission system operator. This would be done according to the requirements of the electrical power transmission system. In another study, Litipu et al. performed optimal allocation of wind power generation to improve the reliability and environment of power system [86]. Here, wind electric generation was utilized as an accessory of power service resources. This was exercised to improve the reliability index in energy supply of existing power system. The total optimal capacity of wind power turbine was determined on the basis of the characteristics of the wind condition. The optimal wind capacity of each target bus was determined to manage the supply reliability of the existing power system. Wind electric energy with existing units provided an acceptable level of reliability index. Decision for selection of the target sites for installation was taken from two criteria. One was probabilistic security index obtained from the generator outage probability and the other one was operation characteristic of wind power turbine.

It has been evidenced here that individual DG integration can be beneficial in terms of reliability benefits. Reliability augmentation can also be achieved by performing proper capacitor placement. The effect of both DG and capacitor allocation studied by several research groups have been illustrated in the next section.

2.5.3 DG penetration involving capacitors

Simultaneous suitable capacitor allocation and DG integration in a power system network can be more effective than individual capacitor or DG placement. In this regard, Baghipour et al. studied both DG and capacitor placement for voltage profile, loss, and reliability enhancement using Binary Particle Swarm Optimization [87]. Here, a multi-objective function had been optimized. The objective function incorporated voltage profile index, DG's and capacitor's investment cost index, active power loss index and reliability index. In that attempt, a comparative study was performed to check the effectiveness of the proposed method on 10 and 33 bus distribution systems. In another work, a new method was proposed considering DG and capacitor placement for line loss and reliability improvement [88]. The proposed objective function included the investment cost of DGs and capacitors and cost equivalent of line loss and reliability. The bus voltage and line current were considered as the limiting function. Hybrid Particle Swarm Optimization method had been used for performing the simulation study. The proposed technique was tested on IEEE 69 bus test system. The results showed that lowest cost planning could be gained by performing both DG and capacitor allocation.

There are also other approaches available in the literature which had been considered for reliability augmentation of a power distribution system network. These have been discussed in the following sections.

2.5.4 Other approaches concerning to reliability augmentation

2.5.4.1 Use of soft computing techniques for reliability enhancement

Soft computing based techniques can be effectively implemented for performing engineering optimization concerning to reliability improvement. Arya et al. performed reliability enhancement of a radial distribution system using coordinated aggregation based particle swarm optimization (CAPSO) considering customer and energy based indices [89]. Here, an algorithm was implemented for best possible alterations for failure rate and repair time for a radial electrical distribution system. The changes were with connection to a penalty cost function minimization. The price function had been decreased subject to the energy based and customer oriented indices, i.e. AENS, SAIFI, SAIDI and CAIDI. The algorithm has been employed on a model radial distribution system. The results achieved had been weighed against with those attained employing PSO. On the other hand, Fard et al. applied self adaptive modified bat algorithm (SAMBA) to enhance reliability of the distribution system [90]. Here, the reliability indices viz. system average interruption frequency index (SAIFI) and average energy not supplied (AENS) were investigated as objective function. Furthermore total active power losses and the total network cost were also examined as objective function. Wind power source had been considered as the renewable energy source to check the effect on reliability of the power system. In another work, Genetic algorithm (GA) had been implemented by Gupta et al. for power quality and reliability improvement in distribution system [91]. Here, two new objective functions were constructed to check power quality and reliability issues. A single objective function was formulated on the basis of feeder power loss, system's node voltage deviation, system's average interruption frequency index, system's average interruption unavailability index and energy not supplied. The objective function was solved by the GA based method. In another attempt, an improved genetic algorithm (IGA) was employed for reliability enhancement in distribution system [92]. Here, the reliability cost/worth model of distribution system and the assessment technique were introduced. In that attempt, a mathematical model had also been constructed concerning to that said cost model. This IGA technique searched the global optimal solution for the expected customer interruption cost minimization problem. The simulation results for IEEE Roy Billinton Test system bus 2 had shown the effectiveness and feasibility of the chosen IGA technique. Shareef et al. used quantum firefly algorithm (QFA) for power quality and reliability improvement in distribution system [93]. Here, the QFA technique was implemented to a system in a specified period to reduce the number of propagated voltage sags and other reliability indexes. The other reliability indexes were average system interruption frequency index, sustained average interruption frequency index and momentary average interruption frequency index. The quantum inspired binary firefly algorithm's performance was compared with the firefly algorithm and the gravitational search. A new multi-objective improved shuffled frog leaping algorithm (ISFLA) was also applied to enhance reliability in distribution system [94]. Here, the total active power loss was considered as objective function. The reliability indices namely system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI) and average energy not supplied (AENS) were also considered as objective functions. The proposed technique namely ISFLA found a set of non-dominated optimal solutions. A standard test system was considered for investigation of the proposed technique. It was found that the proposed technique was feasible and effective. Skoonpong et al. implemented simulated annealing (SA) for reliability enhancement in distribution systems [95]. Here, the importance had been given to improve the reliability of electric power supply such that the customer interruption cost is minimized. This was subjected to the system operational cost. The SA technique had been tested with a distribution system connected at bus 2 of Roy Billinton test system. The simulation results showed that the suitable on/off status of switches could decrease the customer interruption cost.

Cultural algorithm (CA) is also a potential soft computing based technique like the above discussed algorithms but it has not been observed to be implemented for reliability enhancement in distribution system. Though this CA technique has been applied for power system optimization problem but it sometimes fails to reach to the global optima when the system is large and the situation is complex. That's why a modified CA (MCA) can be employed here for performing simultaneous optimal capacitor allocations and DG integrations to observe cost reduction as well as reliability improvement. In addition it has been observed that nature inspired phenomena has been conceptualized for developing evolutionary algorithms which have been applied for reliability improvement in distribution system. In this regard, active and passive electro location phenomena of elephant nose fish and shark can also be thought of to develop the concept of an optimization technique. Fish electrolocation optimization (FEO) algorithm can be developed from these physiological processes of fishes for performing simultaneous optimal capacitor and DG placement to observe further cost based reliability enhancement in comparison to the MCA technique. But application of these techniques deserves special attention when they are applied to the State of the Art technologies.

2.5.4.2 Reliability enhancements using power electronics based system

A key necessity in the function of FACTS devices in power systems is to build up methods which allow system planners to handle the ambiguity linked with these devices. Firuzabad et al. performed power system reliability enhancement using unified power flow controllers [96]. Here, a technique was proposed to assess transmission system reliability while implementing a Unified Power Flow Controller (UPFC). The work provided a scaffold within which the risk connected with managing and the progress of the transmission network can be measured. Reliability indices such as the Loss of Energy Expectation (LOEE), Loss of Load Expectation (LOLE), the Loss of Load Probability (LOLP) and the System Minutes (SM) were used to study the impact of UPFC on the transmission system reliability. The method was demonstrated by appliance to a theoretical system. In another attempt, Pimjaipong et al. studied blackout prevention plan for the stability, security and reliability enhancement in Thailand power grid [97]. Blackout prevention plan was presented for Thailand system. Special protection schemes and FACTS devices were implemented to enhance the power system stability, reliability and security of the power system in Thailand. The application of blackout prevention plan would be beneficial to the Thailand power grid as a whole. Power conditioning system is another inevitable part of the power electronics based system for energy conversion purpose. Reliability issues connecting to this type of system should be given importance for healthy operation. Casadei et al. studied power quality and reliability supply improvement using a power conditioning system with energy storage capability [98]. This power conditioning system with energy storage capacity had been analyzed as the viable solution for reliability improvement. Several tasks could be performed with that quality and reliability improvement. Reactive power compensation, smoothing of pulsating loads and current harmonic reduction had drawn the special attention. Furthermore, the power conditioning system could be operated as an uninterruptible power supply at the short time interruption of the grid. The prescribed system had a flexible structure. It could be operated with several energy storage devices like batteries, flywheels, superconducting magnetic energy storage and supercapacitors etc. However, it is necessary to study the reliability aspects concerning to the demand responses for business purposes.

2.5.4.3 Demand response considerations

Electrical demand of connected loads in a power system changes very frequently with respect to time. Goel et al. did reliability enhancement and nodal price volatility reduction of restructured power systems with stochastic demand side load shift [99]. Here, a methodology was developed to determine demand side load shift. This was also developed to enhance reliability and to reduce nodal price volatility of restructured power systems. The simulation results showed that stochastic demand side load shift is an efficient tool to reduce modal price volatility. The stochastic demand side load shift also enhanced system and nodal reliability of restructured power systems. Again, Goel et al. studied reliability improvement of restructured power system with diversified demand side load shift [100]. Here, an evaluation technique was presented to include the impact of diversified demand side load shift on the system reliability and nodal reliabilities of deregulated power systems. It is a known fact that with the advancement of deregulated power system, electricity prices are exchanged by spot prices. In another work, reliability enhancement of deregulated power system had been studied considering demand response [101]. Here, demand responses and their correlation were presented utilizing the matrix of demand price elasticity. It was observed that demand response could improve the system and nodal reliability. However, high voltage direct current (HVDC) transmission is also another approach which enhances power system reliability.

2.5.4.4 Reliability enhancements considering HVDC

High voltage direct current transmission can be effective as regard as power system reliability is concerned. Sheng et al. performed reliability enhancement of HVDC transmission by standardization of thyristor valve and valve testing [102]. In that attempt, bulk power transmission was discussed by means of HVDC thyristor valves. It was stated that standard thyristor valve design had been accepted in several HVDC projects for reliability improvement in recent years. Zhang et al. again studied transfer capacity enhancement and power system reliability considering VSC-HVDC. Here, several interesting features of VSC-HVDC were demonstrated [103]. It was observed that these features could greatly enhance the reliability and transfer capability of power systems. It was mentioned that VSC-HVDC was able to provide reactive power to the grid independent of its active power transmission. However, a few approaches had also been considered to enhance reliability of a power system network apart from the earlier discussed methods.

2.5.4.5 Reliability improvements by other methods

Reliability augmentation in a power system network is necessary as both customer satisfaction and company profit is crucial for business sustainability. Gauthier et al. discussed planned islanding as a distribution operation tool for reliability enhancement [104]. Here, the procedure of planned islanding was considered for the essential steps that needed to be taken so as to make it a booming project. This scheme needed strong teamwork between the Distribution and Transmission engineers to accomplish the reliability development for the distribution customers when an intended outage is necessitated on the transmission line. The results of the studies were examined thoroughly. The current position of the scheme had also been discussed. On the other hand, Cleveland studied for enhancing the reliability and security of the information infrastructure used to manage the power system [105]. It was discussed that security measures should be built into every system from the moment they were conceived. In another work, Bishop et al. performed distribution system reliability improvements justified by increased oil production [106]. Here, reliability improvement of overhead distribution feeders was discussed for serving oil-pumping facilities. In another attempt, Castro et al. studied reliability improvements of the Guri hydroelectric power plant [107]. Here, computer control system of a large hydroelectric power plant and the reliability augmentation incurred to the automatic generation control and automatic voltage control programs were discussed. Reliability improvement of power systems were exercised with more accurate grounding system resistance estimates [108]. Here, the degree of error was quantified for computing grid resistance, touch voltages and step voltages as a function of maximum pin spacing. In another study, Svensson et al. did cost saving and reliability improvement by using innovative technique for refurbishment of a substation [109]. Here, an innovative solution with disconnecting circuit breakers was found better with regard to power flow than a traditional substation configuration with conventional equipment. On the other hand, power system stabilizers were effectively used for enhancement of power system reliability [110]. Here, an account of the measures and procedures was provided for the effective application of power system stabilizers to ensure functional reliability. In another work, Miyata et al. studied the basic philosophy and improvement on reliability of electric power system in Japan [111]. Here, an extensive study had been performed on system reliability from the viewpoint of equipment and also of operation. Customer reliability improvement on the other hand was exercised with Dynamic Voltage Restorer (DVR) and a Dynamic Uninterruptible Power Supply (DUPS) [112]. In that attempt, control and protection concepts of DVR and DUPS were presented to describe the system performance achievable with these power devices. In another study, Sahay et al. presented super-capacitor energy storage system for power quality and reliability improvement [113]. Here, a critical view had been provided chronologically to improve quality of power with the help of supercapacitors energy storage systems. On the other hand, a value based reliability enhancement scheme was studied for bulk transmission system planning [114]. Here, a unique value based reliability enhancement method was described for bulk transmission system planning. A dollar value quantification of the level of reliability was also proposed. This enabled calculation of benefit of to cost ratios. However, it is a known fact that the modern power system is controlled mainly by SCADA. But it is not suitable for fast system process. In this regard, Kilter et al. performed integration of wide area monitoring technology and enhancement of power system reliability in Baltic power system [115]. Here, more advanced technology was discussed to enhance power system reliability. Wide area monitoring system (WAMS) and possible solutions were used to enhance system reliability. On the other hand, Hosseini et al. studied reliability improvement of distribution system using static series voltage regulator [116]. A reliability assessment algorithm was presented utilizing a static series voltage regulator in distribution systems. This algorithm considered the effects of distributed generation units, system reconfiguration, alternative sources and load shedding distribution system reliability indices. Customer and energy oriented reliability indices were evaluated for reliability assessment. It was observed that the proposed algorithm was effective for large scale distribution systems. Reliability improvement had been performed by Nesrullah et al. in distribution system employing a voltage sag mitigation method using binary gravitational search algorithm [117]. A method for enhancing the level of reliability of distribution system was proposed here. An integrated voltage sag mitigation method comprising of two stage strategy was employed. This strategy was distribution network reconfiguration followed by DSTATCOM placement. It was observed from the simulation results that the proposed method was effective and feasible for enhancing the level of system reliability.

2.6 Concluding remarks

It is observed from above discussions that cost reduction as well as reliability improvement by simultaneous optimal capacitor allocations and distributed generation integrations performed by soft computing techniques may be attempted as an important research topic in microgrid type radial distribution systems. Several studies related to reliability had been performed especially in distribution system where prolonged outages and failures occur. On the other hand, the real power loss is an important phenomenon which has a connection to failure of the electrical line. This causes poor service reliability in distribution system where most of the customers such as rural, urban, office, hospital, commercial, industrial etc are available. Cost incorporated customer specific reliability improvement in distribution system is observed to be sparse. Reliability evaluation was however envisaged by analytical methods, Monte Carlo simulation and a few algorithms. In this regard, nature inspired evolutionary technique can be approached for reliability assessment. Distributed generation integration and reactive power compensations impact on service reliability had been studied individually by many research groups. The combination of the above engineering schemes can be very effective for reliability enhancement as well as loss reduction and cost minimization. Reliability improvement considering reinforcement schemes such as *applying only disconnects* and *implementing lateral protection plus disconnects* can be performed in radial distribution system. The effect of these two schemes on reliability is hardly found in the literature. Reliability optimization and reliability enhancement considering economic issues had been performed by several approaches. But novel technique especially developed from nature inspired phenomena may be another approach for performing optimization in connection to reliability. Most of the reliability indices which had been studied are customer and load based. Cost based reliability index which directly reflects the reliability worth is hardly found in the literature.

From the above attempts of different research groups some points may be noted down. Studies on cost based reliability enhancement may be attempted considering simultaneous optimal distributed generation integrations and capacitor allocations in microgrid type radial distribution systems. Appropriate planning may be exercised for single as well as multi objective situations by suitably choosing DG and capacitor size and location for standard microgrid type distribution systems. Distributed generation penetration at different levels may also be attempted for the total active power load of the microgrid type distribution systems. Distributed generation integration can also be performed considering a maximum of 50% DG penetration keeping the futuristic plan in mind.The cost minimization may be exercised for two specific reinforcement schemes viz. *applying only disconnects* and *implementing disconnects and lateral protection*. Cost based reliability index may be formulated considering reliability worth and real power loss. Customer and the load oriented reliability index viz. SAIFI, SAIDI, AENS etc along with a newly developed cost based reliability index (CBRI) can be studied for reliability analysis for microgrid type radial distribution systems. Two newly developed soft computation schemes namely modified cultural algorithm and fish electrolocation optimization can be applied for performing optimal allocation of DG and capacitor to observe cost reduction and reliability improvement. Modified cultural algorithm can be formulated by performing modification of cultural algorithm. On the other hand, fish electrolocation optimization can be mathematically developed considering active and passive electrolocation phenomena of elephant nose fish and shark, respectively. Comparative studies may be attempted amongst four soft computing techniques viz. real coded genetic algorithm (rcGA), particle swarm optimization (PSO), modified cultural algorithm (MCA) and fish electrolocation optimization (FEO) for achieving better cost, loss and reliability.

Reliability enhancements as well as total cost reductions have been presented later in Chapter 7 after suitable capacitor allocations and DG integrations. Reliability cost and reliability worth have been considered as total cost here. Reliability cost is connected with the investment cost to achieve a certain level of reliability whereas reliability worth is something which has been evaluated by assessing customer interruption cost. Furthermore, quantification of reliability is also necessary to estimate reliability improvement. These economic implications of reliability and distribution system reliability indices have been considered in the next chapter with basic reliability mathematics to comprehend the concept in a planned method.

Chapter 3

Economical reliability analysis of a distribution system

In the previous chapter, the reliability issues connected to power systems have been analyzed from several literatures. This reliability is related with the failure rate of power system equipments. Equipment will fail eventually if it is in service for a long period in a system. The failure rate of electric line and AC cable has only been considered for reliability evaluation in this work. This has been performed considering other power apparatuses as reliable. Cost reduction as well as reliability improvement has been approached performing simultaneous optimal capacitor and DG placements in microgrid type radial distribution systems. Hence it is necessary to consider the basic reliability related mathematics and economic implications of reliability due to power interruption. This has been illustrated here with a few distribution system reliability indices for better understanding of the reliability issues.

3.1 Basic mathematics related to reliability

Mathematical formulations of failure rate and outage time are necessary to develop reliability indices. Life of an electric line, cable or equipment and concept of reliability are also significant to understand the basic principle underlying satisfactory operation of apparatuses.

3.1.1 Failure rate, outage time and annual outage time

The number of expected failures in a certain time interval is defined as failure rate. However, it is considered as an expected value. In any given time interval, the actual number of failures may differ. For example, an electrical line with a failure rate of 24 failures per year does not necessarily have two failures every month. The expression of failure rate is as follows;

$$\lambda^{fl} = \frac{total\ number\ of\ failures}{total\ given\ time} \tag{3.1}$$

In this work, the interest is focused on power distribution system especially microgrid type radial distribution system. A radial distribution system is comprised of a set of series components. The series components incorporate lines, cables, disconnects or isolators, busbars etc. A consumer wants all components connected between load and the supply to operate properly. Line, cable or equipment outages and customer interruptions are primarily related with distribution reliability. The basic parameters related with reliability are *average failure rate*, *average outage time* and *average annual outage time*. These are expressed as follows;

$$\lambda_{avg}^{fl} = \sum_i \lambda_i \tag{3.2}$$

$$An_{avg}^{out} = \sum_i \lambda_i r_i \tag{3.3}$$

$$r_{avg} = \frac{An_{avg}^{out}}{\lambda_{avg}^{fl}} = \frac{\sum_i \lambda_i r_i}{\sum_i \lambda_i} \tag{3.4}$$

The above three equations represent the system average failure rate, system average annual outage time and system average outage time respectively. The stated three primary reliability indices have been considered as *failure rate*, *annual outage time* and *outage time* in this research work. These three primary factors have been considered here to calculate reliability indices for every load bus of the microgrid type radial distribution systems under consideration. However, line, cable or equipment will eventually lead to failure after a certain useful life.

3.1.2 Life of line, cable or equipment

Three major distinguishable periods take place in line, cable or equipment's life. These are infant mortality period, useful life period and wear-out period [118]. The failure rate is high in the infant mortality period. This is high due to the existence of weak spots from the manufacturing process. That may be due to poor workmanship, substandard components, and so on. The failure rate is improved i.e. it is decreased as the weaknesses are manifested one by one by the stress of operation. The failure rate is decreased upto a low constant level. After this period, the line, cable or equipment enters into the useful life period. In this period, the failure occurs at random times by chance. Failures occur irregularly at unpredictable moments. The failure is not dependent on the age of line, cable or equipment in this useful life period. Ultimately this period ends with the starting of wear-out of the line, cable or equipment. The failure rate increases very rapidly due to deterioration when the line, cable or equipment enters into the zone of wear-out period. Though chance failures occur but the wear-out process dominates the failure rate. It is like a bathtub shape curve if the failure rate of line, cable or equipment is plotted against time.

3.1.3 Reliability from the first principle

The probability of not failing for a given time interval is defined as the reliability. The reliability is considered according to population of line, cable or equipment in this approach. The reliability is the ratio between population that survives and original population [118]. Say for example, the original population is N_o. The N_f population fails after a certain time *t*. The surviving population is N_s. Then the reliability at time *t* will be as:

$$R(t) = \frac{N_s(t)}{N_o} = \frac{N_o - N_f(t)}{N_o} \tag{3.5}$$

3.1.4 Reliability model

The reliability modeling can be of different type from the reliability of population discussed in the previous paragraph. The relationship between constant failure rate and reliability can be very simple. For example, the population at the beginning of the observation be N_o. The failure rate is considered as λ^{fl}. After a certain time interval, some units will fail and others will still be operating. The above stated two populations are denoted as N_f and N_s, respectively. In usual course, N_s decreases with time and N_f increases with time. The differential of N_f with respect to time is the number of expected failures per unit time. That is for the present population at the instant. This time rate of increase is equal to the failure rate times the number of units in the present population [118]. This is expressed as;

$$\frac{dN_f}{dt} = \lambda^{fl} N_s \tag{3.6}$$

where N_f and N_s change with time. However, they always sum up to the initial population N_o. It is expressed as;

$$N_f + N_s = N_o \tag{3.7}$$

As discussed in the previous section, reliability is the ratio between surviving units and initial population. It is expressed as;

$$R(t) = \frac{N_s}{N_o} \tag{3.8}$$

Combining the above three expressions, one can get

$$R(t) = \frac{N_s}{N_o} = 1 - \frac{N_f}{N_o} \tag{3.9}$$

$$\frac{dR(t)}{dt} = -\frac{1}{N_o}.\frac{dN_f}{dt}$$

$$= -\frac{1}{N_o}.\lambda^{fl} N_s$$

$$= -\lambda^{fl}\frac{N_s}{N_o}$$

$$= -\lambda^{fl} R(t)$$

$$\int \frac{1}{R} dR = -\int \lambda^{fl} dt$$

$$\ln R(t) = -\lambda^{fl} t$$

$$\boldsymbol{R(t) = e^{-\lambda^{fl} t}}$$

Reliability has been expressed here in a generalized way. This has been considered as the exponential decaying over time. The decay is governed by the failure rate of line, cable or equipment. Distribution system reliability is not strictly assessed by the stated way. However, failure rate is connected to the evaluation procedure of reliability indices. At the same time number of customer plays an important role in determining the reliability indices. In this regard, discussion related to the evaluation procedure of reliability indices is necessary to grasp the idea of reliability indices.

3.2 Reliability evaluation of distribution systems

Reliable and economical electrical supply to customers is the basic operational function of a distribution system. After the year 1965, the real interest for power system reliability evaluation started to grow [118]. This was most notably influenced by New York City black out. The technique changes in operations and configurations of distribution system have been accommodated by the constantly evolving reliability mathematics. Now, photovoltaic system and wind as renewable energy sources have significant impact on operation of distribution system. Deregulation is giving challenges to electric utilities. Consumer/customer is looking for good service i.e. value added service from any utility distribution company. If the customers are not satisfied then they will start shopping. The great number of business failures in numerous industries is due to failure in recognition of customer needs. The characteristics related to business such as focus, strengths, weaknesses and strategies are assessed in the competitive electricity market. This is forcefully done as a movement of the electric industries. Challenge for electric utilities lies in increasing the market value of the reliable power supply they provide. This challenge also lies in lowering the customers' electric cost by decreasing the cost of operation, maintenance, and construction. These are amongst the major challenges. The optimum reliability, for any power system supplying a certain mix of consumers, results in lowest combined cost. In the following section mainly distribution system reliability assessment has been studied as reliability improvement of microgrid type distribution system as is considered in this work.

3.2.1 Assessment of distribution system reliability

It is vital to note that the distribution system is a crucial connection between the bulk power system and its customers. In many cases, these connections are radial in character. That makes them susceptible to customer disruptions due to a single outage event. A radial distribution circuit normally utilizes main feeders and lateral distributors to provide customer energy needs. In the past, the distribution sector of a power system received noticeably less consideration in terms of reliability planning contrast to generation and transmission segments. The fundamental cause behind this is the fact that generation and transmission sectors are very capital concentrated. Furthermore, outages in these sectors can origin wide spread disastrous financial penalty for society.

It has been seen in the literature that more than 80% of all customer disruptions take place due to stoppages in the distribution system [118]. The distribution sector has been the feeble connection between the source of supply and the customer load points. A single distribution system operational policy is relatively reasonably priced compared to a generation or a transmission development scheme. An electric utility usually pays out a large sum of capital and maintenance budget jointly on an enormous number of distribution upgrading projects.

At present, in many electric utilities, satisfactory levels of service continuity are found out by comparing the real disruption frequency and duration indices with capricious targets. For example, monthly reports on service continuity statistics developed by many utilities consist of the subjective targets of system reliability indices for performance comparison intentions. It has long been documented particularly in the deregulated market environment that rules of thumb and implied criteria cannot be employed in a reliable manner. This can't be employed to the outsized number of capital and maintenance venture. It is also applicable for operating decisions that are routinely made. Some reliability programmes with restricted capabilities are accessible. But until very recent times, virtually no utilities did distribution system extension investigations utilizing probabilistic models. Distribution utilities are necessary only to provide historical distribution system performance indices to regulatory organizations. However, the situation is changing very fast due to deregulation.

There are plenty of chances for distribution utilities to sensibly devote resources in distribution sector development activities. This is to convene the future load augmentation by utilizing the probabilistic reliability techniques. It would eradicate the danger of over/under savings in the system while supplying the optimum service reliability at the accurate cost. The unwillingness of electric utilities to utilize the reliability techniques in planning and designing distribution sectors is due to an existing misconception. The perception is that it needs classy probabilistic computer tools and expert engineers in distribution system reliability engineering and planning. However, due to competition the situation is changing very fast.

3.3 Quantification of distribution system reliability as reliability indices

In this work distribution system reliability improvement has been given importance. Here only a few distribution system reliability indices have been illustrated for evaluation purpose [119]. The distribution system reliability indices are described below which have been considered useful and therefore studied thoroughly.

3.3.1 System average interruption frequency index ($SAIFI$)

System average interruption frequency index is a customer oriented distribution system reliability index. This is defined in equation (3.10). It is the ratio between total number of customer disruptions and total number of customers who have consumed electricity from the same feeder. Total number of customer disruption can be enumerated by taking summation of the individual product of failure rate and customer number of a load point i. On the other hand, total number of customer can be calculated by taking the summation of individual consumer number of each load point *i* in the distribution network. The terms $\lambda_i^{fl}$and N_i^{cus} in (3.11) are the failure rate and number of customer of any load point *i* respectively. It is represented as

$$SAIFI = \frac{Total\ number\ of\ customer\ disruptions}{Total\ number\ of\ customers\ who\ have\ consumed\ electricity} \tag{3.10}$$

$$SAIFI = \frac{\sum_{i=1}^{nl} \lambda_i^{fl} . N_i^{cus}}{\sum_{i=1}^{nl} N_i^{cus}} \tag{3.11}$$

3.3.2 System average interruption duration index ($SAIDI$)

System average interruption duration index is also a customer oriented distribution system reliability index like the SAIFI. This is denoted in equation (3.12). It is the ratio between total time durations related to customer interruptions and total number of customers who have consumed electricity from the same grid. Total time durations related to customer interruptions can be calculated by taking the summation of individual product of annual outage time and number of customer for a load point *i*. On the other hand, total number of customers can be easily enumerated like the expression given in equation (3.11). In expression (3.13) the term $An_i^{out}$and $N_i^{cus}$are the annual outage time and number of customers of any load point *i*.

$$SAIDI = \frac{Total\ time\ durations\ related\ to\ customer\ interruptions}{Total\ number\ of\ customers\ who\ have\ consumed\ electricity} \tag{3.12}$$

$$SAIDI = \frac{\sum_{i=1}^{nl} An_i^{out} . N_i^{cus}}{\sum_{i=1}^{nl} N_i^{cus}} \tag{3.13}$$

3.3.3 Customer average interruption duration index ($CAIDI$)

Customer average interruption duration index is another customer oriented reliability index. This is defined in expression (3.14). This can be expressed as the ratio between total time durations related to customer interruptions and total number of customer disruptions. How total time durations related to customer interruptions and total number of customer disruptions can be calculated that has been shown and expressed for reliability index SAIDI and SAIFI in the above sections. It is the ratio of $SAIDI$ and $SAIFI$ as shown in expression (3.15).

$$CAIDI = \frac{Total\ time\ durations\ related\ to\ customer\ interruptions}{Total\ number\ of\ customer\ disruptions} \tag{3.14}$$

$$CAIDI = \frac{\sum_{i=1}^{nl} An_i^{out}.N_i^{cus}}{\sum_{i=1}^{nl} \lambda_i^{fl}.N_i^{cus}} \tag{3.15}$$

3.3.4 Average service unavailability/availability index ($ASUI/ASAI$)

Average service unavailability/availability index is a dimensionless customer oriented reliability index. The value of average service unavailability index ($ASUI$) is calculated as stated below and given in equation (3.16). The reliability index $ASUI$ is the ratio between customer hours service unavailability and customer hours service demanded. Customer hours service unavailability can be enumerated by taking the summation of individual product of annual outage time and number of customer for a load point *i*. On the other hand, customer hours service demand can be calculated by taking the summation of individual product of customer number for a load point *i* and hours in a year. Here, 8760 is the number of hours in a calendar year. The notations used in defining $ASUI$ in expression (3.17) can be easily understood as it has samilarity with the expression of reliability index $SAIDI$. The average service availability index ($ASAI$) is also another reliability index which deals with the available service hours. This can be expressed as the ratio between customer hours of available service and customer hours service demand as shown in (3.18). This reliability index $ASAI$ is considered as the subtraction of $ASUI$ from unity as observable in (3.19).

$$ASUI = \frac{Customer\ hours\ service\ unavailability}{Customer\ hours\ service\ demand} \tag{3.16}$$

$$ASUI = \frac{\sum_{i=1}^{nl} An_i^{out}.N_i^{cus}}{\sum_{i=1}^{nl} N_i^{cus}.8760} \tag{3.17}$$

$$ASAI = \frac{Customer\ hours\ of\ available\ service}{Customers\ hours\ service\ demand} \tag{3.18}$$

$$ASAI = 1 - ASUI \tag{3.19}$$

3.3.5 Average energy not supplied ($AENS$)

The last load oriented reliability index i.e. average energy not supplied ($AENS$) is calculated in equation (3.20). This can be expressed as the ratio between total amounts of energy not provided and total number of customers who have consumed electricity from the same feeder. The total amounts of energy not provided can be enumerated by taking the summation of individual product of load and annual outage time connected to load bus *i*. On the other hand, total number of customers who have consumed electricity can be calculated by taking the summation of individual customer number for every load point *i*. In the expression (3.21) $La_i$is the load connected to load point *i*. Other notations in equation (3.21) have same meaning as considered in the above sections.

$$AENS = \frac{Total\ amounts\ of\ energy\ not\ provided}{Total\ number\ of\ customers\ who\ have\ consumed\ electricity} \tag{3.20}$$

$$AENS = \frac{\sum_{i=1}^{nl} La_i . An_i^{out}}{\sum_{i=1}^{nl} N_i^{cus}} \tag{3.21}$$

3.3.6 Cost based reliability index ($CBRI$)

The newly developed reliability index $CBRI$ is a cost based reliability index. The $CBRI$ term is expressed in equation (3.22). The term is a ratio of two items. The numerator of that ratio denotes the subtraction of two terms multiplied with $loss^{ini}$. These two terms are connected to power interruption cost (*PIC*). Power interruption cost or reliability worth is evaluated considering cost of interruption, connected load and failure rate. The cost of interruption has been considered later as customer disruption cost. Here, PIC^{ini} and PIC^{it} are two terms derived from PIC where PIC^{ini} value has been considered as the initial reliability worth value i.e. without capacitor and DG placement. The PIC^{it} value is denoted as reliability worth value after capacitor and DG placement at certain iteration. The $loss^{ini}$ denotes the initial loss value without DG integration and capacitor allocation. The denominator of the ratio in equation (3.22) defines the multiplication of two terms i.e. $loss^{it}$ and $cost^{it}$. The term $loss^{it}$ defines the loss value at certain iteration after performing capacitor allocation and DG integration. Another term $cost^{it}$ of the denominator of the R.H.S of expression (3.22) defines the cost due to loss at certain iteration.

$$CBRI = \frac{\left(PIC^{ini} - PIC^{it}\right). loss^{ini}}{loss^{it}. cost^{it}} \tag{3.22}$$

This index is a reflection of reduction in power interruption cost after capacitor allocation and DG integration. The value of this reliability index is zero when there is no capacitor allocation or DG integration into the distribution system network. The improvement of this reliability index is achieved while performing maximization not minimization. So it defines that higher CBRI value means improved situation. However, this newly developed reliability index has a connection with reliability worth. There is a difference between reliability cost and reliability worth. Reliability cost is the investment necessary to achieve certain level of reliability whereas reliability worth is the benefit incurred by the society and customer. Appropriate planning has been performed in this work considering optimal capacitor and DG placements to observe cost reduction as well as reliability improvements. Hence discussion of economic issues connected to reliability is important to understand the situation in a better way.

3.4 Economic worth of reliability in connection to distribution system

As discussed in the earlier section, reliability is not an abstract academic concept. It can be quantified as an index. However, the necessary task of an electric distribution system is to satisfy the energy requirements and system load as economically as possible and with a sensible assurance of continuity and quality. The two features of comparatively low cost electrical energy at a high level of reliability are frequently in direct variance. Present power system managers, planners, and operators deal with an extensive range of tough problems due to this issue. Electric power utilities are also considering increasing connectivity to the economic, political, societal, and environmental limitations under which they function and plan their upcoming systems. This has produced growing necessities for widespread explanation of new amenities and augmented importance on the optimization of system reliability and costs. An essential part in the general difficulty of assigning operating resources and capital is the evaluation of reliability worth and reliability cost [119]. The capability to evaluate the costs related to trustworthy service is sensibly well ascertained and acknowledged. In disparity, the capability to evaluate the worth of providing reliable service is not well ascertained. Significant effort will be necessitated before these methods can be well thought-out to be entirely suitable for reliability worth assessment in distribution system. Ascertaining the worth of service reliability is a complicated and one-sided job. It is due to the fact that straight assessment does not come out to be possible at this moment. A realistic substitute is to assess the influence of disruption and understanding the financial losses acquired by clients owing to electric power supply stoppage. Customer disruption costs give an important substitute for the real worth of electric power distribution supply reliability.

3.4.1 Inherent/precise assessment of reliability worth

The common arrangement difficulty in an electric power system consists conventionally of a judgment between diverse choices for system growth prepared on the basis of system cost [119]. The system cost can be approached in two basic ways. Electrical energy consumers in developed countries enjoy the first approach. Here an inherent socioeconomic cost is connected with the choice of the reliability norm. The deterministic or probabilistic condition accepted by a utility are therefore supposed to be supported on an insight of public requirement. It has also been formed by monetary and/or dogmatic forces to utterly incorporate acknowledgment of the socioeconomic costs. Consumption of such measures should therefore replicate the best trade-offs between the benefits accessed by people and the cost of accomplishing the necessary reliability. The explicit cost technique is recognized as the second approach. It includes reliability in the costing procedure by evaluating the overall costs. This also incorporates the societal costs of unreliability. These costs are acquired by the utility in every year of the time duration thought in both methods. Those are compared using present worth study. Subjective and objective measures of customer monetary losses are considered by the explicit cost approach. Those measures arise from electric energy supply reduction. The unit cost of losses owing to energy not provided is a combined constraint. It is developed from the diverse classes of customers influenced by a given disruption.

The fundamental concepts linked with the explicit cost approach to the reliability-cost/reliability–worth assessment are comparatively straightforward. These can be illustrated by the cost/reliability curves shown in Figure 3.1 [119].

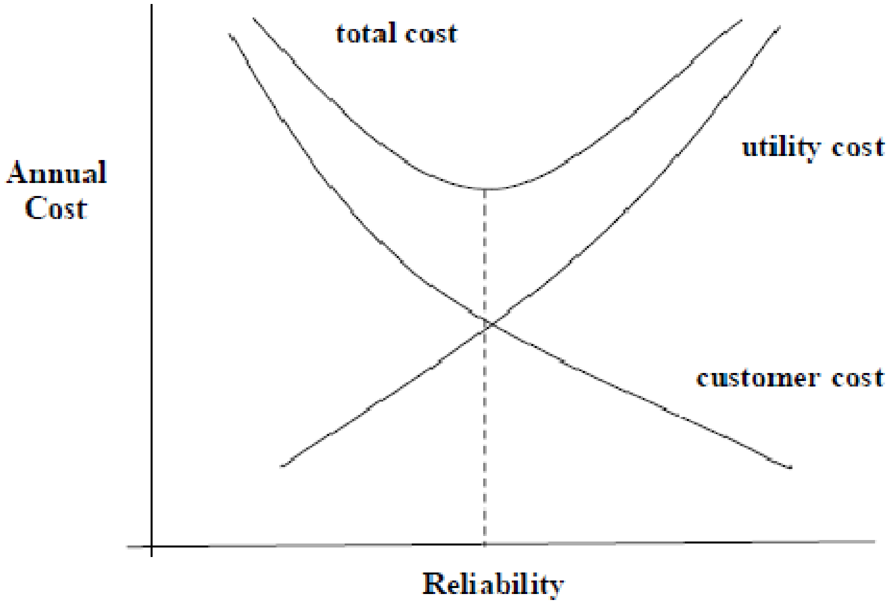

Figure 3.1: Cost curves related with system reliability [119]

These curves demonstrate that the investment cost usually augments with higher reliability. On the other hand, the customer costs linked with failures diminish as the reliability amplifies. So, the entire costs are the summation of these two individual costs. It displays a least amount so that a desired level of reliability is reached. This perception is reasonably suitable. However, cost of interruption or customer disruption cost evaluation is necessary for reliability worth assessment.

3.4.2 Customer disruption cost estimation

Customer impacts have been evaluated by the utilization of various methods due to interruptions. These methods can be clustered into three extensive categories on the basis of the methodological approach. Those categories are diverse indirect methodical assessments, customer reviews, and case studies of blackouts [119]. Utilities emerge to support customer reviews as the ways to resolve exact information for their uses. It is performed when a particular approach has not been commonly accepted.

An essential preliminary step to determine interruption costs is an appreciative of the nature and diversity of customer impacts ensuing from electric service disruptions. The difference between long-term and short-term impacts relates to the nature of the disruption. Specially, long-term impacts are frequently recognized as adaptive reactions conceived to evade upcoming disruption costs. This also incorporates voltage regulation equipment, cogeneration, and installation of protective switchgear.

The cost of a stoppage from the customer's view is connected to the nature of the degree to which the actions disrupted are reliant on electrical supply. This reliance is a consequence of both disruption and customer characteristics. Disruption attributes are comprised of a few things. It incorporates frequency, duration and time of happening of disruptions. It also includes the completeness or partiality of disruption, prior caution about the stoppage or duration information regarding disruption and the type of area impacted by the stoppage. Customer attributes comprise nature of the customer's actions, type of customer, size of operation, additional demographic data, requirement, energy demands, energy reliance as a function of time of day, etc. Finally, the impact of a disruption is somewhat reliant on the approach and awareness of customers. This consecutively is connected to on hand reliability levels.

3.4.2.1 Notional basis regarding interruption cost

System expansion/upgrading or major rate revision are the specific objectives to be considered for costs of interruption. Urban residential, industrial, commercial, rural, etc. are typically chosen as the appropriate major customer categories or sectors. Category-specific inspection instruments can be exercised for that purpose. The standard industrial classification (SIC) system of customer recognition is usually undertaken due to its all purpose approval by government and industry [119]. Frequently it has been accepted by the utility for other grounds. A chief and significant step in this approach is the improvement of inspection equipments for every customer sectors. A perceptive of representative sample assortment, non-response bias, questionnaire bias, negotiating questionnaire substance with extent to guarantee suitable reply rates, etc are required for questionnaire research and the assistant review approaches. In addition, a sound notional basis and an understandable statement of intentions should be reflected by the nature and approach of the inspection appliance.

3.4.2.2 Cost inference techniques

Cost of interruption can be evaluated by asking questions to the customers in various ways [119]. Though there is no unique concept related to questionnaire design but it is the only way to estimate the cost of disruption. Asking direct questions to consumers concerning to the interruption losses can be a useful way for cost estimation when the losses are substantial and identifiable [119]. The industrial, commercial, and most large users are the implementation ground of this approach. Office buildings and large institutions have also been considered for the application of this approach. The major demerits of this technique emerge when impacts of interruption tend to be less substantial and the financial loss is not directly recognized.

Another approach can be the estimation of cost by asking customers about what amount of cash they are willing to pay to avoid power cut. The question can also be to the customers like what amount of money they are willing to accept to experience the interruption.

Indirect worth assessment is considered as third methodology. Customer-selected choices or replies to indirect approach queries can be utilized to develop a value. This may be utilized when thorough estimation is not feasible. It can again be accomplished by inquiring the customers. The customers can relate those queries in the perspective of their knowledge. However, customer disruption cost has been considered as a major part for customer damage function which leads to the estimation of reliability worth. This customer damage function has been assessed as composite customer damage function as there are various types of customers such as urban, commercial, hospital, rural, industrial etc available in a distribution system.

3.4.3 Functions concerning to customer damage

3.4.3.1 Mathematical development of damage function

Customer disruption costs can be presented in the form of customer damage functions (CDF) in an expedient way. The CDF can be decided for a known customer category. It can also be combined to create sector customer damage functions (SCDF) for diverse types of customers in the system. A composite customer damage function (CCDF) can be developed at any specific load point in the system by the collection of the sector CDF and sector peak load or energy percentage value at that load point [119]. This sector CDF, sector peak and energy percentage values differ from customer to customer. The postulation in this approach is that all load restrictions will be dispersed fairly across all the customer regions. The per-unit energy for each sector is usually considered for the weighting used to create a CCDF. On the other hand, the per-unit peak demand for every region is occasionally utilized for small disruption periods.

In this work reliability worth assessment has been performed in distribution functional zone i.e. in microgrid type radial distribution systems. The load point CCDF value considered for enumeration purpose here is tabulated below.

Table 3.1: Load point composite customer damage function (CCDF) for radial distribution system [119]

Duration	US$/kW
1 min	0.1530
20 min	1.2434
1 hour	3.7100
4 hours	15.4752
8 hours	42.6172

Reliability worth has been primarily considered as power interruption cost (PIC) as stated earlier. The expression of power interruption cost is shown in equation (3.23) as

$$PIC = \sum_{i=1}^{nl} La_i \,.\, C_i . \lambda_i^{fl} \tag{3.23}$$

The term La_i is considered as active load connected to *i*th bus in (3.23). Another term C_i is chosen as composite customer damage function of *i*th bus in the R.H.S of (3.23). The last term λ_i^{fl} in the R.H.S of (3.23) is considered as failure rate of *i*th bus. The power interruption cost is a sub part of total cost. Here power interruption cost along with cost due to line loss, operation & maintenance cost and investment or installation cost of DG and capacitor have been simultaneously considered as total cost in the next chapter.

It is a known fact that most of the customers are available in distribution systems. Distribution system can be of various types according to topology but radial distribution system is very common and standard in different countries around the world. Microgrid power system network is like a sub system of a macro grid or conventional distribution system network. Now-a-days several utility companies are coming to do business in a microgrid power system network. Sustainability in the business is a vital issue as deregulation is prevailing these days. In this restructured power scenario customer can choose a utility company on the basis of electricity price and reliability. So the utility companies will try to provide economic power with utmost reliability. This reliability issue is also important in a microgrid radial distribution system as there is a chance of incorporation of renewable energy sources. So cost based reliability study in a microgrid radial distribution system having a few mega watts or a few tens of mega watts of active load is important from the business perspective. This study is also crucial as this microgrid radial distribution system will be enhanced in respect of load growth in future. That's why here a microgrid radial distribution system is considered for simulation purpose. The mathematical formulations related to cost based reliability on radial distribution system such as a microgrid has been illustrated in the next chapter.

Chapter 4

Cost based reliability in a microgrid type radial distribution system

Power distribution system reliability issues have been briefly illustrated in the previous chapter. Quantification of distribution system reliability along with description of economic worth of reliability has also been presented. Reliability of a power system network denotes uninterruptible supply with standard voltage and frequency. Reliable and economic power supply is an important criterion in deregulated power business. Here in this chapter cost factor based reliability issues have been mathematically addressed for microgrid based radial distribution system.

4.1 Economical reliability improvement in a microgrid type power system

Cost based reliability enhancement in a power distribution system can be performed by many means. In this work, reliability improvement has been studied by installing shunt capacitor and integrating Distributed Generation (DG) suitably in radial distribution system resembling microgrid for economic purposes. The first objective function has been formulated on the basis of only reactive power compensation accomplishing shunt capacitor installation. The second objective function has been formulated considering both DG penetration and shunt capacitor installation. Appropriate capacitor allocation indirectly reduces real power loss. This decreases the heating or melting effect of electric line thus reducing the failure rate. On the other hand, distributed generator penetration reduces the loading of electric lines at particular segments. This decreases the amperage flow in the electric line and reduces the heating effect which reduces the failure rate effectively. Reliability improves with the decrement of failure rate. The mathematical expressions of those objective functions have been illustrated for better understanding.

4.1.1 Capacitor placement

Reactive power compensation can improve the failure rate of the electric lines by reducing the heat loss caused due to real power loss. This also decreases the power interruption cost linked with failure rate. Thus cost can be minimized by installing shunt capacitor suitably at load buses. This has been performed in 69 bus radial distribution system like microgrid to observe the cost, reliability worth and various distribution system reliability indices. The objective of this optimal capacitor allocation problem is shown in (4.1) as

$$Minimize\ S_{cost} \tag{4.1}$$

The expression of combined cost is shown in expression (4.2). The combined cost S_{cost} is the summation of cost associated with power interruption i.e. PIC, cost due to energy loss and capacitor installation cost in sixty nine bus microgrid radial distribution system.

$$S_{cost} = (PIC + K_P.Eloss).T_{lifetime} + \sum_{j=1}^{nb} K_j.Q_j \tag{4.2}$$

The reliability worth value i.e. PIC is calculated using expression written earlier in Chapter 3. Here the tenure of this capacitor placement project has been considered for twelve years. However, failure rate modification after capacitor placement is important to understand for this simulation based study.

4.1.1.1 Failure rate adjustment after capacitor allocation

The failure rate of electric line will change due to capacitor allocation. This has been discussed earlier. The current flowing in the line gets modified after reactive power compensation by capacitor installation [73]. The current ratio α_i has been defined in equation (4.3) as

$$\alpha_i = \frac{Inew^i}{Iold^i} \tag{4.3}$$

It is the ratio of reactive component of current after and before capacitor allocation, respectively. The term $Inew^i$ and $Iold^i$ are defined as the reactive power component of current after and before compensation, respectively of i th branch. The value of new failure rate after compensation has been enumerated in expression (4.4) as

$$\lambda^{new} = \alpha_i(\lambda^{uncomp} - \lambda^{comp}) + \lambda^{comp} \tag{4.4}$$

The terms λ^{new}, λ^{uncomp} and λ^{comp} are denoted as new failure rate, failure rate at uncompensated state and failure rate after total compensation respectively. The value of λ^{comp}has been chosen as a percentage value of λ^{uncomp}. The value of the λ^{comp} is less than the value of λ^{uncomp}.

Cost reduction has also been studied by installing shunt capacitor for the reinforcement scheme i.e. applying disconnects between buses with lateral protection for 69 bus radial distribution system resembling microgrid. The same optimal capacitor allocation data has been considered for the other reinforcement scheme i.e. applying only disconnects between buses to observe cost minimization. Microgrid type distribution system reliability indices have been evaluated for two reinforcement schemes after optimal capacitor allocation. On the other hand, voltage and maximum capacitor value restrictions have been applied while performing the simulation study.

Capacitor allocation can improve the reliability of a microgrid radial distribution system. But distributed generation integration along with capacitor placement can further enhance the distribution system reliability. It has also the potential of further total cost minimization. Simultaneous capacitor allocation and DG integration is necessary for further clarification regarding reliability improvement of a microgrid power system.

4.1.2 Distributed generation integration and shunt capacitor installation

Reliability can be improved by installing shunt capacitor as stated earlier. It can also be enhanced by performing distributed generation (DG) integration. Here, both DG integration and shunt capacitor allocation have been performed to assess the reliability of a microgrid power system economically. Simultaneous capacitor allocation and DG integration have been performed on 34 bus and 69 bus radial distribution system resembling microgrid. Distributed generator source has been considered as bio mass power plant in both 34 bus and 69 bus microgrid type radial distribution system. Solar photovoltaic plant has also been considered as DG source in 69 bus microgrid based radial distribution system. Single objective and multi-objective optimization situations have been considered in thirty four and sixty nine bus radial distribution systems. Five conflicting objectives viz. loss minimization, total cost minimization, $SAIFI$ improvement, $SAIDI$ improvement and $AENS$ improvement have been considered here for objective function formulation.

4.1.2.1 Loss minimization

The first single objective considered in this work is the loss minimization of the microgrid system. Loss has been considered here as real power loss and energy loss in 34 and 69 bus radial distribution system similar to microgrid, respectively. Four evolutionary techniques have been applied to get the comparable values from the original value obtained by normal load flow analysis. The objective function is expressed in (4.5) as

$$Minimize \quad E, loss \tag{4.5}$$

4.1.2.2 Total cost minimization

The second singular objective considered here is the total cost minimization given in (4.6). Total cost is comprised of power interruption cost (PIC), cost due to loss, shunt capacitor installation cost and DG capital cost. The expression of total cost has been shown in equation (4.7). Power interruption cost is actually the reliability worth which has been elaborated in Chapter 3.

$$Minimize \quad T, Cost \tag{4.6}$$

$$T, Cost = (PIC + K_P . E, loss). T_{lifetime} + \sum_{j=1}^{nc} K_j . Cap_j + \sum_{i=1}^{ng} K_i . DG_i \tag{4.7}$$

4.1.2.3 SAIFI improvement

The third objective is to improve the customer oriented reliability index SAIFI (system average interruption frequency index). The four evolutionary computation techniques have also been implemented to get improved SAIFI value by intelligently placing DG and shunt capacitor in the chosen microgrid power system. The objective function can be written in (4.8) as

$$Minimize \quad SAIFI \tag{4.8}$$

4.1.2.4 SAIDI improvement

The fourth objective is to improve the SAIDI (system average interruption duration index) by minimization. This customer-oriented reliability index has been reduced from the original configuration value by suitably allocating DG and shunt capacitor in the chosen radial distribution system resembling microgrid. The objective function is expressed in (4.9) as

$$Minimize \quad SAIDI \tag{4.9}$$

4.1.2.5 AENS improvement

The only load or energy–oriented reliability index considered for improvement is AENS (average energy not supplied). This reliability index has been improved by performing minimization from the original configuration value by doing optimal placement of DG and shunt capacitor in the microgrid power network. The objective function has been shown in equation (4.10) as

$$Minimize \quad AENS \tag{4.10}$$

The considered five objectives have been found improved after suitable placement of distributed generators and shunt capacitors at the load buses of a microgrid power distribution system. Reliability is an important issue in a microgrid power system network. Here this reliability has only been considered to be connected with AC cable or electric line failure assuming other connected apparatuses to the microgrid radial distribution system as trustworthy. That's why the study related to the modification of line failure rate after capacitor and DG placement requires special attention.

4.1.2.6 Change of failure rate by DG integration and capacitor placement

The reliability improvement is connected with the failure rate of overhead line and underground cable in a microgrid radial distribution system. The underground cable has a maximum operating temperature. If the temperature exceeds that value then insulation will gradually deteriorate. This would increase the probability of cable failure [73]. Furthermore, the life period of insulating material decreases exponentially with the increments of operating temperature [120].Temperature rise due to heating effect causes sag in the overhead line. This will decrease the ground clearance and enhance the probability of electric failure [121]. However, the change in branch current of the feeder is linked with the variance of resistive losses which is the cause of heat. Any engineering option that would decrease the branch current magnitude will reduce the heating effect and also the chance of electric line failure.

Distributed generation integration and capacitor allocation reduce the current magnitude of the electric line. In this way, simultaneous DG and capacitor placement decreases the probability of cable failure. Here, the ratio of old and new branch current before and after DG and capacitor allocation has been considered for new failure rate development in equation (4.11). This ratio has been enumerated in equation (4.12).

$$\lambda_{i-new}^{fl} = \begin{cases} \alpha\left(\lambda_{i-line}^{fl} - \lambda_{i-min}^{fl}\right) + \lambda_{i-min}^{fl} & if \ \ \alpha > 0.5 \\ \lambda_{i-min}^{fl} & if \ \ \alpha \leq 0.5 \end{cases} \tag{4.11}$$

$$\alpha = \frac{I_{new}}{I_{old}} \tag{4.12}$$

4.1.3 Constraints concerning DG and capacitor placement

A few constraints have been chosen for this simulation based study. These limitations have been selected for performing both single and multi-objective optimizations. The voltage of each bus has been restricted within the range of minimum and maximum p.u. voltage value. This has been expressed as

$$V^{min} \leq |V_i| \leq V^{max} \tag{4.13}$$

On the other hand, the installed shunt capacitor value at j^{th} bus should be less than equal to the total reactive power load of the distribution system. This can be written as

$$Cap_j \leq \sum_{j=1}^{nl} Q_j^L \tag{4.14}$$

Like the capacitor installation limit of each load bus, the total allocated distributed generator value has been limited to a prespecified margin. This has been expressed in (4.15) as

$$\sum_{i=1}^{ng} DG_i \leq DG^{limit} \tag{4.15}$$

Like single objective situations considered earlier, multi-objective capacitor allocation and DG penetration has also been performed for 34 and 69 bus microgrid radial distribution system. The mathematical formulations regarding multi-objective situation is important to understand.

4.1.4 Multi-objective capacitor allocation and DG integration

Multi-objective optimization has been completed after performing single objective optimization as depicted in the earlier subsections. Four evolutionary computation techniques have been applied on objective function for the simulation based study while performing single objective optimization. Two new algorithms have been selected amongst the four techniques to study their effectiveness to perform multi-objective optimization. This has been discussed in the later section. However, the formulation of multi-objective optimization has been illustrated in (4.16). The five conflicting objectives have been considered simultaneously. The conflicting objectives are real power loss, total cost, SAIFI, SAIDI and AENS, respectively for thirty four bus radial distribution system resembling microgrid. Only real power loss has been changed to energy loss in the case of single and multi-objective situations for sixty nine bus radial distribution system like microgrid. Electricity price deals with electrical energy consumption of customer. In this regard, energy loss is vital for enumeration of cost due to loss. That's why energy loss has been considered in for 69 bus microgrid radial distribution system for more clear view. The decision variables considered for both single objective and multi-objective optimization are real power value of the distributed generator and reactive power value of the shunt capacitor. The mathematical expression for multi-objective situation considering five conflicting objectives has been written as

$$\begin{gathered} Minimize \quad F(x) \\ F(x) = [f_1(x), f_2(x), f_3(x), f_4(x), f_5(x)] \\ f_1(x) = E, loss \\ f_2(x) = T, Cost \\ f_3(x) = SAIFI \\ f_4(x) = SAIDI \\ f_5(x) = AENS \\ x = [DG_1, DG_2, \dots \dots \dots, Cap_1, Cap_2, \dots \dots \dots .] \end{gathered} \tag{4.16}$$

Modified cultural algorithm (MCA) and fish electrolocation optimization (FEO) have been applied here for performing multi-objective DG integration and capacitor allocation. However, both the developed algorithms work on best candidate solution. This actually means these techniques perform on the basis of best found solution. In this regard weighted sum method is easier and trustworthy for finding pareto optimal solutions for multi-objective optimization [122]. This is due to the fact that weighted sum technique develops one expression comprising of all the considered objectives. Finally it becomes similar to the single objective optimization method. In this work, influence of weighted sum technique has been drawn to the developed MCA and FEO technique discussed later in Chapter 6. But the scaling factor for each conflicting objective in multi objective situation is very significant for obtaining good quality solutions. Here scaling factor (w_1,w_2, w_3, w_4, w_5) of 0.2 has been considered for all the five conflicting objectives. To elaborate the cause of choosing 0.2 for each objective it will be prudent to understand the basic problem. Distribution system reliability indices viz. SAIFI, SAIDI and AENS are connected with the failure rate. Those indices get improved due to the decrement in failure rate. Furthermore, change in failure rate is linked with the modification of current flow after DG integration and capacitor placement. On the other hand, change in current flow is connected with the increment or decrement of energy loss. Finally total cost has also have connection with change in current flow as it is consisted of power interruption cost, loss cost, capacitor installation cost and DG cost. Lastly it has been observed after several trial runs that considering 0.2 scaling factor for each conflicting objective gives good quality solution. The expression for weighted sum value regarding multi-objective optimization problem has been shown in (4.17) as

$$MO = w_1.E,loss + w_2.T,Cost + w_3.SAIFI + w_4.SAIDI + w_5.AENS \tag{4.17}$$

Multi-objective situations have also been developed considering two different conflicting objectives in sixty nine bus microgrid radial distribution system. But the mathematical formulation regarding this has not been illustrated here as it's easy to understand from the expressions of equation (4.16). However, decision making is very crucial to understand after performing multi-objective optimization.

4.1.5 Decision making techniques

The true pareto-optimal front is unknown in any type of real world multi-objective optimization. In this regard, all the non-dominated solutions would not satisfy the desired target. That's why there is a necessity to focus on one particular solution which will satisfy the desired criteria. Decision making is a subject of operation research which helps to find out an appropriate solution amongst a set of solutions. Here, a couple of decision making techniques have been used for getting feasible and appropriate solution after performing multi-objective capacitor allocation and DG integration in a microgrid radial distribution system.

4.1.5.1 Newly developed technique

A decision making technique has been developed newly for implementing it in thirty four bus radial distribution system resembling microgrid. In the first attempt, equal importance has been provided to all the selected conflicting objectives for having an appropriate solution in 34 bus microgrid radial distribution system. To reach that perspective pseudo weights have been calculated for every conflicting objective concerning to each non-dominated solution after performing multi-objective capacitor allocation and DG integration. The pseudo weight has been enumerated according to equation (4.18) [122] as

$$W_i = \frac{f_i^{max} - f_i}{f_i^{max} - f_i^{min}} \Bigg/ \sum_{j=1}^{M} \frac{f_j^{max} - f_j}{f_j^{max} - f_j^{min}} \tag{4.18}$$

The summation of the desired or chosen weights for all the conflicting objectives is equated to one as shown in (4.19). The chosen weights are all considered as equal. The reason behind this is that equal importance has been given to all the chosen weights. These weights are selected as equal considering the urban type of customer who wants uninterruptible power supply, reduced electricity price and improved power quality altogether.

$$\sum_{j=1}^{M} Wt_j^{chosen} = 1 \tag{4.19}$$

The deviation value has been calculated between the chosen weight and the enumerated pseudo weight available from (4.20). The deviation value for each conflicting objective is shown as

$$dev(j) = Wt_j^{chosen} {\sim} W_i \tag{4.20}$$

The total deviation value has also been calculated to find out a specific solution for this multi-objective optimization problem. This is expressed as

$$dev^{total} = \sum_{j=1}^{M} dev(j) \tag{4.21}$$

The appropriate solution's weight value for each conflicting objective will be very close to the chosen weight value i.e. Wt_j^{chosen}. So the total deviation value i.e. dev^{total} of a proper solution will be least amongst all the non-dominated solutions at hand. This theory has been considered in this newly developed decision making technique for finding an appropriate solution.

The decision making procedure has been implemented considering equal significance for all the conflicting objectives in thirty four bus radial distribution system resembling microgrid. But critical situation arises when conflicting objectives can have various importances. In the second attempt, sixty nine bus microgrid type radial distribution system has been considered. This system is more complex than the thirty four bus microgrid type radial distribution system. On the other hand, appropriate solution for different customers like rural, urban, commercial, office/building, hospital, industrial etc cannot be obtained considering equal significance to each conflicting objective. The suitable solution in this situation can be achieved by considering the standard TOPSIS method.

4.1.5.2 Implementation of TOPSIS method

The TOPSIS method is a procedure which is governed by the order preference considering resemblance to best solution [123]. This was developed by Hwang and Yoon in 1981. TOPSIS method has been implemented considering the suitable weight for selection of appropriate planning scheme of DG integration and capacitor allocation. This method works through a few steps. These are as follows:

- Step 1: Construction of normalized decision matrix

First of all decision matrix has been formulated taking the obtained solutions by the chosen algorithm. Here for decision making, non-dominated solutions achieved after MCA and FEO implementation have been considered separately. This has been discussed later in Chapter 8. However, the results obtained by any of the developed algorithms are non-dominated solutions related to five criteria. The decision matrix has five columns for each set of results. But the number of rows is different as the number of pareto-optimal solutions found by each developed algorithm is not same. The decision matrix Y has been shown in (4.22).

$$Y = \begin{bmatrix} y_{11} & y_{12} & y_{13} & y_{14} & y_{15} \\ y_{21} & y_{22} & y_{23} & y_{24} & y_{25} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ y_{N1} & y_{N2} & . & . & y_{N5} \end{bmatrix} \tag{4.22}$$

The five attributes are energy loss, total cost, SAIFI, SAIDI and AENS. They have various units. They are made dimensionless. Finally the decision matrix becomes non-dimensional or normalized decision matrix. Each element of that normalized decision matrix has been calculated using equation (4.23) as

$$x_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{N} y_{ij}^2}} \tag{4.23}$$

The non-dimensional decision matrix has no use without the influence of weight factor which has been chosen justifiably later in Chapter 7. The influence of weight factor for different customer has been illustrated in the next step.

- Step 2: Making of weighted normalized decision matrix

Five weights have been assigned for five different criteria as discussed earlier. Weighted normalized decision matrix has been generated by multiplying each element of the matrix with weight factor. This has been shown in (4.24) as

$$S = \begin{bmatrix} W_1.x_{11} & W_2.x_{12} & W_3.x_{13} & W_4.x_{14} & W_5.x_{15} \\ W_1.x_{21} & W_2.x_{22} & W_3.x_{23} & W_4.x_{24} & W_5.x_{25} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ W_1.x_{N1} & W_2.x_{N2} & W_3.x_{N3} & W_4.x_{N4} & W_5.x_{N5} \end{bmatrix} \tag{4.24}$$

The weighted normalized decision matrix is different for various customers. This is due to the reason that the weight factors chosen for different consumer are dissimilar. In the next step ideal and negative ideal solution from this weighted normalized decision matrix has been evaluated. This is done because it is an inherent process. It guides the selection methodology of finding an appropriate solution closer to an ideal solution.

- Step 3: Finding the ideal and negative ideal solution

Ideal and negative ideal solutions have been found out by selecting minimum and maximum values for each attributes. The attributes are energy loss, total cost, SAIFI, SAIDI and AENS as stated earlier. The value of each criterion will be considered as best when it is the minimum amongst all the available alternatives. That's why the minimum value of each attribute concerning to the obtained weighted normalized decision matrix has been chosen as ideal solution. On the other hand the maximum value has been considered for the negative ideal solution. The ideal and negative ideal solutions have been calculated as expressed in (4.25) and (4.26) respectively.

$$B^* = \{(\min S_{ij})\} = \{S_1^*, S_2^*, S_3^*, S_4^*, S_5^*\} \tag{4.25}$$

$$B^- = \{(\max S_{ij})\} = \{S_1^-, S_2^-, S_3^-, S_4^-, S_5^-\} \tag{4.26}$$

The most preferable and least preferable alternative has been enumerated in this step. They are utilized to find out the separation measure in the next step.

- Step 4: Enumeration of the separation measure

The distance of every solution from the ideal and negative ideal solution has been calculated in this step. The separation of each solution from the ideal solution has been enumerated as given in (4.27). On the other hand, separation of each solution from the negative ideal solution has been calculated using equation (4.28).

$$D_i^* = \left(\Sigma \left(S_{ij} - S_i^* \right)^2 \right)^{1/2} \tag{4.27}$$

$$D_i^- = \left(\Sigma \left(S_{ij} - S_i^- \right)^2 \right)^{1/2} \tag{4.28}$$

Finally, the separation measures concerning to the most preferable and least preferable solution are considered to find out the relative closeness to the ideal solution. That relative closeness has been enumerated in the next step.

- Step 5: Calculating the relative closeness to the ideal solution

The relative closeness of a solution with respect to an ideal solution has been calculated in this step. That relative closeness is expressed in (4.29) as

$$A_i = \frac{D_i^-}{D_i^* + D_i^-} \tag{4.29}$$

The value of A_i for solution *i* defines the above stated relative closeness. It has been termed as the rank value for every solution. If a solution is close to the ideal solution then its rank value will be higher in comparison to the other solutions. On the other hand, if that rank value is lower in comparison to other solution then it signifies that the chosen solution is close to the negative ideal solution. However that rank value has been set for the available solutions in the next step.

- Step 6: Set the rank value for the available solutions

The best alternative or solution has been found out by choosing the maximum rank value amongst all the solutions. The best solution will be that one which is closer or have the shortest distance to the ideal solution. The rank value has been determined in such a fashion in this work that highest rank value will be the closest to the most preferable solution. All the rank values for achieved solutions by any algorithm for any type of consumer have been shown in bar chart to have a clear view. The reader can easily find out the highest rank value by seeing the bar diagram in Chapter 7.

All the simulation based studies have been performed on microgrid radial distribution system considering two reinforcement schemes. The failure rate and outage time considering two reinforcement schemes have been exercised before enumerating any reliability index or cost. How the microgrid radial distribution system is look like considering the reinforcement schemes is needed to be addressed. In addition, the calculation of basic parameter such as outage time is important to understand.

4.2 Microgrid type radial distribution system considering two schemes for reliability evaluation

A sample microgrid type radial distribution system has been considered for case study purpose as shown in Figure 4.1. This is done as pictorial representation of a bigger bus system is difficult in a limited space. The radial distribution system like microgrid has nine bus and two laterals. Two schemes viz. scheme I and scheme II have been considered in this study. Applying only disconnects is considered as the first scheme. On the other hand, disconnects with lateral protection is selected as scheme II. These two schemes have been considered in this work as they are very common and standard [119]. The microgrid power system network has eight branches. There is a main feeder breaker at bus 1. There are disconnects or isolator between two buses.

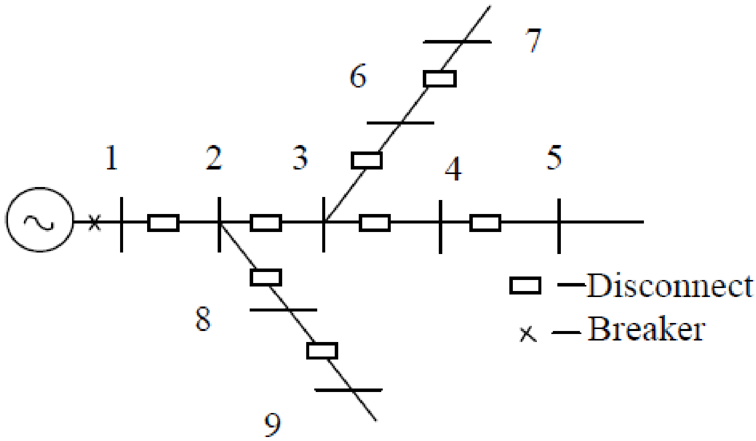

Figure 4.1. Typical microgrid type radial distribution system with disconnects

The first scheme (Scheme I) has been considered with only disconnects i.e. there is no lateral protection. So for a fault anywhere in the line the main feeder breaker operates. Suppose there is a fault between bus 4 and 5. To isolate the faulty portion from the healthy system, the main feeder breaker operates. Current will be interrupted at every load point in the microgrid radial distribution system due to that breaker operation. Disconnect or isolator between bus 4 and 5 has been opened after that short circuit failure. Then main feeder breaker recloses the circuit and again current flows. Here failure rate of each and every load point is connected with all branch failure rates but the interruption time is different. The outage time map will be formulated by considering the repair time and isolation time of branches. For bus 3, the outage map will include the repair time of branch 1 and 2 and isolation time or switching time for other buses. Outage time map for scheme I has been shown in (4.30) considering repair time of main feeder and lateral as 4hr and 2hr respectively and isolation time is considered as 0.5hr.

$$outagemap^{I} = \begin{bmatrix} 4 & 4 & 4 & 4 & 4 & 4 & 4 & 4 \\ 0.5 & 4 & 4 & 4 & 4 & 4 & 0.5 & 0.5 \\ 0.5 & 0.5 & 4 & 4 & 0.5 & 0.5 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 & 4 & 0.5 & 0.5 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 & 0.5 & 2 & 2 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 2 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 2 & 2 \\ 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 2 \end{bmatrix} \quad (4.30)$$

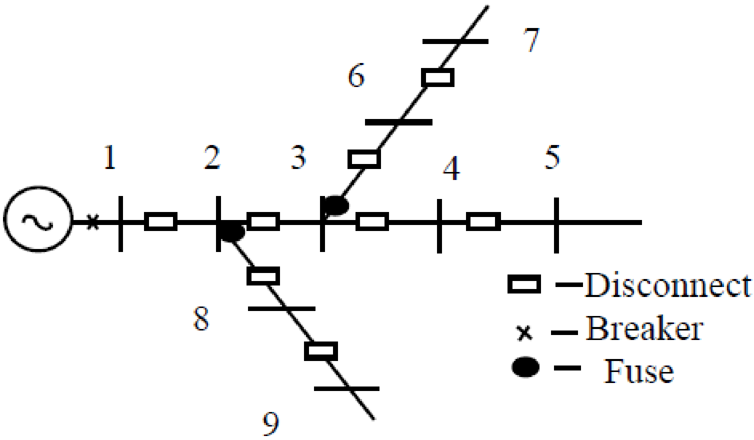

Figure 4.2. Typical microgrid type radial distribution system with disconnects and lateral protection

In Figure 4.2 there is a fuse protection at the T junction point of lateral and main feeder. The Scheme II has been considered here taking additional fuse protection or lateral protection with disconnects. Suppose there is a short circuit between bus 2 and 8. Then fuse at that junction point will melt to isolate the faulted portion from the system. The rest of the microgrid radial distribution system apart from the lateral will have healthy supply of electrical power. In this case the calculation of failure rate will be little bit different from that mentioned in scheme I. The failure rate of buses at lateral feeder will be the addition of failure rate of main feeder and that particular lateral feeder. The outage time calculation will be similar as failure rate. The outage time map for scheme II has been shown in (4.31) considering the similar repair time and isolation time as discussed for scheme I earlier.

$$outagemap^{II} = \begin{bmatrix} 4 & 4 & 4 & 4 & 4 & 4 & 4 & 4 \\ 0.5 & 4 & 4 & 4 & 4 & 4 & 0.5 & 0.5 \\ 0.5 & 0.5 & 4 & 4 & 0.5 & 0.5 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 & 4 & 0.5 & 0.5 & 0.5 & 0.5 \\ 0 & 0 & 0 & 0 & 2 & 2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.5 & 2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2 & 2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 2 \end{bmatrix} \quad (4.31)$$

Here thirty four and sixty nine bus microgrid type radial distribution systems have been considered for performing single and multi-objective capacitor allocation and DG integration to study the cost based reliability improvements. Decision making is important for multi-objective situations as have been evidenced. But before that one has to take care of the optimization tools for obtaining multiple good quality pareto optimal solutions. Strong searching tools are also necessary for finding excellent solutions in single objective domain also. In this thesis, single objective and multi-objective optimizations have been performed considering soft computing tools. Minor details of these tools are necessary to understand how they are utilized for different types of optimization.

Chapter 5

Soft computing techniques

Mathematical tool is necessary for searching feasible solutions for any kind of engineering optimization problem. However, in this regard soft computing techniques are drawing special attentions these days.

5.1 Beginning of the soft computing methods

Soft computing is a special domain of computer science. In the early 1990s, this had originated as a branch of computer science. Soft computing tool includes neural network, support vector machine, fuzzy logic, and evolutionary computation. Evolutionary computation includes evolutionary algorithms and meta-heuristic and swarm intelligence. Evolutionary algorithm mainly consists of genetic algorithm and differential evolution. On the other hand, meta-heuristic and swarm intelligence contains algorithm like ant colony optimization, particle swarm optimization, firefly algorithm and cuckoo search etc. Here, evolutionary computation techniques have been considered as optimization tool for cost based reliability enhancement of a microgrid radial distribution system by suitable capacitor allocation and DG integration discussed earlier in Chapter 4.

Several natural procedures were mimicked as soft computing based optimization tools. A few soft computing techniques especially evolutionary techniques have been discussed in this chapter to have a clear concept about the well established and normally considered methods for engineering optimization problem.

5.2 Brief ideas about well established evolutionary techniques

5.2.1 Genetic algorithm

The genetic algorithm (GA) was proposed by John Holland and his collaborators in the 1960s and 1970s. In the earlier 70's Holland adopted the idea of Charles Darwin's theory of natural selection [124] to formulate genetic algorithm. Later Goldberg studied that elaborately for making it fit for optimization and machine learning [125]. It is a mathematical model of natural fruition based on the Charles Darwin's hypothesis of natural selection. Crossover and recombination, mutation, and selection were first utilized by Holland in the study of adaptive and artificial systems. These genetic operators shape the necessary part of the genetic algorithm as an analytical strategy. Since then, many variants of genetic algorithms have been developed. They have been implemented to a wide range of optimization problems. These are graph coloring, pattern recognition, travelling salesman problem, efficient design of airfoil in airspace engineering, financial market and multi-objective engineering optimization.

The importance of genetic algorithms engages the encoding of an optimization function as arrays of bits or character strings. It is done to represent the chromosomes. Furthermore, the handling process of strings by genetic operators, and the assortment according to their fitness with the plan to find a solution to the problem concerned are also represented by that encoding. This is frequently performed by the subsequent procedure:

- Encoding the optimization functions or objectives;
- Defining a selection criterion or fitness function;
- Set a population of individuals;

- Assessing the fitness of all the individuals in the population;
- Developing a new population by executing crossover, mutation, fitness proportionate reproduction etc;
- Evolving the population awaiting certain termination condition is met;
- Decoding the outcomes to attain the solution to the problem

Chromosomal representation as arrays of binary number is considered for population formation in binary coded genetic algorithm. The binary to decimal conversion is time consuming. Real value coding for population formulation requires lesser time in comparison to the binary coding. Here real coded genetic algorithm (rcGA) has been considered for discrete or combinatorial real world optimization situation like the discussed capacitor allocation and DG integration. This rcGA technique has been selected for comparison purpose with the newly developed MCA and FEO techniques discussed later in Chapter 6. Crossover and mutation operations for real coded genetic algorithm (rcGA) are unlike those of binary coded genetic algorithm. The crossover operation of real coded genetic algorithm is taken from the reference [126]. Mutation operation has also been developed taking influence from the same literature [126]. The mutation operation has been formulated for chosen capacitor and DG placement problem. The expression of mutation operation is written in (5.1) as [126]

$$\begin{gathered} if\ \ rand > P^{mut} \\ k = floor(rand \times pop) + 1 \\ m = randperm\big(length(X)\big) \\ n \in m \\ x^k = X(n) \\ end \end{gathered} \tag{5.1}$$

Here real coded genetic algorithm (rcGA) has been implemented in this work for single objective situations considering capacitor allocation and DG integration. The obtained results after implementing rcGA technique has been compared with PSO, MCA and FEO algorithms in Chapter 7.

Like crossover and mutation phenomena of genetic algorithm, annealing procedure is another natural practice which had been considered for formulating simulated annealing algorithm.

5.2.2 Simulated annealing

Simulated annealing (SA) is a soft computing technique for global optimization problems. It mathematically mimics the annealing procedure in material processing. The procedure is dictated below. With the minimum energy and larger crystal size, a metal cools and freezes into a crystalline state. This occurs to minimize the imperfections in metallic structures. The annealing procedure incorporates the watchful control of cooling rate and temperature, frequently called annealing schedule.

The implementation of simulated annealing into optimization problems was proposed by Kirckpatrik, Gelatt and Vecchi in 1983. Researchers and scientists have been performing studies about that issue since 1983. Kirkpatrick et al. developed simulated annealing considering the metal’s annealing process [127]. The process behind the algorithm includes the metal’s cooling and freezing phenomena into crystalline state with larger crystal size and minimum energy. It is not like the gradient-based methods and other deterministic search methods. These techniques have the shortcoming of being rapt into local minima. The major benefit of the simulated annealing is its ability to evade being rapt in local minima. In fact, it has been established that the simulated annealing will congregate to its global optimality if sufficient randomness is utilized in combination with extremely sluggish cooling. Simulated annealing algorithm is a search technique utilizing a Markov chain. This congregates under suitable conditions regarding its conversion probability. On the other hand, food searching method of ant guided by ant's pheromone secretion had also been imitated for developing various ant algorithms.

5.2.3 Ant algorithms

Earlier discussions on genetic algorithm helped us to understand that one can improve the search efficiency by using randomness. It will also augment the variety of the solutions so as to keep away from being trapped in local optima. The assortment of the best individuals is also alike to utilizing memory. In fact, there are other types of selection e.g. utilizing chemical messenger (pheromone). That is generally utilized by ants, honey bees, and many other insects. Foraging behaviour of ants especially built on chemical messenger pheromone was studied by Dorigo [128]. Dorigo et al. presented that meta-heuristic technique as ant colony optimization [129].
Artificial bee colony algorithm was proposed by Karaboga et al. [130]. Bee colony optimization was also developed in this regard [131]. Nakrani et al. proposed honey bee algorithm [132]. Later Yang proposed virtual bee algorithm for implementation in engineering optimization [133]. Pham et al. studied the concept of honey bee's behavior and developed bee algorithm [134]. Here, nature inspired ant colony optimization as a meta-heuristic method is briefly discussed.

5.2.3.1 Ant colony optimization

Ants use pheromone for foraging purpose. An ant chooses a certain path for food searching purpose based on pheromone concentration and desirability of that route. Some former experience about the path for example the distance is frequently used for selection of shorter route. This is also governed by the ant's shorter travelling time which is due to the higher pheromone concentrations on a certain path. As the traveling time is shorter, less amount of pheromone gets evaporated during this short period. This pheromone concentration can be changed over the passage of time due to evaporation. This has a beneficial effect of being not trapped into local optima. On the other hand, if there is no evaporation of pheromone in a path selected randomly by first ants then that route has been chosen as the preffered path by the other ants due to attraction of pheromone hormone. This physiological principle has been mathematically mimicked to develop ant colony optimization. Scientists have formulated a number of influential ant colony algorithms with significant development made in recent years based on characteristics of ant behavior [128-129]. However, bee algorithms formulate an additional set of algorithms which are strongly related to the ant colony optimization.

5.2.3.2 Bee algorithms

Bee algorithms have been mathematically developed on the basis of the foraging activities of honey bees. There are numerous alternatives of bee algorithms such as honey bee algorithm (HBA), virtual bee algorithm (VBA), artificial bee colony (ABC) optimization, honey bee mating algorithm (HBMA) and others.The communication or broad casting ability of a bee to some neighborhood bees is the essence of the bee algorithm. The communication ability of the bees helps them to know and follow a bee to the best source, locations or routes to complete the optimization task. The explicit application would depend on the actual algorithms. The implementation procedure may differ slightly and vary with different variants.

Like foraging of bees, fish or bird schooling phenomena had been considered for developing meta-heuristic technique called particle swarm optimization.

5.2.4 Particle swarm optimization

Kennedy and Eberhat formulated particle swarm optimization (PSO) in 1995 [136]. This was mathematically developed on the basis of swarm behavior such as fish and bird schooling in nature. The behavior of the so called swarm intelligence is utilized by numerous algorithms such as ant colony algorithms and virtual ant algorithms. Particle swarm optimization may have some alikeness with genetic algorithm and ant algorithm discussed earlier. But it is much simpler. The reason is that it does not utilize mutation/crossover operators or pheromone. It utilizes the real-number randomness and the global communication amongst the swarm particles. There is no encoding or decoding of the parameters into binary strings like binary coded genetic algorithm. It is also easier to apply in that sense.

The space of an objective function is searched by this algorithm by adjusting the trajectories of individual agents. Those agents are called particles. The so called trajectories developed piecewise paths in a quasi-stochastic manner. The movement of a swarming particle is consisted of two major components. Those are a stochastic component and a deterministic component. Each agent has a tendency to move randomly. At the same time it is moved by attraction toward the position of the current global best g^* and its own best location x_i^* in history. The particle updates it as the new current best for agent x_i when that particle explores a location which is better than any previously found locations. A current best is considered to be there for all *n* particles at any time *t* during iterations. The motive is to fetch the global best amongst all the current best solutions. This is done until the objective no longer shows betterment or after a specific number of iterations. Here particle swarm optimization technique has been considered like the earlier discussed rcGA technique for cost based reliability enhancement performing capacitor allocation and DG integration in a microgrid type radial distribution system. The expression of particle evolvement is written in (5.2) as

$$x_i^{new} = x_i + \alpha \times rand \times (x_i^* - x_i) + \beta \times rand \times (g^* - x_i) \tag{5.2}$$

Particle swarm optimization has been applied for single objective situations in this thesis. Comparative studies have been performed with rcGA, MCA and FEO techniques to observe cost based reliability improvement discussed later in Chapter 7.

Like fish or bird schooling, harmony of music is also a nature inspired process which had been chosen for developing another technique called harmony search algorithm.

5.2.5 Harmony search

Z. W. Geem et al. first formulated the harmony search (HS) in 2001. This is a relatively new heuristic optimization algorithm. Since 2001, that HS algorithm has been implemented to solve numerous optimization problems. Geem et al. proposed harmony search algorithm inspired by harmony of music [137]. Later this technique was applied for continuous engineering optimization problem [138]. Combination possibility between harmony search and other algorithms such as particle swarm optimization (PSO) has also been investigated.

Harmony search was mathematically developed as a music-inspired meta-heuristic optimization algorithm. The aim of music is to fetch for a perfect state of harmony. This harmony in music is considered as analogous to find the optimal solution in an optimization problem. The fetching process in optimization can be taken for comparison with the musician's improvisation process. Audio aesthetic standard is considered for determination of that perfectly pleasing harmony. Pitch/frequency, timbre/ sound quality and amplitude/loudness are the criteria for essential determination of aesthetic quality of a musical instrument. Sound quality is largely determined by the harmony content. Determination of harmony content is done by the waveforms or modulations of the sound signal. However, the created harmonies would largely depend on the frequency range or pitch of the particular instrument.

The improvisation process by a musician can be considered for detail explanation of harmony search. A musician has three possible choices when he/she is improvising. The first possible choice is he/she can play any famous piece of music exactly from his/her memory. That is considered as a series of pitches in harmony. The second choice may be that he/she can play something similar to a known piece. This would be considered as adjustment of the pitch slightly. The last choice may be that he/she can compose new or random notes. Usage of harmony memory, pitch adjustment and randomization are the three components regarding optimization analyzed just above as three choices.

Similar to harmony of music, flashing characteristics of fireflies had also been the research context for developing a nature inspired meta-heuristic technique named firefly algorithm.

5.2.6 Firefly algorithm

Some of the flashing characteristics of fireflies can be conceptualized to develop firefly-inspired algorithm. Xin She Yang at Cambridge University developed new firefly algorithm in 2007 [139]. This has been formulated by the three rules. The first rule states that all fireflies are unisex. That means regardless of sex, one firefly will be attracted to other fireflies. The second rule states that attractiveness is proportional to their brightness. That's why the less bright one will move towards the brighter one. On the other hand, both the attractiveness and brightness decrease as the distance increases. However, a specific firefly will move randomly if there is no brighter one. The last rule states that the landscape of the objective function determines the brightness of a firefly.

There are other techniques available in the literature which also draws special attention of the reader.

5.3 Other meta-heuristic techniques

Meta-heuristic techniques had mostly been generated from genetic theory, swarm intelligence and bee colony behavior. In this regard, Moscato had established mimetic algorithm derived from genetic algorithm and martial art [140]. Reynolds proposed cultural algorithm (CA) considering belief space and population space as the two main ingredients [141]. This technique has been elaborately described in Chapter 6 as modified CA has been newly developed for cost based reliability enhancement in this thesis. On the other hand, Storn proposed differential evolution as a useful tool for function optimization [142]. Later Storn et al. applied this technique for global optimization over continuous spaces [143]. Another method called Biogeography based optimization technique was developed by Simon [144]. Cuckoo's breeding procedure had also got the attention of researcher to build a meta-heuristic technique [145]. Foraging behavior of few animals was also mathematically studied as optimization method. Passino et al. developed bacterial foraging algorithm conceptualizing survival mechanism of *Escherecia Coli* in changing environment [146]. Monkey Search algorithm was formulated imitating the behavior of monkey climbing trees in its search for food [147]. Bioluminescence

[148-149] had also been selected for developing higher level searching tool. Not only the animal's behavior was imitated but also the plant's growth [150] and its photosynthesis process [151] was also considered for this kind of technique development. Cai et al. developed plant growth optimization on the basis of leaf growth, branching, phototropism and spatial occupancy [152]. It has also been evidenced that above algorithms were sometimes modified and also hybridized to have better soft computing tool [153-154]. Prey searching technique had become an encouraging research context for developing meta-heuristic technique. Group hunting of animals such as lions, wolves, and dolphins was studied as a soft computing technique named hunting search algorithm [155]. On the other hand, collective animal [156] and animal searching behavior [157] were also chosen to formulate optimization algorithm. Furthermore, bat's echolocation [158-159] had also been considered to develop meta-heuristic technique conceptualizing prey catching phenomena of it.

It is a known fact that the available algorithms are not abstract academic concept. These have practical implications on real world situations. Distributed generator integration and capacitor allocation has been considered in this thesis for cost based reliability enhancement in a radial distribution system resembling microgrid. In this regard, strong searching tools are necessary for finding excellent solutions.

5.4 Reasons behind developing and implementing optimization algorithms

Soft computing techniques had been applied for several engineering optimization tasks. Power system optimization has been the broad subject area of the work considered here. So far optimization techniques had been implemented for engineering schemes like DG integration, capacitor allocation, network reconfiguration, power system planning etc.

5.4.1 Involving DG integration

Simulated annealing (SA) was utilized for performing multi-objective optimal distributed generator placement [160]. Here, the results showed that SA could find the optimal location and size with less computing time than genetic algorithm and tabu search. An application of firefly algorithm was proposed to determine the optimal location and size of distributed generator in distribution power network [161]. In that attempt, the effectiveness of firefly algorithm was shown on an IEEE 69 bus distribution test system. Singh et al. implemented genetic algorithm for performing multi-objective optimization for DG planning with different load models [162]. Here, index based size and location determination of distributed generation was performed in distribution systems. Genetic algorithm was chosen by Shukla et al. for optimal sizing of distributed generation placed on radial distribution systems [163]. Here, the multi-location distributed generation placement problem aimed to reduce the total real power loss of radial distribution networks. Genetic algorithm was again implemented for optimal sitting and sizing of distributed generations in radial and networked systems [164]. In that attempt, the objective was to minimize the power loss. Harmony search algorithm with differential operator was presented to install multiple DG units optimally in distribution system [165]. Improvement of voltage profile and minimization of active power loss were the objectives of that paper. Improved reinitialized social structures particle swarm optimization was presented for optimal multiple distributed generation placement in microgrid system [166]. Here, the purpose of this approach was to minimize the real power loss within real and reactive power generation limits and voltage restrictions. Modified artificial bee colony algorithm was applied for optimal distributed generation sizing and allocation in distribution systems [167]. Here, a modification in the neighboring search of the artificial bee colony algorithm was performed to minimize the total system real power loss. Artificial bee colony algorithm was applied for optimal distributed generation allocation and sizing in distribution systems [168]. Here, the aim of the work was to reduce the total system real power loss. Particle swarm intelligence was considered for optimum capacity allocation of DG units based on unbalanced three-phase optimal power flow [169]. Genetic algorithm was chosen for optimal distributed generation placement with voltage sag effect minimization [170]. In that attempt, hybrid combinations of technical factors were considered along with economical factors. Genetic algorithm was considered as simulation technique for multi-objective DG planning with different load models by Singh et al. [171]. Genetic based tabu search algorithm was considered for optimal distributed generator integration in distribution systems by Gandomkar et al. [172]. Here, DG units were optimally placed to find out the amount of reduction related to resistive line losses. Binary particle swarm optimization-based method was introduced to find out optimal location of biomass-fuelled systems for distributed power generation [173]. Here, the supply area for the biomass plant was provided taking technical constraints into consideration. Genetic algorithm and particle swarm optimization were coupled for optimal DG location and sizing in distribution systems [174]. Here, the objectives were to reduce network power loss, better voltage regulation and improve the voltage stability within the framework of system operation and security constraints. On the other hand, network real power loss can also be reduced by performing reactive power compensation considering capacitor placement. In this regard, strong searching tool is necessary for performing optimal capacitor placement.

5.4.2 Considering capacitor placement

A new optimization method using genetic algorithm was presented to determine the optimal selection of capacitors [175]. Here, novel design tactic had been considered to determine the type, location, size, and number of capacitors to be installed on a radial distribution network. A novel approach based on particle swarm optimization was proposed to determine optimal location and size of capacitors on radial distribution systems [176]. In that attempt, the capacitor placement and sizing were performed by loss sensitivity factors implementing PSO to enhance the voltage profile and reduce the active power loss. Genetic algorithm was chosen for optimal capacitor allocation in a distribution system considering operation costs by Park et al. [177]. Here, reduction of installation costs and minimization of loss related to electrical energy were performed incorporating the device lifetimes in the mathematical formulation. Particle swarm optimization was utilized for optimal capacitor placement and sizing in unbalanced distribution systems with harmonics consideration [178]. Here, discrete version of PSO had been combined with a radial distribution power flow algorithm to formulate hybrid PSO algorithm. Simulated annealing with heuristic search technique was proposed for optimal capacitor placement in distribution system [179]. Here, the effects of supply harmonics, network and load unbalances, and load non-linearity had been studied. Genetic algorithm was utilized for solving capacitor placement problems in distribution system [180]. In that attempt, a new composition of genetic string was presented for the coding of capacitor allocation problem. Plant growth simulation algorithm was utilized for optimal capacitor placement in a radial distribution system by Rao et al. [181]. Here, the objective was to improve the voltage profile and minimization of power loss. Network reconfiguration is another engineering option which also has the capability to reduce real power loss. Proper network reconfiguration can be achieved by considering meta-heuristic techniques.

5.4.3 Opting network reconfiguration

Zhu did optimal reconfiguration of electrical distribution network using the refined genetic algorithm [182]. The objective of that work was to minimize system power loss. On the other hand, Tabu Search algorithm is an efficient meta-heuristic searching algorithm. An improved Tabu Search algorithm was applied by Zhang et al. for loss minimum reconfiguration in large-scale distribution system [183]. A binary particle swarm optimization search was adopted to determine distribution feeder scheduling considering variable load profile and outage costs [184]. Here, results of a multi-objective feeder operation optimization problem were presented. Switching and reliability cost and balancing of network efficiency were incorporated in the mathematical formulation part. Evolutionary programming (EP) algorithm was applied for optimal reconfiguration of radial distribution system to maximize loadability [185]. Here, adaptation of fuzzy technique to the EP algorithm was accomplished due to the discrete nature of the solution space. Harmony search algorithm was presented to perform optimal network reconfiguration of large scale distribution system [186]. Here, the objective was to get optimal switching combination in the network that would result minimum loss. A novel method based on fuzzy mutated genetic algorithm was presented for performing optimal distribution system reconfiguration [187]. Here, the proposed method resolved the issue related to the discrete nature of the reconfiguration problem and also attempted non continuous multi-objective optimization. Particle swarm optimization was applied for distribution feeder reconfiguration considering distributed generators [188]. The effectiveness of the proposed algorithm had been compared with genetic algorithm, tabu search and differential evolution on a realistic distribution test system. Self-adaptive particle swarm optimization and modified shuffled frog leaping algorithm were integrated for performing distribution feeder reconfiguration by Niknam et al. [189]. The hybridization had been accomplished to utilize the adopted techniques' advantages and avoid their demerits. An efficient multi-objective modified shuffled frog leaping algorithm was implemented for distribution feeder reconfiguration [190]. The main focus of that work was to reduce the real power loss, deviation of the nodes' voltages and the number of switching operations. Discrete particle swarm optimization and honey bee mating optimization algorithm were integrated for multi-objective distribution feeder reconfiguration [191]. Discrete particle swarm optimization, ant colony optimization and fuzzy multi-objective approach were integrated together for multi-objective distribution feeder reconfiguration [192]. The objectives of that approach were reduction of real power loss, deviation of nodes voltage, the number of switching operations, and the balancing of the loads on the feeders. Particle swarm optimization and ant colony optimization were hybridized for distribution feeder reconfiguration (DFR) [193]. The presented DFR problem was a multi-objective and non-differentiable optimization problem where the objectives were minimization of real power loss, deviation of the nodes' voltage, the number of switching operations, and to balance the loads on the feeders. Tribe modified shuffled frog leaping algorithm was implemented for multi-objective distribution feeder reconfiguration considering distributed generator units [194]. The main aim of that study were to minimize the real power loss, deviation of the nodes' voltage, emission produced by DG units and distribution companies, and total cost of the active power generated by DG units and distribution companies. Modified simulated annealing technique and the ϵ-constrained method were considered for optimal network reconfigurations in distribution systems [195]. Here, the main focus was both loss reduction and load balancing considering load constraints and operation constraints. Modified honey bee mating optimization algorithm was chosen for multi-objective distribution feeder reconfiguration considering distributed generators [196]. Here, the main objective of the reconfiguration problem was to minimize the real power loss and deviation of the nodes' voltage. Refined genetic algorithm was applied for distribution feeder reconfiguration to minimize losses [197]. In that attempt, the problem was optimized in a stochastic searching manner alike to that of the conventional GA. A meta-heuristic harmony search algorithm was proposed for performing optimal distribution system reconfiguration and DG allocation in an efficient way [198]. The objective of this simultaneous reconfiguration and DG placement was to minimize power loss. Like optimal network reconfiguration appropriate power system planning is another domain of research which requires soft computing tool for finding excellent solution.

5.4.4 Performing power system planning

Genetic algorithm was implemented to find the optimal solution related to improved distribution system planning [199]. A design optimization framework named design by expectation was developed. Modified differential evolutionary (DE) algorithm was applied for power system planning [200]. Here, detailed numerical studies were performed to present the characterization of the performance of several DE mutation methods with and without fitness sharing scheme. Differential evolution algorithm was implemented directly to the DC power flow model to solve the problems of static and multistage transmission expansion planning (TEP) with efficacy [201]. Here, the aim of TEP was to minimize the transmission investment cost associated with technical operation and economical limitations. A new method based on bacterial foraging technique was presented for optimal feeder routing in radial distribution system planning [202]. Here, the efficacy of the bacterial foraging technique was reported for solving combinatorial optimization problems with faster convergence and enhanced probability to achieve a global optimum solution of the distribution planning problem. Improved genetic algorithm was applied for optimal planning in large distribution networks [203]. In that attempt, optimal sizing and locating of the high and medium voltage substations were performed with the routing of the medium voltage feeders utilizing their corresponding fixed and variable costs. Differential evolution based method was utilized for power system planning [204]. Here, a comparative study was carried out amongst genetic algorithm, evolutionary strategy and five different DE schemes on two benchmark power systems. Particle swarm optimization was applied for multi-objective planning of electrical distribution systems [205]. Here, the objectives were minimization of total installation cost and total fault cost. Ant colony system (ACS) algorithm was chosen for the planning of primary distribution circuits [206]. In that attempt, the ACS methodology had been combined with a conventional distribution system load flow algorithm to solve the primary distribution system planning problem. Rao et al. utilized harmony search algorithm with a differential operator to solve the optimal conductor size selection problem in distribution systems [207]. The purpose of this network planning approach was to minimize real power loss and enhancement of voltage profile. However, there are other engineering problems related to power system which can be efficiently solved by optimization technique.

5.4.5 Related other schemes

Genetic algorithm was utilized to achieve optimal integral gains in fuzzy based active power-frequency control of non-reheat and reheat thermal generating systems [208]. Here, optimal transient responses had been resolved by utilizing sugeno fuzzy logic technique with GA based optimal gains. Adaptive hybrid genetic algorithm was proposed for technical loss reduction in distribution networks under variable demands [209]. Here, the new optimization approach was capable to deal with energy flows instead of only instantaneous power flows. Simulated annealing and fuzzy technique based dynamic programming was proposed for the unit commitment problem by Patra et al. [210]. Here, the obstacle of dimensionality of the dynamic programming method was eradicated by reducing the number of prospective solution paths to be stored at each stage of the search procedure. Differential evolution algorithm was considered for solving unit commitment with ramp constraints [211]. Here, both binary and integer code had been developed to implement the proposed algorithm. Simulated annealing algorithm was utilized for performing optimization of electrical distribution feeders [212]. The aim of that paper was to minimize both the investment cost for feeder and substations, and the power loss cost. Simulated annealing algorithm was proposed for optimal switching device placement in radial distribution systems [213]. Here, the optimization technique was presented to determine the number of sectionalizing switches and the locations of the switches. Gray-based genetic algorithm was utilized with probabilistic load flow for optimal VAR control considering wind farms [214]. Here, a method was presented using wind generator voltages, static compensators, and transformer taps as controllers to adjust the voltage profile. Parallel simulated annealing was introduced for power system decomposition [215]. Here, the objective was to equally separate the subsystems in terms of the number of nodes and control variables. Plant growth simulation algorithm was presented to perform reactive power optimization [216]. Here, the objective was to minimize the system active power loss. Plant growth simulation algorithm was chosen for integrated optimization of the construction/expansion capacity of high voltage/medium voltage substations and the configuration of the medium voltage radial distribution network [217]. In that attempt, fixed cost and variable cost were considered under the constraints of branch capacity, substation capacity and bus voltage. Again, plant growth simulation algorithm was presented for optimal conductor selection in radial distribution system [218]. Here, the objective was to reduce the overall cost of annual energy losses and depreciation on the cost of conductors. Further, plant growth simulation algorithm was utilized for fault location of distribution network [219]. In that attempt, a way was presented to transform the currents of switches and equipments into integer variables to set up a model for fault location.

It can be said from the above discussion that for any kind of power system optimization where a huge number of solutions are there in the feasible domain, optimization technique is necessary to find the appropriate one. Both distributed generation penetration and shunt capacitor allocation are the chosen engineering schemes in this work. It has been evidenced from the earlier paragraphs that several well established algorithms had been attempted to study DG integration and capacitor placement individually. It has also been evidenced in Chapter two that both the stated options had been chosen for reliability study. However, distributed generator capacity has been considered as of fixed value such as 50 kW, 100 kW etc in this work. This has not been considered as continuous variable value. On the other hand, capacitor value has also been selected as of discrete nature for shunt capacitor allocation. So, the engineering problem is a critical and complex combinatorial optimization problem. Scientists, researchers and power engineers are still searching for better optimization tool to find optimal solution for such kind of technical problem. They are searching for better optimization technique due to some shortcomings of the available evolutionary algorithms.

5.4.6 Shortcomings of available evolutionary techniques

The available searching techniques sometimes fall short in finding the optimal solution when the situation is critical and complex. The tendency of getting trapped into local optima while performing optimization has also been evidenced in standard methods for some intricate situations. Genetic algorithm (GA) and particle swarm optimization (PSO) are standard techniques available in the literature. Most of the techniques already discussed in earlier sections are more or less modification of the GA or PSO. The inner parameters of the stated algorithms have to be tuned for each and every optimization situation. To find the exact values of the inner parameters for a specific combinatorial optimization problem is very difficult. On the other hand, several evolutionary techniques have multiple inner parameters for performing randomization and localization tasks. This sometimes induces uncertainty in finding the global optimal solution. That’s why special meta-heuristic techniques are necessary as searching tools.

Recently it has been observed that cultural algorithm is coming as a strong meta-heuristic technique in the domain of engineering optimization. This cultural algorithm has been described later in Chapter 6. Belief space and population space are two inherent parameters of this algorithm. But this technique sometimes falls short in finding global optimal value when the solution domain is large and the optimization problem is combinatorial. Appropriate capacitor allocation and DG penetration in a microgrid power system network has been considered as the engineering scheme in this thesis. This is a critical and combinatorial optimization problem which also deals with a huge set of solutions. In this regard, modification has been done to this cultural algorithm for having good quality solutions performing capacitor allocation and DG integration. The development and implementation procedure of this new technique named modified cultural algorithm (MCA) has been described in Chapter 6.

It has been observed from the simulation results discussed in Chapter 7 that modified cultural algorithm is efficient in comparison to the well established genetic algorithm and particle swarm optimization. But there is always a chance of getting better solution in a real world combinatorial optimization problem. Search for a more efficient novel evolutionary technique has been started with the hope of having even better solution than modified cultural algorithm.

Nature inspired phenomenon which is analogous to a searching process has the potential to be considered as plan for developing an efficient optimization technique. This concept has been coming up now-a-days. In this regard, active and passive electro location phenomena of elephant nose fish and shark is interesting and significant as a searching process. This physiological process has been considered in this thesis for developing a novel evolutionary technique named fish electrolocation optimization (FEO) illustrated later also in Chapter 6. However, a note regarding this newly developed MCA and FEO techniques is necessary before understanding these in details.

5.5 Evolutionary techniques applied in this thesis

Evolutionary techniques have been considered as optimization tools for combinatorial capacitor allocation and DG integration in a radial distribution system resembling microgrid in this thesis. Real coded genetic algorithm and particle swarm optimization have been coded for stated combinatorial optimization problem. Modified cultural algorithm (MCA) and fish electrolocation optimization (FEO) have been newly developed and implemented here. Modified cultural algorithm is an optimization tool created from the original cultural algorithm. This algorithm mathematically imitates the evolution of society through certain beliefs or knowledge sources. Population space and belief space are the two main factors of this technique. There is a communication protocol between the two stated spaces. This communication channel performs a few functions such as update, accept, modify and evolve. The stated functions mainly perform changes in knowledge sources viz. Situation knowledge, history knowledge, domain knowledge, topographical knowledge and normative knowledge. Modified cultural algorithm has been developed considering two knowledge sources of belief space which are situation knowledge and history knowledge. Four new mathematical operators have been incorporated in the Situation Knowledge influence for MCA. History knowledge influence has been performed considering a few plans. The influence work of both situation and history knowledge has been mathematically formulated in MCA technique for specifically implementing the algorithm on combinatorial optimization problem. The cost based reliability enhancement objective discussed in Chapter 4 is a complex combinatorial optimization problem. Modified cultural algorithm works effectively for DG integration and capacitor allocation project to reduce cost and also to improve a few reliability indices discussed in Chapter 3. On the other hand, fish electrolocation optimization is a novel algorithm mathematically developed for both continuous and discrete optimization problem. The theoretical concept behind this technique is active and passive electrolocation phenomena of elephant nose fish and shark. The said method is mathematically analogous to a conceptual electro fish who can not only detect the quality of the targeted food object but also measure the distance from that object by the sense of active electro location. The conceptual electro fish mimics the nature of elephant nose fish for this purpose. It does that intelligently by verifying the electrical capacitance value analyzing the projected electric image on the fish's body. In addition, the conceptual electro fish can assess the space between the wanted food source and itself judging the feeble electric pulse by the sense of passive electro location. This time it imitates the shark which can sense the meager electric pulse originated from the muscle twitching behavior of small living beings. The conceptual electro fish toggles between active and passive electro location depending on the situation of the optimization problem at hand. Nevertheless, randomization and localization have been performed in a well manner considering three probabilities in FEO technique. The probabilities are probability of divergence, probability of range and probability of selection, respectively. Microgrid radial distribution system reliability has been improved with monetary factors implementing this FEO technique considering DG integration and capacitor placement in this thesis.

The above discussion is not sufficient to understand the execution procedure and mathematical formulations of rcGA, PSO, MCA and FEO techniques. It is pretty essential to discuss the methods individually in details. The next chapter elaborates all these techniques as an optimization tool for DG integration and capacitor allocation in a microgrid power system network.

Chapter 6

Developed soft computing techniques for cost based reliability improvement

Soft computing tools especially evolutionary techniques have been applied here to reduce cost and also to improve reliability. Modified cultural algorithm (MCA) and fish electrolocation optimization (FEO) have been newly developed in this thesis for the above stated work. Real coded genetic algorithm (rcGA) and particle swarm optimization (PSO) have also been implemented here to observe cost based reliability enhancement.

6.1 Implementation of real coded genetic algorithm

Real coded genetic algorithm (rcGA) has been applied for DG integration and capacitor allocation project in microgrid type radial distribution system at hand. Crossover and mutation operations are the two main factors in genetic algorithm. These stated two operations help real coded genetic algorithm to converge near the optimal solution. A brief about real coded genetic algorithm has been illustrated earlier in Chapter 5. But how this technique has been implemented for capacitor allocation in 69 bus and both DG and capacitor placement in 34 bus and 69 bus microgrid based radial distribution system has not been described earlier. The implementation procedure of rcGA technique is important to understand. The processes related to capacitor allocation and both DG and capacitor placement are more or less similar. The reader can easily have the idea of the procedure concerning to capacitor placement from the application steps of rcGA for simultaneous DG integration and capacitor allocation. That's why algorithmic steps of rcGA have been discussed here for simultaneous optimal capacitor and DG incorporation.

Step 1: Initialize the maximum generation number (here it is considered as the maximum load flow solution number), set crossover probability and mutation probability.
Step 2: Formulate population randomly for simultaneous optimal DG integration and capacitor allocation. Set fitness value.
Step 3: Perform crossover if random number if greater than crossover probability and evaluate total cost, line loss, distribution system reliability indices respectively.
Step 4: Check fitness value (objective function value) whether it is better than the old value or not. If it is better than the old value then replace that old value with the new one. Choose that population individual connected to that better fitness value for the next iteration.
Step 5: Perform mutation operation if random number is greater than the mutation probability value.
Step 6: Enumerate the total cost, line loss and distribution system reliability indices.
Step 7: Change the better fitness value related population individual for simultaneous optimal DG and capacitor placement.
Step 8: Store all the population individual's objective function values. Find out the best objective function value amongst all the population individuals and connected DG and capacitor values for that iteration.
Step 9: Check whether the termination condition embedded in the algorithm is satisfied or not. If it is satisfied then stop the simulation and print the best individual's objective function value, and connected DG and capacitor values. Otherwise go to step 3.

Particle swarm optimization has also been implemented for cost reduction as well as reliability improvement like real coded genetic algorithm. The application procedure regarding this technique is necessary to understand.

6.2 Application of particle swarm optimization

Particle swarm optimization (PSO) has been employed for simultaneous DG integration and capacitor allocation in 34 bus and 69 bus microgrid radial distribution system. This technique has been applied to observe cost reduction, loss minimization and reliability improvement of the microgrid type distribution system at hand. Mathematical formulation and working principle of this algorithm has already been discussed in Chapter 5. The implementation procedure of PSO technique for both capacitor and DG placement has not been described earlier. This has been stated here through some algorithmic steps.

Step 1: Initialize maximum iteration number (here it has been considered as the maximum powerflow number). Set α and β values as shown in equation (5.2) for particle swarm optimization. Initialize individual current best and global best related to distributed generator and capacitor for simultaneous optimal DG and capacitor allocation.
Step 2: Develop population individuals concerning to capacitor and distributed generator by randomly choosing capacitor and distributed generator values.
Step 3: Evaluate the objective function value for every individual of population.
Step 4: Get the current best location and value for every individual of population.
Step 5: Find the global best location and value for all the individuals of population for DG and capacitor placement.
Step 6: Check whether the powerflow or load flow solution number has reached the maximum limit or not. If it reaches to the maximum value then go to step 8 otherwise go to step 7.
Step 7: After finding the current best and global best value for DG and capacitor allocation problem, formulate new population individuals guided by those obtained current best and global best column vectors and go to step 3.
Step 8: Print the global best objective function value and connected DG and capacitor values for simultaneous optimal DG and capacitor placement and stop the simulation procedure.

Particle swarm optimization and real coded genetic algorithm are standard techniques available in the literature. These techniques sometimes fall short in finding the optimal solution in combinatorial optimization problem like the DG integration and capacitor allocation. Furthermore, convergence to the global optimal solution is not always achieved by these techniques when the situation is critical and complex. In this regard, cultural algorithm (CA) has proved its potential in critical and complex combinatorial optimization situation. But this CA technique sometimes also entrapped in local minima when the system topology is complex and the size of the system is bigger. That’s why the technique has been modified to apply here for cost based reliability enhancement. This modified CA named MCA is a newly developed technique in this thesis. The working procedure and also the implementation steps of this MCA are important to understand.

6.3 Modified cultural algorithm

Robert G. Reynolds first proposed cultural algorithm (CA). It has been considered as an evolutionary algorithm. Evolution of culture, in a society, has been described as an idea in this

technique. Several classes of people live inside a society. Each class of people has their own rules and regulations. The high or elite class people are considered as the best individual amongst all the classes. Selection of that particular class has usually been performed based on their knowledge and wealth. Gradually, the concept or ideas of those elite class people becomes the governing factor of the society. The other classes of people more or less obey those rules and regulations of the elite class. They not only obey it but also circulate those ideas to their children. In this fashion, the culture or knowledge progresses from one generation to the next generation making them more up to date and fit for the survival.
The above stated idea has simply been mathematically implemented in cultural algorithm (CA). Performance function or objective function is utilized to select the best individual. That is here the elite class people. Belief space is the knowledge or concept. Communication protocol is nothing but the circulation of that concept from parent to children. There are two functions in communication protocol. These are *accept functions* and *influence functions*. The *belief space* is updated by the *accept function*. On the other hand, the population is guided by *the influence function* taking knowledge from the belief space. The diagram illustrating the concept of cultural algorithm is depicted below.

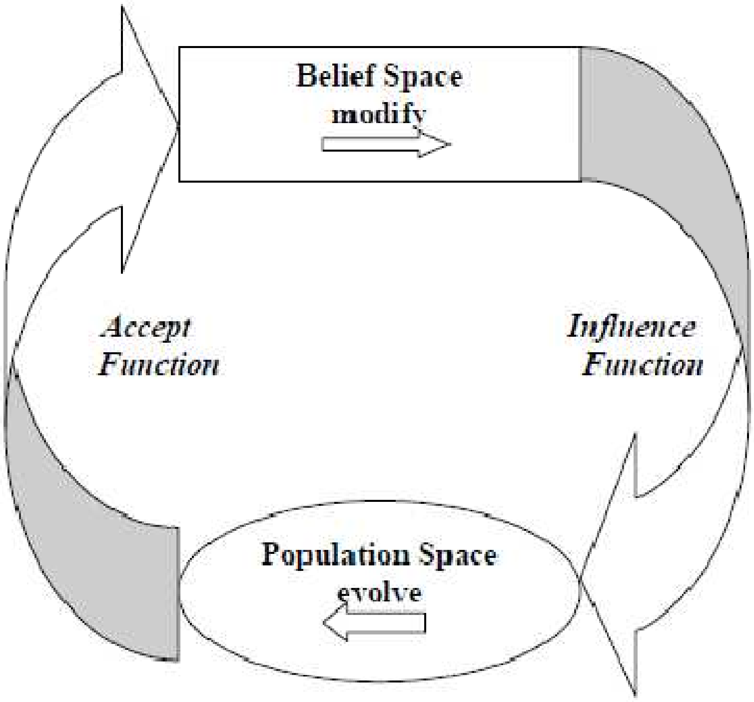

Figure 6.1: Conceptual diagram of cultural algorithm

6.3.1 Overview of cultural algorithm

Cultural Algorithm has been described as a dual inheritance system. As stated earlier, *population space* and *belief space* are two main components. *Influence function* and *accept function* are two significant functions. First of all, the evaluation work regarding each and every individual is performed. After that the best individual in the population space is determined to impact the *belief space*. The best individual amongst the *population space* has been considered as $globalbest$. The beliefs or knowledge is updated by the utilization of update function using the experience of elite class individuals. In the next step, the *belief space* knowledge is utilized to

modify the population space. New population is generated from old population under the influence of *belief space*. Individual of the new population has been termed as $offspring$. The $offspring$ is developed from $parent$ which is the individual of old population. *Accept function* and *influence function* are treated as two feedback functions. These functions make the total procedure a dual inheritance system of *population space* and *belief space*.
Cultural algorithm has been studied as knowledge based system by Jin [220]. A hierarchical architecture has been formulated in this algorithm to guide the search of evolutionary computation. *Belief space* which is a main part of this soft computing technique has been illustrated as a tree like hierarchical structure consisting of belief cells. Each and every cell has a few characteristics. Capability of storing knowledge of corresponding region is possessed by every cell. However, regional knowledge has been illustrated in the research work of Jin [220]. This knowledge includes two sub knowledges. *Constraint knowledge* and *normative knowledge* are two sub knowledges. The above discussed cells are judged on the basis of count of different types of individuals to update the *constraint knowledge*. These are feasible, infeasible and semi-feasible types of individuals. Eminent or ordinary cells are chosen to update normative knowledge. *Influence function* takes idea from normative and constraint knowledge to influence the population in population space. The search procedure which is selected in Jin's research work is based on some basic rules. The individuals situated at the intersection of eminent and non-infeasible cells have been considered as very good cells. Children are created from them just doing little manipulation of their values. On the other hand, the next category of individuals belongs to the infeasible cells. That category is moved to the class of non-infeasible cells. However, the last category of individuals belongs to the class of ordinary cells. These cells are guided to the category of eminent cells. Selection of cells has been done by the application of Roulette Wheel Selection Method. Every cell is weighted before selection. Feasibility of cell is the basis of defining the weight of each cell. It makes the selection method simpler. The offspring has a higher probability to appear in the eminent cell for a specific condition. The condition is that the parent should be inside an ordinary cell. *Offspring* is obtained from *parent* by the utilization of normative knowledge. An eminent cell is utilized to attract the individuals. That eminent cell is chosen randomly from a set of eminent cells.

6.3.2 About knowledge sources of cultural algorithm

Cultural algorithm has five knowledge sources. These are situation knowledge, normative knowledge, topographical knowledge, domain knowledge and history knowledge. A guideline is formed from knowledge sources to update the individual of the population space. These knowledge sources give a set of variable ranges. Adjustment of individuals amongst population can be done within this variable range. A set of ideal cases is considered as situation knowledge. Individual gets help from situation knowledge to reach those ideal ones. The next knowledge source is normative knowledge which helps the individual to move to the good zone. On the other hand, spatial characteristic is the basis of topographical knowledge. Region based schemata or plans are kept in it. The population is guided by the domain knowledge with the usage of its domain knowledge. Episodic memory is kept inside historical knowledge. During iterations, important events are recorded in it. It is called temporal knowledge. Influence work is done to the population space by these above mentioned knowledge sources. The belief space knowledge is updated by the best individual of population space. A special tool called *communication protocol* performs the above discussed influence and update procedure. The main components of this *communication protocol* are *accept function* and *influence function*. Selection of best individual's experiences is performed by *accept function*. It also updates the *knowledge* of *belief space* during iteration. The experience of the top individuals is actually taken by the accept function. The above discussed knowledge sources communicate with each other. Furthermore, they update their knowledge by taking experiences from the top class individuals. Five knowledge sources are briefly described here which influence the population.

- Situation Knowledge:

A set of ideal individuals from the population is contained in situation knowledge. The value of fitness and the value of parameters are contained in each best individual or the ideal one.

- Normative knowledge:

Normative knowledge has been presented in the form of intervals. A range for acceptable variables is contained in it. Data structure is used to store lower and upper limits of each individual and the performance value. Normative knowledge is generally updated by shifting those ranges and modifying performance values.

- Topographical Knowledge:

Like normative knowledge, topographical knowledge is also presented in the form of data structure. It is termed as the regional schemata. The value of lower and upper limit for each variable is stored in each cell in the data structure. The sampling of solution in every cell and a list of best cells are contained in the initial knowledge structure. The update or modification procedure is considered when an individual value is found better than the value of the cell best. The update procedure is also considered if the fitness value is increased with a change of an event.

- Domain knowledge:

This knowledge source keeps domain ranges and like situation knowledge it stores exemplars from population space. It is utilized to predict the gradient of incline or decline for locating the resources in the dynamic environment.

- History knowledge:

History knowledge archives global features. The information of shifts in distance and direction of the optimum value are stored in it. It has an episodic memory. In this regard it can be termed as temporal knowledge. A more global view than the other knowledge is provided by this knowledge source. The average change in the parameter values and shift in the direction of the optimum from its previous position are determined by the usage of history knowledge. Every event change updates this knowledge. Modification of history list and moving averages for each parameter is done with the change of this knowledge source. Implementation of this knowledge is done as a list of a certain temporal points. The search path contains those episodic points.
Cultural algorithm is a potential optimization technique but this algorithm sometimes falls short in finding global optimal solution when the situation is critical and intricate. There is also a chance of getting trapped into the local optima when the solution domain is large. Tuning and modification of this technique is a good way to develop a better technique. This has been performed to cultural algorithm for having excellent solutions related to combinatorial capacitor allocation and DG penetration in a microgrid power system network.

6.3.3 Development of modified cultural algorithm (MCA)

Modified cultural algorithm (MCA) has been developed from original Cultural Algorithm (CA). In MCA, $offspring$ is formulated on the basis of the value of $globalbest$ and $parent$ but the creation procedure of $offspring$ is different from that approach of CA. In addition $parent$ individual is developed through *population pool*. The concept of *population pool* (*PP*) has also been newly incorporated in MCA to formulate the *PS* and also for the satisfactory operation of *SK*. During iteration, the *BS* is updated taking the values from the best individual. Among all the *Knowledge* sources of CA, only *situation knowledge* (*SK*) and *history knowledge* (*HK*) have been considered for the formation of MCA [221]. In MCA, *Addition*, *Multiplication*, *Replacement* and *Unchanged* operators and f_{eff} are newly introduced for the influence work of *SK*. Best selected global individual's information, developed by *SK*, is taken for the influence work of *HK* in MCA. This particular information is manipulated for the progress of searching and to find the optimum solution.

It is necessary and also significant to understand the detail application procedure of this newly proposed technique MCA on DG penetration and capacitor allocation problem. The implementation procedure of MCA has been discussed in the next section.

6.3.4 Proposed MCA implementation on single and multi objective optimization involving capacitor and DG

The implementation logic of MCA on single and multi objective optimization problem is more or less straightforward. Optimal capacitor placement has been exercised by MCA technique on sixty nine bus radial distribution system similar to a subsystem or microgrid. The aim of that single objective optimization is total cost minimization. On the other hand, simultaneous DG penetration and capacitor allocation have been performed on both 34 and 69 bus radial distribution system like microgrid. The plans of that simultaneous DG and capacitor placement are both single as well as multi objective. Single objective cases are loss minimization, total cost minimization, SAIFI improvement, SAIDI improvement and AENS improvement. The multi objective approach considers all the stated five conflicting objectives. Whatever be the objective, the MCA algorithm chooses capacitor value and position and both DG and capacitor magnitude and location suitably for capacitor placement and simultaneous DG and capacitor allocation. The implementation procedure of MCA on optimal capacitor placement can be easily understood by comprehending the MCA approach on simultaneous DG and capacitor value and location selection for any optimization situation. That's why here the MCA technique has been elaborately described for simultaneous DG integration and capacitor allocation in a radial distribution system resembling microgrid. The formulations of internal parameters of MCA like *PS* and *BS* and influence work of *knowledge* sources of *BS* require special attention.

6.3.4.1 Formulation of population space (*PS*)

The population space (*PS*) is generated from the population pool (*PP*) which has been newly thought in MCA development process. The MCA based simulation study related to distributed generation penetration and capacitor allocation in radial distribution system requires two PSs and PPs. The *PSI* and *PSII* are developed for simultaneous DG integration and capacitor placement purpose, respectively. Initially a combination of '0' and '1' is created randomly to form the *PPI* and *PPII*. Initial *PPI* and *PPII* are shown in Figure 6.1 and Figure 6.2 for capacitor placement and DG integration, respectively. Capacitor value set is defined, as $Capval$ in (6.1). It is assumed that there are $m1$ rows and $p1$ columns in both *PPI* and *PPII*. The total number of rows denotes the total number of buses of the feeder. Each column signifies each individual of the *PPI* and *PPII*. The binary digits '1' and '0' is denoted as capacitor 'on' and 'off' condition i.e. capacitor placed and not placed, respectively in PPI. It has been observed from Figure 6.2 that the first column of the *PPI* is $[1 \ \ 0 \ \ 1 \ \ 1 \ \ . \ \ . \ \ 0 \ \ 1]^{\mathrm{T}}$. It defines that at the bus number 1, 3, 4 and $m1$, the capacitor is to be installed. The *PPI* individual defines the selected locations for the capacitor allocation. On the other hand, it has been noticed from Figure 6.3 that the first column of the *PPII* is $[0 \ \ 1 \ \ 0 \ \ 1 \ \ . \ \ . \ \ 0 \ \ 1]^{\mathrm{T}}$. It describes that at the bus number 2, 4 and $m1$, the DG is to be allocated. The *PPII* individual defines the selected locations for the DG penetration. Randomly created combinations of capacitor values, taken from the existing capacitor value set are multiplied with each individual of *PPI* to form the *PSI*. Population Space I's individual defines both the selected buses and the capacitor values, which are shown in Figure 6.2. For example, random vector constructed by choosing $m1$ capacitor values is $[f \ \ k \ \ r \ \ t \ \ . \ \ . \ \ h \ \ s]^{\mathrm{T}}$. After multiplication the first individual of the *PSI* becomes $[f \ \ 0 \ \ r \ \ t \ \ . \ \ . \ \ 0 \ \ s]^{\mathrm{T}}$. It means that at bus number 1, 3, 4 and $m1$ capacitor value of f kVAR, r kVAR, t kVAR and s kVAR are placed respectively. Randomly created combinations of DG values, taken from the existing DG value set are multiplied with each individual of *PPII* to form the *PSII*. Population Space II's individual defines both the selected buses and the DG values, which is shown in Figure 6.2. For example, random vector constructed by choosing $m1$ DG values is $[f_1 \ \ k_1 \ \ r_1 \ \ t_1 \ \ . \ \ . \ \ h_1 \ \ s_1]^{\mathrm{T}}$. After multiplication the first individual of the *PSII* becomes $[0 \ \ k_1 \ \ 0 \ \ t_1 \ \ . \ \ . \ \ 0 \ \ s_1]^{\mathrm{T}}$. It means that at bus number 2, 4 and $m1$ DG value of k_1 kW, t_1 kW and s_1 kW are placed respectively. Finally, each individual's value and position concerning to *PSI* and *PSII* are simultaneously incorporated into the chosen radial distribution system resembling microgrid. Load flow analysis has been exercised to calculate the loss and then to calculate the total cost from Chapter 4 taking the corresponding cost of capacitor from the capacitor cost set $capcost$, shown as (6.2).

$$capval = \{a, b, c, \ldots\ldots, h, \ldots.., w, x, y, z\} \quad (6.1)$$

$$capcost = \{a1, b1, c1, \ldots.., h1, \ldots.., w1, x1, y1, z1\} \quad (6.2)$$

$$DGval = \{a_1, b_1, c_1, \ldots\ldots, h_1, \ldots\ldots, w_1, x_1, y_1, z_1\} \quad (6.3)$$

$$DGcost = \{a_1^1, b_1^1, c_1^1, \ldots.., h_1^1, \ldots.., w_1^1, x_1^1, y_1^1, z_1^1\} \quad (6.4)$$

$$\begin{bmatrix} 1 & 0 & . & . & 1 & . & . & 1 \\ 0 & 1 & . & . & 1 & . & . & 0 \\ 1 & 0 & . & . & 0 & . & . & 1 \\ 1 & 0 & . & . & 1 & . & . & 1 \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ 0 & 1 & . & . & 1 & . & . & 1 \\ 1 & 0 & . & . & 1 & . & . & 1 \end{bmatrix} \Rightarrow \begin{bmatrix} f & 0 & . & . & g & . & . & f \\ 0 & k & . & . & n & . & . & 0 \\ r & 0 & . & . & 0 & . & . & r \\ t & 0 & . & . & t & . & . & n \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ 0 & h & . & . & h & . & . & b \\ s & 0 & . & . & l & . & . & s \end{bmatrix}$$

PPI *PSI*

Figure 6.2: Development of *PSI* from *PPI* for capacitor allocation

$$\begin{bmatrix} 0 & 0 & . & . & 1 & . & . & 1 \\ 1 & 1 & . & . & 1 & . & . & 0 \\ 0 & 0 & . & . & 0 & . & . & 1 \\ 1 & 0 & . & . & 1 & . & . & 1 \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ 0 & 1 & . & . & 1 & . & . & 1 \\ 1 & 0 & . & . & 1 & . & . & 1 \end{bmatrix} \Rightarrow \begin{bmatrix} 0 & 0 & . & . & g_1 & . & . & f_1 \\ k_1 & k_1 & . & . & n_1 & . & . & 0 \\ 0 & 0 & . & . & 0 & . & . & r_1 \\ t_1 & 0 & . & . & t_1 & . & . & n_1 \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ 0 & h_1 & . & . & h_1 & . & . & b_1 \\ s_1 & 0 & . & . & l_1 & . & . & s_1 \end{bmatrix}$$

PPII *PSII*

Figure 6.3: Formulation of *PSII* from *PPII* for DG integration

6.3.4.2 Development of belief space (*BS*)

Belief Space (*BS*) is the plan or theory, which helps to speed up the search procedure. During iteration the best individual is selected for the up gradation of the *BS*. Knowledge or idea is kept in the *BS*. Initially *Knowledge*s and $Blfbest$ are set to zero. At initial stage $BlfbestI$ and $BlfbestII$ concerning to capacitor and DG allocation are shown in (6.5) and (6.6), respectively. Initially no capacitor and DG are placed at any bus. So each element of $Blfbest$ is considered zero.

$$BlfbestI = \begin{bmatrix} 0 & 0 & 0 & 0 & . & . & 0 & 0 \end{bmatrix}^{\mathrm{T}} \tag{6.5}$$

$$BlfbestII = \begin{bmatrix} 0 & 0 & 0 & 0 & . & . & 0 & 0 \end{bmatrix}^{\mathrm{T}} \tag{6.6}$$

Now *SK* and *HK* are adopted to develop the *BS* knowledge. During iteration *SK* is formulated by viewing the best individual of *PS*. It is shown in Table 6.1 and Table 6.2.

Table. 6.1 Situational Knowledge I (*SKI*) for capacitor allocation

Best capacitor position and value						
1	2	4	.	.	$m1-1$	$m1$
f	m	w	.	.	y	e

Table. 6.2 Situational Knowledge II (*SKII*) for DG integration

Best DG location and value					
2	4	.	.	$m1-1$	$m1$
f_1	w_1	.	.	y_1	e_1

It is observed that after certain number of iterations the best individuals are $[f \quad m \quad 0 \quad w \quad . \quad . \quad y \quad e]^T$ and $[0 \quad f_1 \quad 0 \quad w_1 \quad . \quad . \quad y_1 \quad e_1]^T$ concerning to capacitor and DG placement. Then the *SKI and SKII* will store the bus locations and values of capacitor and DG of the best individuals and will eventually influence the *PSI* and *PSII* in the next iteration for those bus locations.

Table. 6.3 History Knowledge I (*HKI*) for capacitor placement

Total selected locations	Best locations	Best capacitor values
5	2, 6, 7, 11, 20	t, d, w, g, k

Table. 6.4 History Knowledge II (*HKII*) for DG integration

Total selected locations	Best positions	Best DG values
4	5, 8, 13, 18	t_1, n_1, p_1, v_1

If there is no significant improvement in the objective function value, then *SK*'s best locations, values and total number of locations concerning to capacitor and DG placement are kept in the *HKI* and *HKII* as observable in Table 6.3 and Table 6.4, respectively. For example, as shown in Table 6.3 at this condition, the bus locations are 2, 6, 7, 11 and 20 respectively in *HKI*. Capacitor values at these selected locations are t kVAR, d kVAR, w kVAR, g kVAR and k kVAR respectively. On the other hand, the bus locations are 5, 8, 13 and 18 respectively in *HKII* shown in Table 6.4. Distributed generator values at these selected locations are t_1, n_1, p_1 and v_1 kW respectively. The selected bus locations and values of capacitor and DG are stored in the *HKI and HKII* respectively. *History knowledge* is used for refined search. This *situation* and *history knowledge* influence is performed under the communication protocol.

6.3.4.3 Communication protocol

Accept function and *Influence function* are the two functions of the *Communication Protocol* which are very important to understand.

6.3.4.3.1 Accept function

Accept function is applied to update or change the *BS* knowledge. The best individual amongst the population is selected according to performance. Here only that best individual does the improvement work in the *BS* and replaces the *Blfbest*.

6.3.4.3.2 Influence function

Influence function on the other hand is used to modify the *PP* and also the *PS*. Here the idea which is considered to influence the *PS* by the *BS*'s *Knowledge* sources is discussed below.

6.3.4.3.2.1 Influence work of situation knowledge (*SK*)

The optimal locations for the capacitor allocation are either exactly like the stored locations in the *BS* or it may be greater or lesser than that stored number. This concept has been utilized for the *SK*'s influence work. The selected bus locations from the *SK* are taken to influence the *PS*. The selected buses and the other bus locations i.e. not selected ones of *SK* are considered as '1' and '0' respectively to formulate the column vector f_{eff}. As *PPI and PPII* only contains the capacitor and DG locations, these are first modified with the f_{eff} to update the *PSI* and *PSII*. Modified *PPI* and *PPII* are shown in Figure 6.4 and Figure 6.5 respectively. For example, the stored locations in the *SKI* and *SKII* are 1, 2, 4, 7 and 9 and 2, 4, 7 and 9 for a 9 bus feeder and the total number of individuals is 12 in every population pool. So, the fI_{eff} and fII_{eff} are defined as $[1 \; 1 \; 0 \; 1 \; 0 \; 0 \; 1 \; 0 \; 1]^T$ and $[0 \; 1 \; 0 \; 1 \; 0 \; 0 \; 1 \; 0 \; 1]^T$ respectively. In this thesis half of the every generated *population pool* is left unchanged through iterations. This has been performed to introduce randomization in the searching of optimal solution such that the proposed MCA does not get entrapped into the local minimum for any optimization situation. The rest half of every *population pool* is manipulated with the f_{eff}. The 7th and 8th individual's each row element is multiplied with the f_{eff}'s column element. The 9th individual is totally replaced by the f_{eff}. The 10th, 11th and 12th individual's each row element is added with each element of f_{eff}. *Multiplication* operation is just like binary multiplication. *Addition* operation is also similar like binary addition but when both f_{eff} and *parent* is '1' then *offspring* is considered as '1'. Sometimes this operation is performed considering more selected bus positions than the f_{eff}. This manipulation with the other half of the *population pool* is exercised to search around the highest fitness value achieved solution in every iteration. The *Unchanged*, *Replacement*, *Multiplication* and *Addition* can be expressed like this:

Unchanged

$$offspring = parent$$

Replacement

$$offspring = f_{eff}$$

Multiplication

$$offspring = parent \times f_{eff}$$

Addition

$$offspring = parent + f_{eff}$$

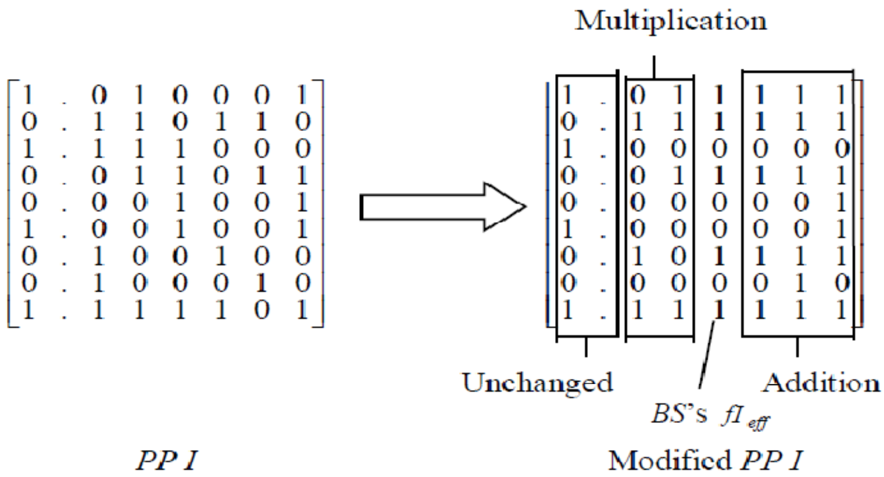

Figure. 6.4 Modified *PPI* after the influence work of *SKI*

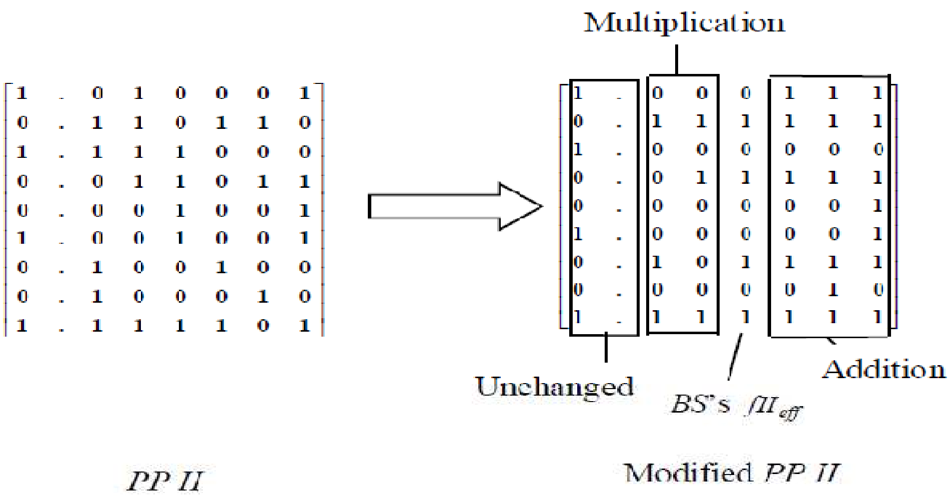

Figure 6.5: Construction of *PPII* after the influence work of *SKII*

Capacitor and DG values are randomly chosen from (6.1) and (6.3) for each individual of *PPI* and *PPII* to form *PSI* and *PSII* respectively. After certain number of iterations or preset condition the role of influence work is reversed from *situation knowledge* to *history knowledge* and it takes the charge to search the global optimal value.

6.3.4.3.2.2 Influence work of history knowledge (*HK*)

The optimal locations for this capacitor and DG installation may be the same as stored in the *history knowledge* (*HK*) of *BS* but the DG and capacitor values for those locations can be different. On the other hand, the optimal capacitor and DG values may be found similar as in the *HKI* and *HKII*, respectively but the bus positions are different for DG and capacitor. It can also be like that the total number of optimal bus locations is same but both locations and values of

DG and capacitor are different. Keeping the above-mentioned idea in mind, the *PS* is modified for the next iteration. Here, modified *PSI* and *PSII* after the *HKI* and *HKII* influence are shown in Figure 6.6 and Figure 6.7, respectively. For example, the selected capacitor and DG values in *HKI* and HKII for 9 bus distribution system with 12 number of individuals in *PSI* and *PSII* are t kVAR, r kVAR, u kVAR and f kVAR; and t_1 kW, r_1 kW, u_1 kW and f_1 kW, respectively. The total number of bus locations is four and bus locations are 2, 4, 7 and 9 respectively. It is shown in Figure 6.6 and Figure 6.7 that one third of the *PSI* and PSII individual's locations are kept same i.e. from 1st to 4th column but the capacitor and DG values are randomly selected from the available capacitor and DG value set. That's why the values are different. It is also shown in Figure 6.6 and Figure 6.7 that the next four columns i.e. from column 5th to 8th have the capacitor and DG values as t kVAR , r kVAR, u kVAR and f kVAR; and t_1 kW, r_1 kW, u_1 kW and f_1 kW which are exactly same as the capacitor and DG values stored in *HKI* and *HKII* but the bus locations are selected randomly. Finally the last four columns, in Figure 6.6 and Figure 6.7, have total four capacitors and DGs 'on' locations but the bus locations and capacitor and DG values are both chosen randomly.

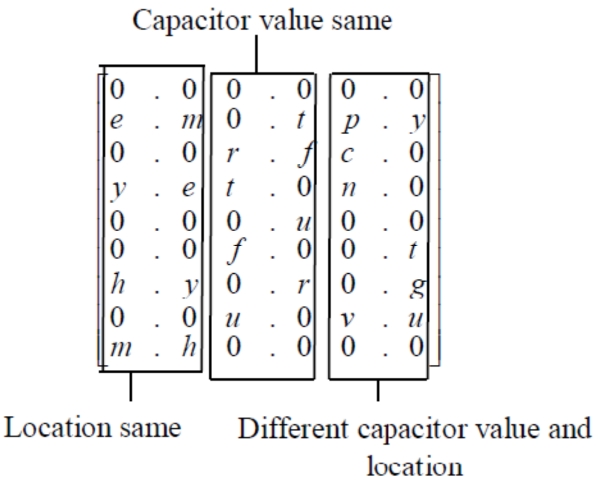

Figure. 6.6 Creation of *PSI* after the influence work of *HKI*

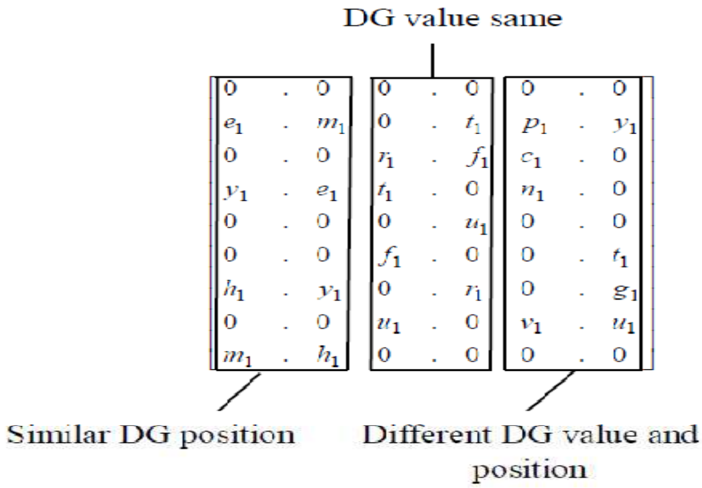

Figure. 6.7: Development of *PSII* after the influence work of *HKII*

In this way history knowledge influences the population after the completion of situation knowledge influence work. The entire procedure regarding MCA technique has been described considering both DG penetration and capacitor allocation. That's why the inherent parameters such as *PP*, *PS*, *SK*, and *HK* etc have been developed in two formats. One format is constructed for capacitor allocation and the other for DG integration. When the MCA has only been applied for capacitor placement problem then only one format of the said inherent parameters has been utilized. However, Modified Cultural Algorithm works in the stated fashion for single objective optimization cases considered in this work. Conversely, multi-objective optimization which seeks more attention has also been effectively approached by MCA technique described in later section.

The approach of MCA on multi-objective optimization is more or less similar with the single objective optimization procedure. The multi-objective MCA has been developed taking inspiration from weighted sum method. Performance function or the objective function inside MCA has been created on the basis of weighted sum method for multi-objective optimization. This is discussed with the choice of scaling factors in Chapter four. Nevertheless, a memory has also been newly incorporated to store the non-dominated solutions through iterations. However, the multi-objective MCA approach has not been elaborated here like single objective optimization approach. Only the flowchart of the multi-objective MCA technique has been shown here for understanding the whole issue. This has been depicted in Figure 6.8 for multi-objective DG penetration and capacitor allocation problem.

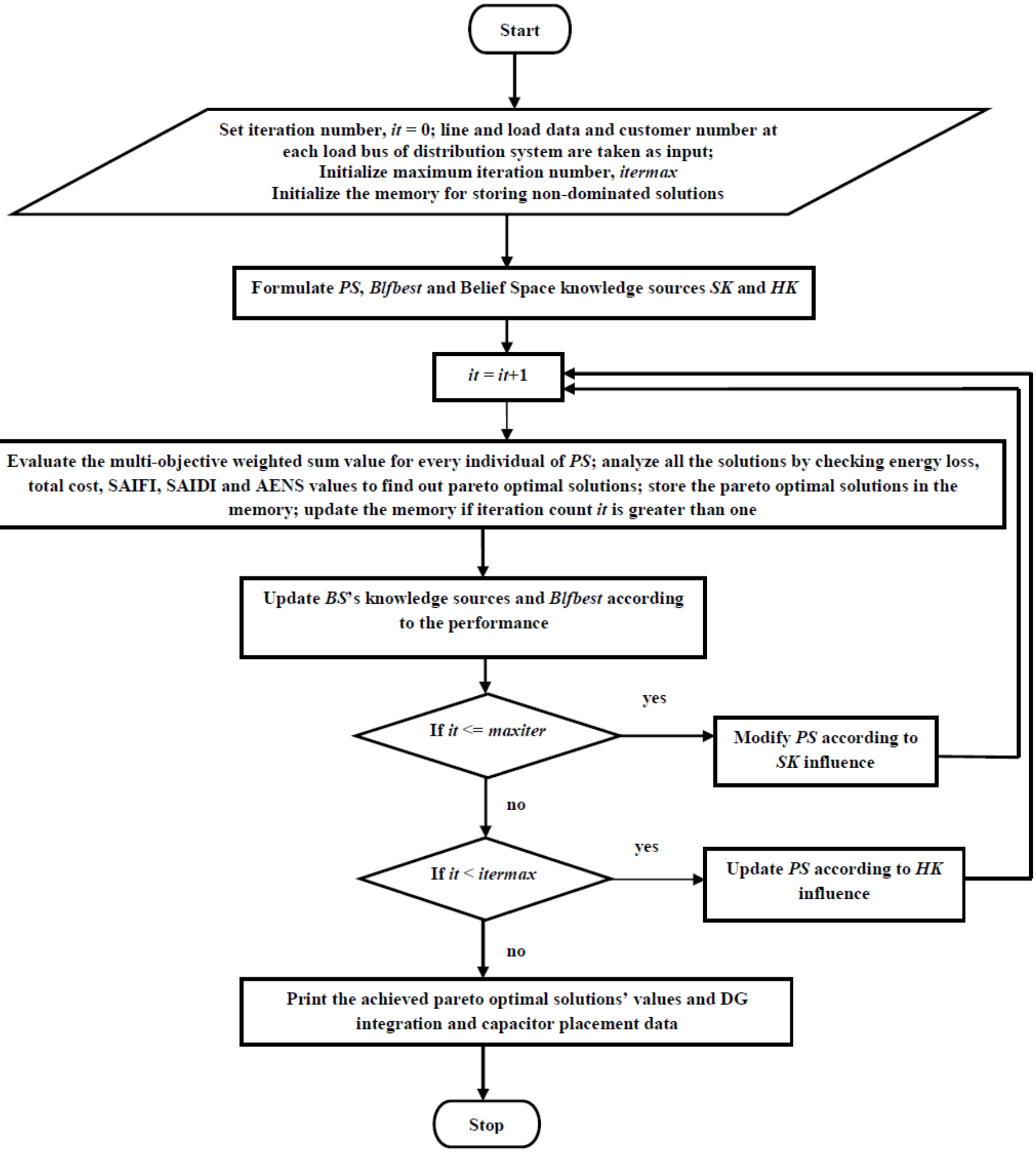

Figure 6.8: Flowchart of MCA technique applied for multi-objective DG integration and capacitor placement problem

6.4 Search for a novel algorithm for cost based reliability enhancement

Cost based reliability improvement is the objective of this work. It has already been illustrated in chapter four. The technique MCA has been applied for total cost minimization considering reliability worth discussed earlier in Chapter 3. Furthermore, it has been implemented for reliability index SAIFI, SAIDI and AENS improvement. The algorithm has also been applied for real power loss and energy loss minimization in 34 bus and 69 bus radial distribution system resembling microgrid, respectively. The above stated optimization approaches considers mainly simultaneous DG penetration and capacitor allocation as engineering schemes. Capacitor placement has only been considered for total cost minimization in 69 bus radial distribution system by MCA algorithm. The simulation results and analysis has been discussed later. It has been observed in Chapter 7 that MCA technique has performed efficiently. But all considered optimization problems deal with discrete values and positions of distributed generation and capacitor. The solution space is obviously huge. It's a mammoth task to find out the optimal and pareto optimal solution for single and multi-objective optimization problem. Nobody can assure that further improvement is impossible in terms of getting a better solution than the achieved one at termination condition embedded in any meta-heuristic algorithm. That's why another optimization algorithm has been searched. This searching has been performed to have even better result than modified cultural algorithm. In this regard, genetic algorithm (GA) and particle swarm optimization (PSO) technique have already been considered for comparison purpose with MCA technique. Most of the well-established population based meta-heuristic techniques in the available literature are more or less similar with GA or PSO technique. On the other hand, it has been observed that evolutionary techniques developed taking inspiration from nature have been coming as effective optimization tool for critical combinatorial optimization problems. So, a novel optimization technique has been developed mathematically analogous to electro location phenomena of fish.

The new technique named fish electrolocation optimization (FEO) has been implemented for reliability enhancement considering monetary factors in microgrid radial distribution system. Though a short note about this novel technique has been written in Chapter 5 but it is very important to understand the FEO algorithm in details for effective application.

6.5 Fish electrolocation optimization

The electric fish *Gnathonemus Petersii* possesses electric discharge organ [222-226]. The electric wave generated from that organ hits surrounding objects in water. An electrical image is created on the surface of the fish's body due to the difference in sensing the electrical field with and without objects. Minute analysis of that image is performed thereafter. The fish evaluates electrical capacitance value of any object depending on image parameters. The capacitance value of food particles is already known to fish. If it feels that the targeted object is within the range of known capacitance then proceeds towards it calculating the distance from the targeted object. Otherwise it generates electric wave of new amplitude. When it finds out the desired object then stops its electric organ discharge.

On the other hand, like active electrolocation, passive electrolocation is used by shark fish *Scyliorhinus Canicula* for food catching purpose [227-228]. Shark does not generate electric wave like elephant nose fish. But it can sense feeble electric pulse generated from the muscle contraction of other living beings in the water. If the shark finds out that kind of electric pulse then it quickly targets towards that direction from which the electrical wave is coming. This food searching technique of the above said electric fishes can be useful as optimization technique.

The active electrolocation of elephant nose fish had been studied on robotic sensor technology [229]. Algorithm inspired from the electrolocation behavior of electric fish has been implemented in autonomous robot. Artificial sensor array was developed by mimicking this special biological phenomenon [230]. This could provide electro sensory capabilities to a submarine robotic explorer. Robotic sensing system was also designed to locate objects underwater [231-232]. This was done through active movement of an electric field emitter and sensor apparatus. Echolocation and electrolocation were both biologically studied as sensory acquisition in active sensing system [233]. Recently Ammari et al. proposed a complex conductivity model for the quantitative analysis of electro location phenomenon [234]. However, concept of electro location as an optimization method has been hardly found in the literature. Passive electro location of shark has also not been conceptualized as searching tool hitherto. Here a soft computing based meta-heuristic method called fish electrolocation optimization (FEO) is developed by mixing both active and passive electro location procedure of two fish viz. elephant nose fish and shark, respectively. The proposed algorithm's theoretical background requires minute attention.

6.5.1 Concept behind fish electrolocation optimization (FEO)

Fish electrolocation optimization (FEO) has been thought on the context of electro sensory perception of electric fish. Nocturnal animal generally rely on other senses instead of vision for object localization and prey catching. Weakly electric fish strongly depends on its electro sensory organs which are more or less situated throughout its whole body [235]. Electrolocation is an adopted navigational approach for finding food item. Elephant nose fish *Gnathonemus Petersii* adopts this navigational procedure in dark and fulfils basic need. It does electric organ discharge in water. It generates electrical wave of a certain voltage amplitude and waveform from its tail electric organ. This is shown in Figure 6.9.

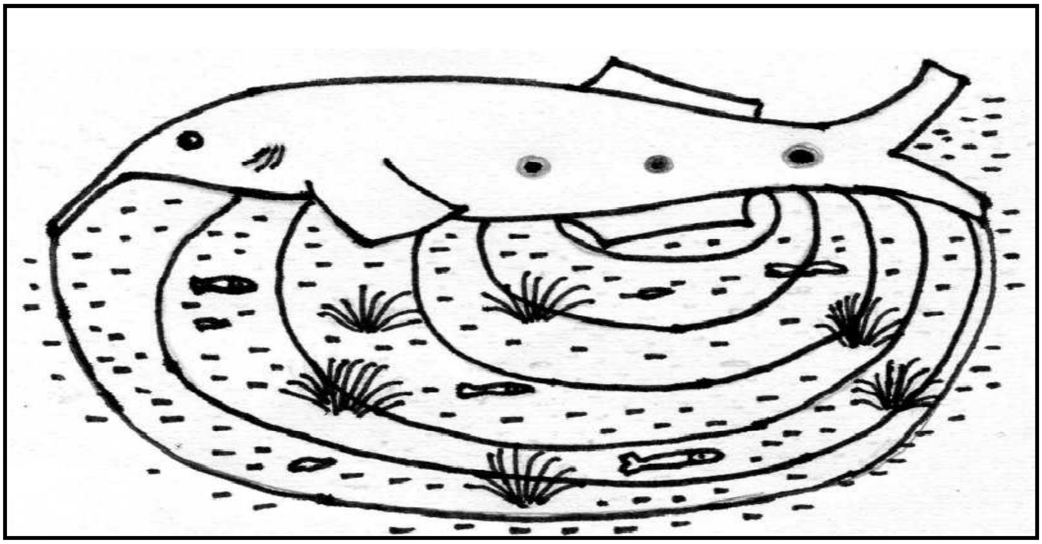

Figure 6.9 Active electrolocation phenomena of elephant nose fish

It is depicted in Figure 6.9 that the circular lines fencing the electric fish are electric field lines. After the electrical discharge in water, electric images of peripheral items are developed on the skin of that fish. The black circular spots shown in Figure 6.9, on fish's body, are denoted as the electric image of food and other non food particles inside water. The electric image is formed on the basis of change in electrical voltage amplitude and waveform distortion with and without the object in the surrounding water. The fish searches its food depending on that image slope, image width; distance from the object, resistance and capacitance value. Food objects, which are either water plant or larvae, have specific impedance in respect of electrical characteristics. And more to it, food objects have a certain range of capacitance value. The fish's electro sensory organs are sensitive within that particular interval of capacitance value. Beyond that limit whether it is in the lower or upper boundary area, the fish is insensitive i.e. it can't sense any more. Depending on this analyzed capacitance value and distance from the targeted object, it approaches towards

the wanted prey. Interestingly, the resistance value depends on the voltage or electrical wave amplitude but capacitance value depends on the wave form distortion. On the other hand, image slope is considered as transition from rim to centre area of image and it's necessary to obtain the distance from the prey. Distance is considered as the ratio of image slope and voltage peak amplitude. Depending on both targeted object distance from fish's body and quality and quantity of that object, the fish generates electric pulse and proceeds towards it. Finally it catches the prey without using any vision but using active electro location intelligently [236].
Unlike active electro location, shark uses its sense of passive electro location for detecting small fishes inside water [237-238]. A glimpse of passive electro location by shark is shown in Figure 6.10. Dotted circular lines surrounding small fishes available in Figure 6.10 show the low voltage signals. The shark has so much strong electro sensory organ that it can sense fish dug in sand sensing muscular organism of that fish. It also uses passive electro location for navigation purpose analyzing ocean current and earth's magnetic field.

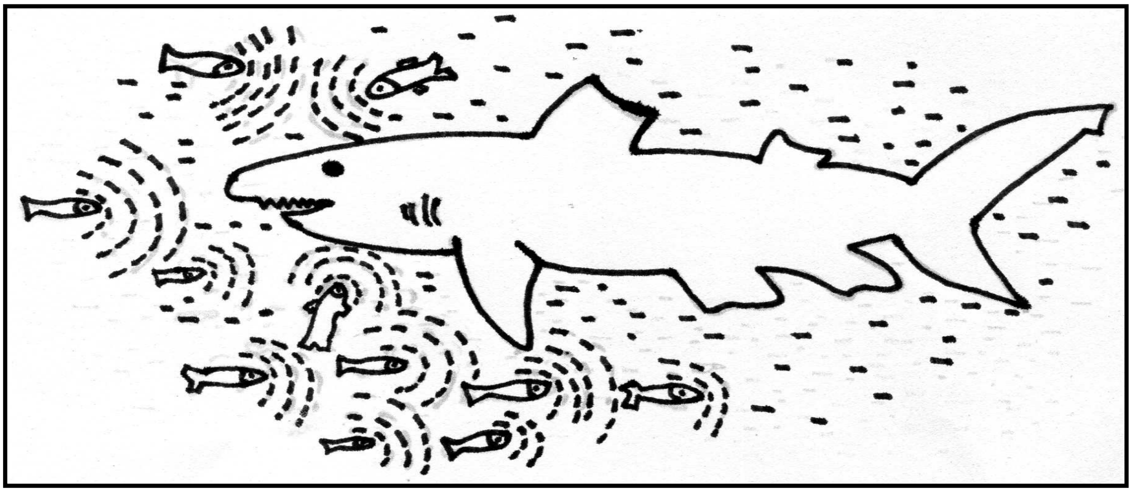

Figure 6.10 Passive electrolocation phenomena of shark

In this work, a conceptual electro-fish is imagined to develop the fish electrolocation optimization (FEO). The fish has both the sense of active and passive electro location like the previously discussed elephant nose fish and shark respectively. It can not only generate electrical wave and analyze the electric image on the basis of electrical characteristics but also can sense feeble electric pulse from other fishes. How it detects and localizes an object has to be mathematically formulated as an algorithm for overall concept development.

6.5.2 Development of FEO through mathematical expressions

Fish electrolocation optimization (FEO) has been mathematically developed through logical expression related to the conceptual electro fish. The fish searches its wanted food item by sensing feeble electric wave and also analyzing projected electric image. It simultaneously emanates electric pulse and senses feeble electrical wave. Feeble electrical wave is sensed in narrow range whereas projected electric image gives the vision of surrounding environment. Sometimes it acts like elephant nose fish and sometimes it acts like shark. It toggles between active and passive electrolocation. This role reversal is linked with the capacitance and distance value owing to toggle switch judgment. Resistance value, discussed in the previous section as a judgmental issue of elephant nose fish, has not been taken into consideration. This is done to restrict the list of parameters of this developed technique. However, FEO algorithm works through range discrimination/development, electric pulse calculation from slope analysis, distance calculation from wanted prey object; capacitance detection from waveform distortion value, toggle switch judgment through capacitance evaluation and finally electric organ discharge with tuned voltage amplitude. How these have been mathematically developed that is described below sequentially.

6.5.2.1 Construction of search space

The imagined electro fish uses electro location dividing their search domain in a few zones. These zones have certain solution values with a definite difference between two consecutive values inside two limiting margins. Three kinds of ranges have been formulated based on difference between variable's maximum and minimum value i.e. $diff$ and different multiplication factors. The $diff$ value is shown in (6.7).

$$diff = x^{max} - x^{min} \tag{6.7}$$

The term $longrange$ is defined as the constant long search domain in (6.8).

$$longrange = \{diff \times p1_l : diff \times p2_l : diff \times p3_l\} \tag{6.8}$$

Constant terms $p1_l$, $p2_l$ and $p3_l$ are multiplied with the $diff$value for defining the lower margin, gap value and higher margin, respectively. The domain is consisted of solution points between higher range i.e. $diff \times p1_l$ and lower range i.e. $diff \times p3_l$ with interval of $diff \times p2_l$ between any two consecutive values. Similarly, $shortrange$ is also restricted between $diff \times p1_s$ and $diff \times p3_s$with a gap of $diff \times p2_s$ between two consecutive values in (6.9).

$$shortrange = \{diff \times p1_s : diff \times p2_s : diff \times p3_s\} \tag{6.9}$$

The last solution domain which is used by the conceptual electro fish is the $vshortrange$ mimicking the feeble electric pulse sensation of shark. This range is constricted within $\frac{x^{min}}{diff}$ and $\frac{x^{max}}{diff}$ with an interval gap of vs between two consecutive values shown in (6.10) as

$$vshortrange = \left\{\frac{x^{min}}{diff} : vs : \frac{x^{max}}{diff}\right\} \tag{6.10}$$

6.5.2.2 Generation of electric pulse wave analyzing $longrange$ and $slope$

The electric pulse i.e. $elec^{pulse}$ is calculated depending on projected image slope and developed $longrange$. The $slope$ of the projected image is considered as the absolute difference between the best and worst found individual value amongst population at iteration *t* in (6.11) as

$$slope = |x^t_{best} - x^t_{worst}| \tag{6.11}$$

The value of $elec^{pulse}$ is important for formation of electric organ discharge by the conceptual electro fish discussed later. However the $elec^{pulse}$ is mathematically developed as a product of two terms given in (6.12) as

$$elec^{pulse} = longrange(n) \times \frac{slope}{[(slope^{const} \times rand) + x_{best}^{t}]} \quad (6.12)$$
$$n \in S$$
$$S = randperm\{length(longrange)\}$$

The first term is chosen by taking a random value from $longrange$. Another term is considered as the ratio of $slope$ and addition of two terms. However, the distance from the targeted object by the conceptual electro fish is needed to be found out just like calculation of $elec^{pulse}$. This has been developed below.

6.5.2.3 Assessing the distance from desired food source

The obtained minimum and maximum objective function value for all the individuals amongst population is considered as $ch1$ and $ch2$ at first iteration shown in (6.13) as

$$ch1 = min\{f(x_i)\} \qquad i = 1, \ldots \ldots .., n \quad (6.13)$$
$$ch2 = max\{f(x_i)\} \qquad i = 1, \ldots \ldots .., n$$

The nearness value towards targeted prey or food object is conditionally evaluated in (6.14) as

$$Distance = \begin{Bmatrix} \dfrac{g1}{1 + g2|ch1 - ch2|} & if\ x_{best}^{t} = ch1 \\ \dfrac{g1}{1 + g2|x_{best}^{t} - ch1|} & otherwise \end{Bmatrix} \quad (6.14)$$

After calculation of $Distance$ value, the conceptual electro fish tries to find out the capacitance value of the targeted object.

6.5.2.4 Estimation of electrical capacitance from waveform distortion value

Running capacitor value i.e. cap^{run} is found by taking the standard deviation value amongst all the objective function values generated from every individual of population. The waveform distortion value is considered as the standard deviation value shown in (6.15).

$$cap^{run} = \sigma\{f(x_1), f(x_2), \ldots \ldots ., f(x_n)\} \quad (6.15)$$

Capacitor upper limit, for judging whether the object is a food particle or not, is selected as $capint$ and $caphover$ for first and next iterations respectively. This is shown in (6.16).

$$capu = \begin{Bmatrix} capint & if\ iter = 1 \\ caphover & otherwise \end{Bmatrix} \quad (6.16)$$

Conceptual electro fish reaches to the decision formation part when it gets the capacitance value.

6.5.2.5 Action of toggle switch evaluating electrical capacitance

Toggle switch acts like changeover switch for the conceptual electro fish's action. It is made '1' when running capacitor value is within the upper and lower limit and $Distance$ value is less than $setdist$. It is made '0' if the above condition is not satisfied. This is shown in (6.17).

$$toggle = \begin{cases} 1 & if \ \ capl < cap^{run} < capu \ \ and \ \ Distance < setdist \\ 0 & otherwise \end{cases} \tag{6.17}$$

The $setdist$ value works like a variable throughout the iterations guiding the $Distance$ i.e. nearness from the targeted object. This is manipulated as represented in (6.18).

$$setdist = Distance \quad if \ capl < cap^{run} < capu \ \ and \ \ Distance < setdist \tag{6.18}$$

After the decision formation conceptual electro fish gears up its electric organ for emanation of next electrical wave.

6.5.2.6 New electric wave generation

The conceptual electro fish generates new electric wave as $xnew$ considering $toggle$ switch operation in (6.19).

$$xnew = x_{best}^{t} + elec^{pulse} \times randn \qquad if \ \ toggle = 1 \tag{6.19}$$

If $toggle$ switch shows '1' then $xnew$ is generated incorporating $elec^{pulse}$ got earlier by doing $slope$ analysis. When the $toggle$ switch shows '0' then electrical wave is generated analyzing three kinds of probabilities. The three probabilities are $prob^{sel}$, $prob^{div}$and $prob^{rng}$ respectively. Probability of selection i.e. $prob^{sel}$ selects either randomization/diversification operation or localization operation. Randomization operation is taken place when the random variable $rand$ is greater than $prob^{sel}$. Apart from the above condition the conceptual electro fish does localization. This is shown in (6.20).

$$\begin{gathered} if \ \ rand > prob^{sel} \\ do{:}\, randomization/diversification \\ else \\ do{:}\, localization \\ end \end{gathered} \tag{6.20}$$

6.5.2.6.1 Operation on the basis of randomness principle

Divergence operation helps to create new electrical wave governed by the $prob^{div}$. The new electrical wave is generated randomly by the conceptual electro fish in the whole search region. This is nothing but the randomization concept described in (6.21).

$$xnew = \begin{cases} x^{min} + diff \times rand_i & if \ \ rand > prob^{div} \\ x^{min} + diff \times rand_i^j & otherwise \end{cases} \tag{6.21}$$

6.5.2.6.2 Operation concentrating on best found individual

Under the localization operation the imagined electro fish emanates electric wave around the best found individual i.e. x_{best}^{t} at iteration *t*. It does that with the influence of $prob^{rng}$. The two terms $c2$ and $c3$ are taken randomly from the set of $shortrange$ and $vshortrange$ respectively. How those terms have been chosen is shown in (6.22) and (6.23), respectively.

$$\begin{gathered} m1 = randperm\big(length(shortrange)\big) \\ h1 \in m1 \\ c2 = shortrange(h1) \end{gathered} \tag{6.22}$$

$$\begin{gathered} m2 = randperm\big(length(vshortrange)\big) \\ h2 \in m2 \\ c3 = vshortrange(h2) \end{gathered} \tag{6.23}$$

When the random variable $rand$ is greater than $prob^{rng}$ then new electrical wave $xnew$ is formulated in vicinity of $c2$ and $c3$ shown in (6.24).

$$xnew = \begin{bmatrix} \begin{Bmatrix} x_{best}^{t} - c2 + 2 \times c2 \times rand & for\ \ j = 2, \dots \dots, pop-1 \\ x_{best}^{t} + c3 & for\ \ j = 1, pop \end{Bmatrix} & if\ rand > prob^{rng} \\ \begin{Bmatrix} x_{best}^{t} + elec^{pulse} \times randn & for\ \ j = 2, \dots \dots, pop-1 \\ x_{best}^{t} + c3 & for\ \ j = 1, pop \end{Bmatrix} & otherwise \end{bmatrix} \tag{6.24}$$

It is also shown in (7.18) that if the random variable $rand$ is not greater than $prob^{rng}$ then new electrical wave is generated around the x_{best}^{t} taking $elec^{pulse}$ and $c3$ into consideration. How this newly developed Fish Electrolocation Optimization (FEO) works as a meta-heuristic algorithm is described as generalized algorithm in the next section.

6.5.3 Generalized algorithmic steps of fish electrolocation optimization

Step 1: Initialize $longrange$, $shortrange$ and $vshortrange$

Step 2: Set $capint$, $caphover$, $capl$ and $setdist$

Step 3: Select three probabilities viz. $prob^{div}$, $prob^{rng}$ and $prob^{sel}$

Step 4: Generate electrical wave randomly in the total search domain

Step 5: Analyze the objective function values to calculate $slope$, cap^{run} and $x_{best}^{t}$and x_{worst}^{t}.

Step 6: Determine the $elec^{pulse}$ value and $Distance$ or nearness value from the targeted object.

Step 7: Do $toggle$ switch judgment and evaluate $setdist$ value

Step 8: If $toggle$ switch shows '1' then do $longrange$ operation otherwise consider $shortrange$ and $vshortrange$ for doing diversification and localization operation based on three mentioned probabilities to generate electrical wave.

Step 9: Repeat steps 5 to 8 until the convergence criterion is met or maximum iteration number is reached. Otherwise stop iteration process.

6.5.4 Implementation of FEO for combinatorial DG and capacitor placement

Fish Electrolocation Optimization has been applied for combinatorial DG penetration and capacitor allocation problem. This has been performed for various single objective situations.

Single objective optimizations include minimization of total cost, loss reduction and improvement of reliability indices viz. SAIFI, SAIDI and AENS. The evolutionary technique has been applied here through a few steps involving *population formation*, *capacitance value determination and toggle switch judgment*, $longrange$ *and* $shortrange$ *selection*, and *electric organ discharge*. The generalized expressions about the stated inbuilt methods/approaches of FEO have already been shown and explained in earlier sections. But how these approaches act on any type of discrete single objective situation considering simultaneous capacitor and DG placement is important to understand.

6.5.4.1 Population formation

First of all population is formulated for capacitor allocation and DG integration problem. Two population matrices consisted of n number of column vectors have been developed considering the well known theory of real coded genetic algorithm (rcGA). One population matrix has been formed for capacitor allocation and the other one has been formulated for DG integration. Randomly choosing DG and capacitor value from the available DG and capacitor set both the population matrices have been constructed.

6.5.4.2 Capacitance value determination and toggle switch judgment

The conceptual electro fish searches food object by judging the capacitance value of the electric image. Mathematically the capacitance value has been enumerated by checking the standard deviation value of the objective function of all population individuals. Distance from the wanted prey i.e. distance from the solution is calculated. When the distance and capacitance value are less than certain values and within the range of certain values then toggle switch is in 'ON' condition. Otherwise it is made 'OFF'. The distance value is calculated according to equations (6.13) and (6.14). The conceptual electro fish after having the values of electrical capacitance and distance, it does electric organ discharge with tuned voltage amplitude. Before doing that it does $longrange$ and $shortrange$ selection.

6.5.4.3 $longrange$ and $shortrange$ selection

$longrange$ is a set of variable values in the upper range. $shortrange$ is another set of variable values in the lower range. In the case of capacitor and DG placement problem half of the available capacitor and DG value in the lower range is considered as the $shortrange$. The other half of available capacitor and DG value is considered to be in the $longrange$. However, this $longrange$ and $shortrange$ idea is very primitive i.e. inborn in the conceptual electro fish. Having that idea, it toggles between the $longrange$ and $shortrange$ and sometimes mixes both the ranges. It does this phenomenon with the discharge of electric pulse from its tail electric organ. How this has been mathematically done is discussed in the next section.

6.5.4.4 Electric organ discharge

The imagined electric fish generates new electric wave considering the toggle switch status. The electric fish generates electric wave near about the value of best found individual through iterations. Here for capacitor allocation and DG penetration problem, these are two column vectors i.e. the best found individual value at certain iteration amongst the population matrix. This is taken from equation (6.19). Here $toggle$ = 1 means that the toggle switch is in 'ON' condition. The expression for $elec^{pulse}$ is developed from (6.12). In case of capacitor allocation and DG penetration, the $longrange$ is formulated for individual capacitor placement and DG penetration cases. When the toggle switch is in 'OFF' status, two probabilities are considered for new electric wave creation. The two probabilities are probability of selection i.e. $Prob^{sel}$ and probability of range i.e. $Prob^{rng}$. The probability of selection does its action according to equation (6.20). The diversification or randomization is done selecting capacitor and DG value from the capacitor and DG set respectively. The localization work is done according to equation (6.24). The $shortrange$ is formulated by taking the lower range of capacitor and DG value from the capacitor and DG value set respectively.

Convergence to the optimal solution for considered types of single objective situations depends on appropriate evolvement of population. This has been performed here via the above discussed inherent approaches of FEO. Although the optimal solution finding mechanism of FEO for single objective DG and capacitor placement problem is understandable from the above discussions still the algorithmic steps will be more helpful for better understanding. This has been illustrated in the next section.

6.5.4.5 Algorithmic steps of FEO for single objective DG placement and capacitor allocation problem

The algorithmic steps of FEO related to any single objective situation stated earlier have been denoted here for simultaneous capacitor allocation and DG integration.

Step 1: Initialize $longrange$ and $shortrange$ for DG integration and capacitor allocation. Set the value of probability of selection, probability of divergence and probability of range.

Step 2: Formulate the electrolocation population for DG and capacitor placement. Set maximum iteration number and electrical capacitance range for prey (solution) detection.

Step 3: Evaluate total cost value, real power loss and distribution system reliability indices for every individual of population maintaining the constraints as shown in 'objective function formulation' section.

Step 4: Find the best capacitor and DG value for that population. Also, find out the worst DG and capacitor value for that population.

Step 5: Calculate the electrical capacitance value from the standard deviation of the objective function values for that population.

Step 6: Enumerate the electrical image slope projected on the conceptual electro fish. Calculate the distance value from the $longrange$ and $shortrange$ and also from the electrical image slope value.

Step 7: Checking the electrical capacitance value toggle switch judgment is done i.e. when it will act as elephant nose fish for active electro location and also as shark for passive electro location.

Step 8: Formulate new population by utilizing probability of selection, probability of divergence and probability of range.

Step 9: Check whether the iteration count has reached the maximum iteration number or not. If it reaches the maximum iteration number, then go to step 10 otherwise go to step 3.

Step 10: Print the best individual's total cost, real power loss, distribution system reliability indices and the DG and capacitor's values and placing.

Fish electrolocation optimization technique has also been implemented for crucial multi-objective situation considering multiple conflicting objectives in this work. This draws special attention of reader and has been described in the next section.

6.5.5 Application of FEO for multi-objective capacitor allocation and DG integration problem

Multi-objective capacitor allocation and DG integration has been performed here implementing FEO algorithm for various cases discussed in the next chapter. Multi-objective optimization approach of FEO is more or less alike the single objective optimization procedure of it. Few modifications have been incorporated in this multi-objective FEO algorithm. Performance function has been enumerated inspired by weighted sum method stated in Chapter 4. In addition, a memory has been developed to store the pareto optimal solutions through iterations. Other inbuilt steps of multi-objective FEO apart from these above stated modifications have already been discussed in the earlier sections for single objective cases. In this regard, a pictorial representation of this multi-objective FEO in the form of a flow chart will be quite helpful to understand the technique. This has been executed here in a flow chart form for a multi-objective situation considering energy loss, total cost and distribution system reliability indices viz. SAIFI, SAIDI and AENS.

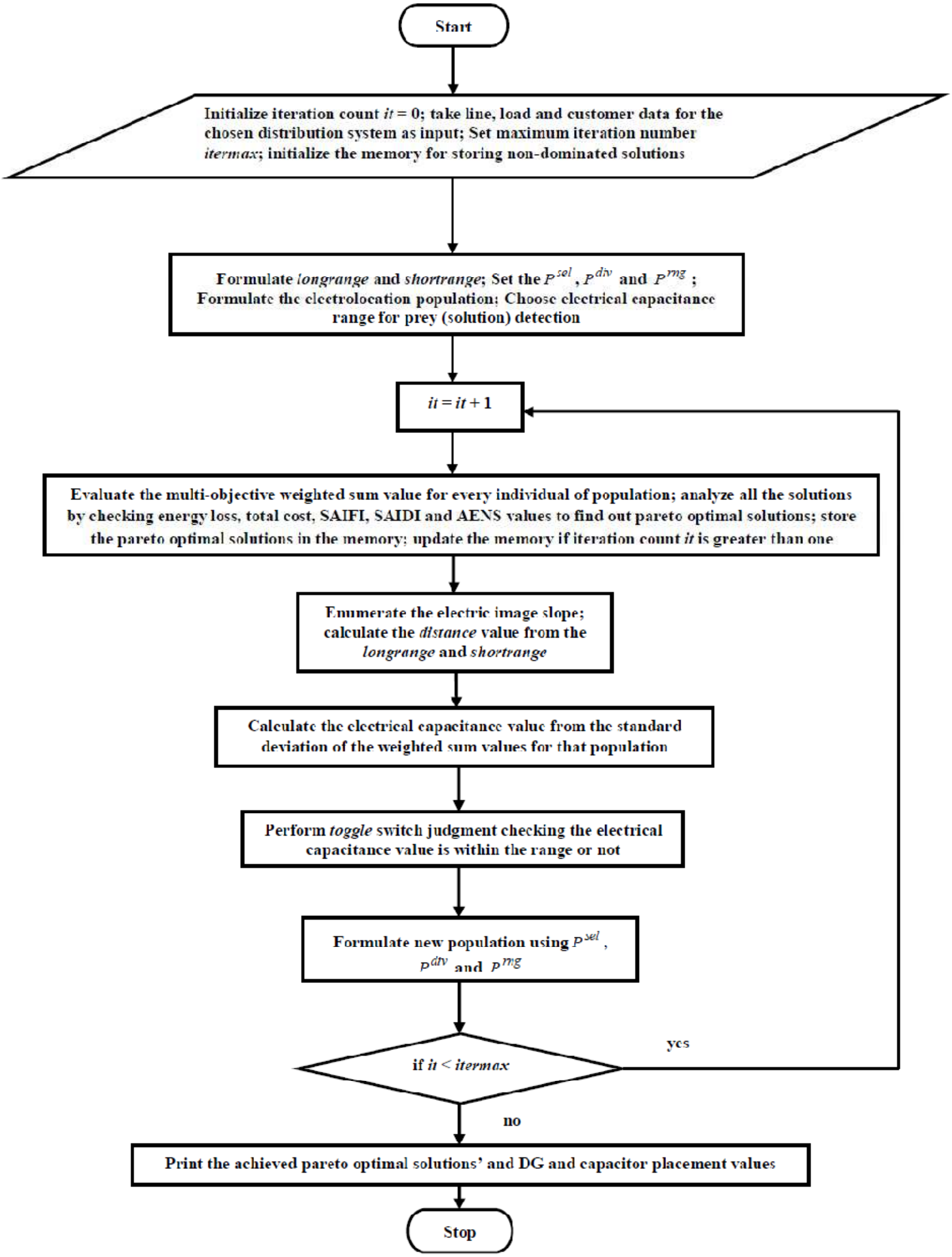

Figure 6.11: Flowchart of FEO algorithm implemented for multi-objective DG penetration and capacitor allocation problem

The Fish Electrolocation Optimization (FEO) has been implemented on 34 and 69 bus microgrid type radial distribution system for simultaneous capacitor allocation and DG penetration. Appropriate planning has been developed considering single and multi objective situations for placing DG and capacitor at suitable bus locations. This has helped to provide economic power with appropriate reliability. Total cost, loss and distribution system reliability indices have been enumerated for both single and multi objective cases. The simulation results achieved after applying FEO has been compared with rcGA, PSO and MCA techniques as discussed earlier. The findings after performing all the considered simulation based studies are promising and encouraging. However, proper analysis is required for the simulated data before they are applied in the real world scenario.

Chapter 7

Simulation results and discussion

Single and multi objective optimizations have been performed considering simultaneous DG integration and capacitor placement in thirty four and sixty nine bus microgrid type radial distribution systems. Again single objective optimization employing only capacitor at suitable load buses has been exercised in sixty nine bus radial distribution system resembling microgrid. The codes of these simulation based studies have been developed on technical software MATLAB^{TM} [239] using personal computer. The configuration of personal computer is Intel Core i5, 3 GHz processor with 4GB RAM. Reliability indices have been studied for two reinforcement schemes. One is applying only disconnects between buses. Another is applying disconnects with fuse-gear protection. Comparative studies have been performed amongst fish electrolocation optimization (FEO), particle swarm optimization (PSO), real coded genetic algorithm (rcGA) and modified cultural algorithm (MCA). This said studies have been performed choosing population number as 30 for all the optimization tools. The population number has been selected after several trial runs considering the best outcome [240-241]. The termination condition embedded in all the considered algorithms has been constrained as 30,000 objective function evaluations for 34 bus and 5,000 objective function evaluations for 69 bus, respectively [240-241]. The termination condition embedded in the considered algorithms has also been fixed after several trial runs. Simulation studies considering DG integration and capacitor allocation have been performed selecting DG penetration levels up to 10%, 15%, 20% and 50% of total active power load of the microgrid type distribution system at hand. These selected DG penetration levels have been considered on the basis of different scenarios and futuristic situation. Distributed generator source has been considered as bio mass power plant in both 34 bus and 69 bus microgrid type radial distribution system as stated earlier in Chapter 4. Solar photovoltaic plant has also been considered as DG source in 69 bus microgrid type radial distribution system mentioned in Chapter 4. Both are considered as DG sources because of their relative availability in this part of the globe. This is the reason behind selection of bio mass and solar photovoltaic power plants as DG sources here.

7.1 Cost based reliability in 34 bus microgrid type radial distribution system

Reliability studies have been performed considering cost in thirty four bus microgrid type radial distribution system. Single line diagram of this distribution system has been shown in Figure A1 in Appendix. All the line and bus data for the 34 bus microgrid type radial distribution system are taken from elsewhere [242]. These bus and line data have been shown in Table A1 and Table A2 in Appendix. The minimum failure rate of electric line has been considered here as 85% of the original failure rate [77]. Maximum and minimum voltage limit for all buses have been considered as 1.1 p.u and 0.9 p.u respectively [77, 243]. Distributed generator unit size has been selected as 100 kW and 200 kW considering the load pattern of the 34 bus microgrid type radial distribution system [244]. Capacitor values and cost have been selected from elsewhere [242]. This is shown in Table A3 in Appendix section. The dollar constant K_P value has been chosen as US$ 525.6/kW as annual basis [245]. The DG and capacitor placement project has been considered for 25 years. The distributed generation cost is actually the biomass power plant capital plus operation and maintenance cost. That K_i value has been considered as US$ 418.84/kW [244]. All the enumeration regarding failure rate and outage time concerning to the reinforcement scheme has been developed from elsewhere [119]. The failure rate of every line has been calculated linearly by fixing the highest and lowest impedance value as 0.5/yr and 0.1/yr, respectively [77]. The number of consumer has been considered as 1000 for maximum load in the considered microgrid type radial distribution system [119]. The number of customer for other load buses apart from zero load bus has been calculated considering the load value**.** If the value of load is zero then the number of customer is considered as zero. The repair times for main feeder and lateral has been considered as 4 hrs and 2 hrs, respectively [119]. The switching time is selected as 0.5 hr [119]. The value of economical damage for 4 hrs power interruption is taken to be considered as US$ 15.4752/kW [119]. The same financial damage value for 2 hrs and 0.5 hr power interruption are chosen as US$7.6317/kW and US$1.8600/kW respectively [119]. The real power loss for the original configuration i.e. without DG and capacitor placement has been obtained as 221.50 kW. On the other hand, the distribution system reliability indices viz. SAIFI, SAIDI, CAIDI, ASUI, ASAI and AENS have been found as 9.5032 interruptions/customer yr, 11.3358 hours/customer yr, 1.1928 hours/customer interruption, 0.001294, 0.998705 and 4.0372 kWh/customer yr respectively without any DG and capacitor placement considering only disconnects between buses. Again the distribution system reliability indices viz. SAIFI, SAIDI, CAIDI, ASUI, ASAI and AENS have been found as 5.2400 interruptions/customer yr, 9.1871 hours/customer yr, 1.7532 hours/customer interruption, 0.001048, 0.998951 and 2.0749 kWh/customer yr respectively without any DG and capacitor placement considering lateral protection with isolator. The more common distribution system reliability indices viz. SAIFI, SAIDI and AENS have been considered for reliability improvement purpose apart from total cost minimization and real power loss reduction. Here total cost minimization has been studied for both reinforcement schemes. But it has been discussed above that the considered distribution system reliability indices viz. SAIFI, SAIDI and AENS have been found more improved choosing reinforcement scheme as ‘disconnects with lateral protection’ in comparison to ‘applying only disconnects’. That’s why reliability index SAIFI, SAIDI and AENS improvement have been assessed considering the reinforcement scheme ‘disconnects with lateral protection’ [119].

7.1.1 Total cost minimization after capacitor allocation and DG integration

Simultaneous capacitor allocation and DG integration have been performed to minimize the total cost from its initial value i.e. without capacitor and DG placement. The minimization of total cost has been conceived for three types of DG penetration level. These considered DG penetration levels are up to 10%, 15% and 20% of total active power load. These penetration levels have been considered for simulation study purpose here as DG penetration levels in different scenarios have been found more or less near to those levels. The total cost is comprised of power interruption cost, cost due to loss, DG cost and capacitor installation cost. The analysis of simulation results for the earlier stated two reinforcement schemes has been discussed in the following sections.

7.1.1.1 Applying disconnects between buses with fuse gear protection

Reduction of total cost has been achieved by simultaneous DG integration and capacitor placement considering the reinforcement scheme i.e. applying disconnects between buses with fuse gear protection. With the DG penetration level at a maximum of 10%, it can be observed from Table 7.1 that total cost value has been found reduced from US$ 6997480.91 to US$ 5921622.20 with the implementation of rcGA. The said reduction in total cost value has been caused due to simultaneous DG and capacitor placement at bus position 10 and 20 for DG and 3, 4, 5, 24, 29, 32 and 33 for capacitor respectively. Distributed generation and capacitor values selected for those bus locations are 200 kW and 200 kW for DG and 150 kVAR, 300 kVAR, 150 kVAR, 1050 kVAR, 300 kVAR, 300 kVAR and 150 kVAR, for capacitor respectively. It has been noticed from Table 7.1 that total cost value has been found reduced from US$ 6997480.91 to US$ 5887841.61 with the implementation of PSO. Distributed generation integration has been performed at bus position 5, 12 and 22 with DG value of 100 kW, 100 kW and 200 kW, respectively. Shunt capacitor has been placed at bus number 6, 10, 18 and 24. Capacitor values obtained by PSO at those selected locations are 450 kVAR, 600 kVAR, 600 kVAR and 900 kVAR as shown in Table 7.1. The total cost value has been observed to be reduced from US$ 6997480.91 to US$ 5851526.37 by the application of FEO shown in Table 7.1. The stated reduction in total cost value has been occurred due to the DG placement at bus location 25 and 28 with DG value of 200 kW in these two locations. Shunt capacitor allocation has also been performed at bus number 2, 12, 18 and 26 with installation of 600 kVAR, 600 kVAR, 1200 kVAR, 600 kVAR, respectively. The total cost value has been observed to be reduced from US$ 6997480.91 to US$ 5863962.14 by the application of MCA. Distributed generation integration has been performed at bus number 21 and 27 with DG value of 200 kW at these two bus locations. Shunt capacitor allocation has also been executed at bus position 8, 20 and 32 with installed capacitor value of 900 kVAR, 1350 kVAR and 150 kVAR, respectively. It can be said from the above discussion that evolutionary technique FEO has found the least total cost value amongst all the chosen meta-heuristic algorithms. The second position is held by the soft computing technique MCA in finding the better total cost value. The study related to the next DG penetration level i.e. up to 15% of the total active power load has been described in the next paragraph.

Table 7.1: Capacitor allocation and DG integration for total cost minimization considering disconnects with lateral protection and up to 10% DG penetration in 34 bus microgrid type radial distribution system

Methods	Total Cost (US$)	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	5921622.20	200, 200	10, 20	150, 300, 150,1050 300, 300, 150	3, 4, 5, 24, 29, 32, 33
PSO	5887841.61	100, 100, 200	5, 12, 22	450, 600, 600, 900	6, 10, 18, 24
FEO	5851526.37	200, 200	25, 28	600, 600, 1200, 600	2, 12, 18, 26
MCA	5863962.14	200, 200	21, 27	900, 1350, 150	8, 20, 32
Without capacitor and DG placement	6997480.91	-	-	-	-

Like the above discussed paragraph, the total cost value has been observed to be reduced from its initial value by the suitable placement of DG and capacitor at the load buses shown in Table 7.2. This time the maximum DG penetration level has been increased by 5% to observe reduction in total cost value. It can be noticed from Table 7.2 that total cost value has been found reduced from US$ 6997480.91 to US$ 5982423.42 with the implementation of rcGA. Distributed generation integration has been exercised at bus positions 14, 24 and 34 with DG value of 200 kW in every selected location. Capacitors are also placed at bus number 14, 21 and 27 with installed capacitor value of 150 kVAR, 1050 kVAR and 1050 kVAR, respectively. The total cost value has been observed to be reduced from US$ 6997480.91 to US$ 6054013.09 by the utilization of PSO as observable in Table 7.2. Load bus number 2 and 23 have been chosen by PSO for allocating 200 kW of DG at every selected location. Shunt capacitors have been placed at bus positions 10, 17 and 21 with installed capacitor value of 600 kVAR, 900 kVAR and 900 kVAR, respectively shown in Table 7.2. Finally it has been observed from Table 7.2 that total cost value has been found reduced from US$ 6997480.91 to US$ 5875178.74 by the utilization of FEO. Distributed generator incorporation has been performed at bus position 9, 14, 23 and 29. The DG value has been chosen as 200 kW, 100 kW, 200 kW and 100 kW, respectively at those selected locations. Shunt capacitor allocation has been executed at bus number 14, 18 and 21 with installed capacitor value of 150 kVAR, 450 kVAR and 1500 kVAR, respectively available in Table 7.2. It has been noticed from Table 7.2 that total cost value has been found reduced from US$ 6997480.91 to US$ 5756486.90 with the implementation of MCA. This time the total cost value achieved by MCA shown in Table 7.2 is lesser in magnitude from the total cost value observed in Table 7.1 by MCA. This further improvement has been caused due to the DG penetration at bus number 24, 26 and 30 with 200 kW of DG value at every selected location. Capacitor placement has also been performed at bus number 18 and 25 with installed capacitor value of 1350 kVAR and 750 kVAR, respectively observable in Table 7.2. It can be said from the above discussion that the total cost value found by MCA is the least amongst all the obtained total cost values by other algorithms. However, further 5% increment in maximum DG penetration level has been exercised to observe the decrement in total cost value shown in Table 7.3.

Table 7.2: DG integration and capacitor placement for total cost minimization considering disconnects supported by fuse gear and a maximum of 15% DG penetration in 34 bus microgrid type radial distribution system

Methods	Total Cost (US$)	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	5982423.42	200, 200, 200	14, 24, 34	150, 1050, 1050	14, 21, 27
PSO	6054013.09	200, 200	2, 23	600, 900, 900	10, 17, 21
FEO	5875178.74	200,100, 200, 100	9, 14, 23, 29	150, 450, 1500	14, 18, 21
MCA	5756486.90	200, 200, 200	24, 26, 30	1350, 750	18, 25
Without capacitor and DG placement	6997480.91	-	-	-	-

It can be noticed from Table 7.3 that total cost value has been found reduced from US$ 6997480.91 to US$ 5681893.92 with the implementation of rcGA. Distributed generator integrations have been performed at bus position 17, 22, 24, 27 and 34. The DG values have been chosen as 200 kW, 200 kW, 200 kW, 100 kW and 200 kW, respectively at those selected locations. Shunt capacitor allocations have been executed at bus number 9 and 25 with installed capacitor values of 1650 kVAR and 750 kVAR, respectively. It can be noticed from Table 7.3 that total cost value has been found reduced from US$ 6997480.91 to US$ 5872604.98 with the implementation of PSO. This time the total cost value achieved by PSO observable in Table 7.3 is lesser in magnitude from the total cost value obtained by PSO shown in Table 7.2. This further reduction has been caused due to the DG integrations at bus number 5, 8, 9, 15 and 33 with 100 kW, 100 kW, 200 kW, 200 kW and 200 kW of DG value at those selected locations. Capacitor placements have also been performed at bus number 6, 9, 18 and 24 with installed capacitor values of 900 kVAR, 450 kVAR, 300 kVAR and 900 kVAR, respectively. Finally it has been observed from Table 7.3 that total cost value has been found reduced from US$ 6997480.91 to US$ 5499326.40 by the utilization of FEO. The total cost value obtained by FEO has been further reduced as shown in Table 7.3 from the total cost value found by FEO observable in Table 7.2 due to the 5% increment in maximum DG penetration level. Distributed generation integrations have been exercised at bus positions 20, 21, 24, 25 and 31 with DG values of 200 kW, 200 kW, 200 kW, 200 kW and 100 kW at those selected locations. Capacitors are also placed at bus number 4, 7, 20, 27 and 31 with installed capacitor values of 450 kVAR, 150 kVAR, 1200 kVAR, 300 kVAR and 600 kVAR, respectively. The total cost value has been observed to be reduced from US$ 6997480.91 to US$ 5628769.11 by the utilization of MCA shown in Table 7.3. In this case the total cost value found by MCA available in Table 7.3 has been found reduced from the total cost values achieved by MCA as observable in Table 7.1 and Table 7.2. Load bus position 6, 15, 18, 24, 27 and 29 have been chosen by MCA for allocating 100 kW, 100 kW, 200 kW, 200 kW, 200 kW and 100 kW of DG. Shunt capacitors have been placed at bus positions 5, 8, 15 and 24 with installed capacitor values of 2100 kVAR, 300 kVAR, 150 kVAR and 750 kVAR, respectively shown in Table 7.3.

Table 7.3: Capacitor placement and DG allocation for total cost minimization considering disconnects with lateral protection at a maximum of 20% DG penetration in 34 bus microgrid type radial distribution system

Methods	Total Cost (US$)	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	5681893.92	200, 200,200, 100, 200	17, 22, 24, 27, 34	1650, 750	9, 25
PSO	5872604.98	100, 100, 200, 200, 200	5, 8, 9, 15, 33	900, 450, 300, 900	6, 9, 18, 24
FEO	5499326.40	200, 200, 200, 200, 100	20, 21, 24, 25, 31	450, 150, 1200, 300, 600	4, 7, 20, 27, 31
MCA	5628769.11	100, 100, 200, 200, 200, 100	6, 15, 18, 24, 27, 29	2100, 300, 150, 750	5, 8, 15, 24
Without capacitor and DG placement	6997480.91	-	-	-	-

It can be said from the above discussion that the total cost value found by FEO is the least amongst all the total cost values obtained by other algorithms shown in Table 7.3. The DG integration and capacitor placement data selected by FEO algorithm for obtaining the least total cost value at US$ 5499326.40 has been again utilized to study the current magnitude variation as shown in Table 7.4. Both DG integration and capacitor allocation reduces resitive line loss. This helps to reduce the failure rate of electric line or cable which in turn enhances reliability. The total cost has a part which is power interruption cost and this is connected to failure rate. Failure rate gets modified due to the change in current flow. It has been observed from Table 7.4 that current magnitudes in branches 19-20, 20-21 and 21-22 have been found reduced from 0.1979 p.u to 0.0982 p.u, from 0.1721 p.u to 0.1055 p.u and 0.1462 p.u to 0.0962 p.u after DG integration of 200 kW at bus location 20 and 21. These reductions in current magnitude help to decrease line loss and improves failure rate as resitive line loss is proportional to the square of current magnitude. Again it has been observed from Table 7.4 that current magnitudes in branches 23-24, 24-25 and 25-26 have been found reduced from 0.0942 p.u to 0.0453 p.u, from 0.0680 p.u to 0.0383 p.u and from 0.0417 p.u to 0.0354 p.u, respectively after DG value of 200 kW has been placed at bus number 24 and 25. It can be noticed from Table 7.4 that current magnitude in the branch 26-27 has been found increased from 0.0154 p.u to 0.0239 p.u. This is not a favorable development as this will increase the failure rate of that particular branch. This is shown in bold in Table 7.4. However, this current magnitude represents the absolute value of current. This has an active and a reactive part. It can be observed from Table 7.3 that capacitor value of 300 kVAR has been placed at bus position 27. This augment of current magnitude in branch 26-27 is due that capacitor placement. Though this increment in current flow increases failure rate of that particular branch but system line loss decreases due to the effect of that capacitor placement. It has been observed from Table 7.4 that system line loss has been found reduced from 221.5 kW to 92.07 kW. This in turn reduces the failure rates of other lines. On the other hand, it has been observed from Table 7.4 that current magnitude has been found reduced in branch 31-32 from 0.0192 p.u to 0.0189 p.u where DG integration of 100 kW has been performed at bus number 31. The current magnitude in branches 1-2, 7-28 and 11-12 have also been found reduced from 0.5193 p.u to 0.3524 p.u, from 0.0253 p.u to 0.0249 p.u and from 0.0151 p.u to 0.0149 p.u due to the combined effect of capacitor allocations and DG integrations by FEO technique as observable in Table 7.3 and Table 7.4.

Table 7.4: Study of current magnitude for total cost minimization by applying FEO technique in 34 bus microgrid type radial distribution system considering DG penetration up to 20%

Branch	Current magnitude before DG and capacitor placement (p.u)	Current magnitude after DG and capacitor placement (p.u)	Loss without DG and capacitor placement (kW)	Loss after DG and capacitor placement (kW)	DG placement chosen by FEO technique	DG value (kW) selected by FEO algorithm
19-20	0.1979	0.0982	221.5	92.07	20, 21, 24, 25, 31	200, 200, 200, 200, 100
20-21	0.1721	0.1055				
21-22	0.1462	0.0960				
23-24	0.0942	0.0453				
24-25	0.0680	0.0383				
25-26	0.0417	0.0354				
26-27	**0.0154**	**0.0239**				
31-32	0.0192	0.0189				
1-2	0.5193	0.3524				
7-28	0.0253	0.0249				
11-12	0.0151	0.0149				

As discussed in this section total cost value has been found reduced from its initial value due to suitable capacitor allocation and DG integration. The techniques MCA and FEO have come out as the effective algorithms in this comparative study. Nevertheless there is always a chance of further decrement in total cost value with the increase in DG penetration level. This has been studied later for a maximum of 50% DG penetration level considering futuristic plan. On the other hand, it is evident that the other considered parameters apart from total cost will be modified due to the capacitor allocations and DG integrations considered in Table 7.1, Table 7.2 and Table 7.3. This has been pictorially depicted and briefly illustrated in the next section.

7.1.1.1.1 Reliability indices and real power loss modification

Simultaneous capacitor allocation and DG integration have been performed to minimize the total cost. This capacitor and DG placement has also changed other reliability and loss parameters from its initial value.

It has been shown in Figure 7.1 that the customer-oriented distribution system reliability index SAIFI has been found reduced from its initial value by the utilization of four algorithms. It has been observed from Figure 7.1 that the SAIFI value is reduced with the increase in maximum DG penetration level with one exception in the case of PSO. The SAIFI value obtained by PSO has been found increased with the increase in maximum DG penetration level from 10% to 15% in Figure 7.1. This may be due to the reason that the primary aim is to minimize the total cost not the SAIFI value. This is a single objective optimization. So, with the increment in DG penetration level the SAIFI value may be increased. The other reason can be the entrapment of PSO algorithm in local minima. However, it can be noticed in Figure 7.1 that the least SAIFI value has been achieved by MCA technique considering DG penetration up to 20%. On the other hand, FEO algorithm has found the second best SAIFI value available in Figure 7.1 at a maximum of 20% DG penetration.

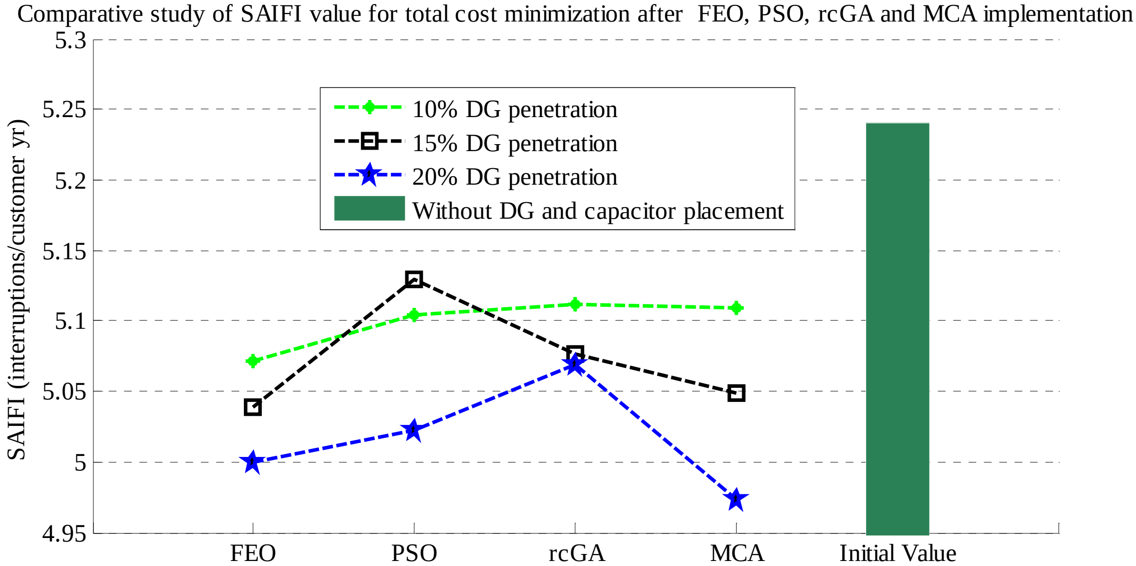

Figure 7.1: Change in SAIFI value due to capacitor allocation and DG integration for total cost minimization considering disconnects with lateral protection in 34 bus microgrid type radial distribution system

Another customer-oriented distribution system reliability index SAIDI has been observed to be improved from its initial value as shown in Figure 7.2. The reason behind the reduction in SAIDI value is capacitor allocation and DG integration for total cost minimization. The SAIDI value has been found increased with the increment of maximum DG penetration level from 10% to 15% by the application of PSO technique which can be observed in Figure 7.2. But the SAIDI value has been observed to be reduced from other two values concerning to DG penetrations up to 10% and 15% by the usage of PSO algorithm at a maximum of 20% DG integration. The primary cause behind this variance is that the objective is to minimize total cost not to reduce the

SAIDI value. Entrapment of PSO algorithm into the local minima is another reason concerning to this issue. The SAIDI value has been found improved with the increase in maximum DG penetration level from 10% to 15% by the application of rcGA technique. But the SAIDI value achieved by rcGA has been increased instead of reduction with another 5% increase in maximum DG penetration level. The reason behind this variance is similar to the case of PSO algorithm discussed above. On the other hand, the change in SAIDI value by the usage of FEO technique is similar to the modification in SAIDI value with the implementation of rcGA technique. Interestingly, the SAIDI value has been observed to be improved with the increase in maximum DG penetration level from 10% to 15% and from 15% to 20% in the case of MCA technique. It has also been observed that the least SAIDI value has been found by MCA method at a maximum of 20% DG penetration shown in Figure 7.2.

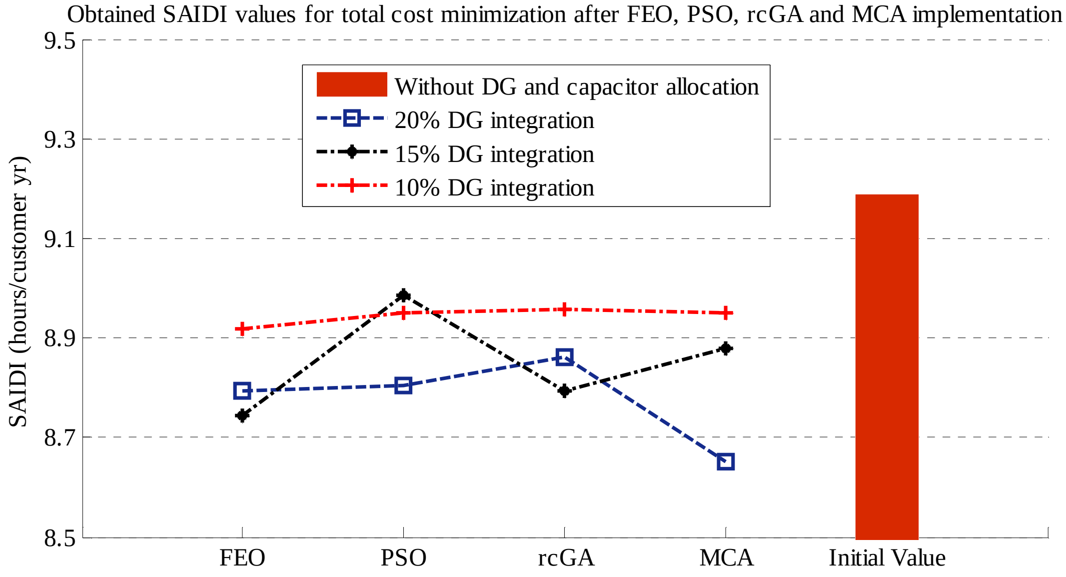

Figure 7.2: Modification in SAIDI value due to DG and capacitor placements for total cost minimization considering disconnects supported by fuse gear in 34 bus microgrid type radial distribution system

Customer average interruption duration index (CAIDI) is also a customer-oriented distribution system reliability index. This index is the ratio of previously discussed SAIDI and SAIFI. The CAIDI value has been observed to be changed from its initial value as shown in Figure 7.3. Unlike the changes of SAIFI and SAIDI, CAIDI value has been observed to be increased from its initial value i.e. without capacitor and DG connectivity by the implementations of FEO and MCA. The soft computing techniques rcGA and PSO have found reducing CAIDI values from its initial value as observable in Figure 7.3. On the other hand, the pattern of change in CAIDI value is also random for all the considered evolutionary techniques which can be observed in Figure 7.3. The reason behind this variance is that the primary objective is to reduce the total cost. Total cost has a major part which is power interruption cost or reliability worth. Power interruption cost is connected with the failure rate of electric line. So, there is always a chance of improvement in SAIFI and SAIDI value. But CAIDI is the ratio between SAIDI and SAIFI as stated in Chapter 3. That’s why the change in CAIDI value lacks any specific pattern shown in Figure 7.3.

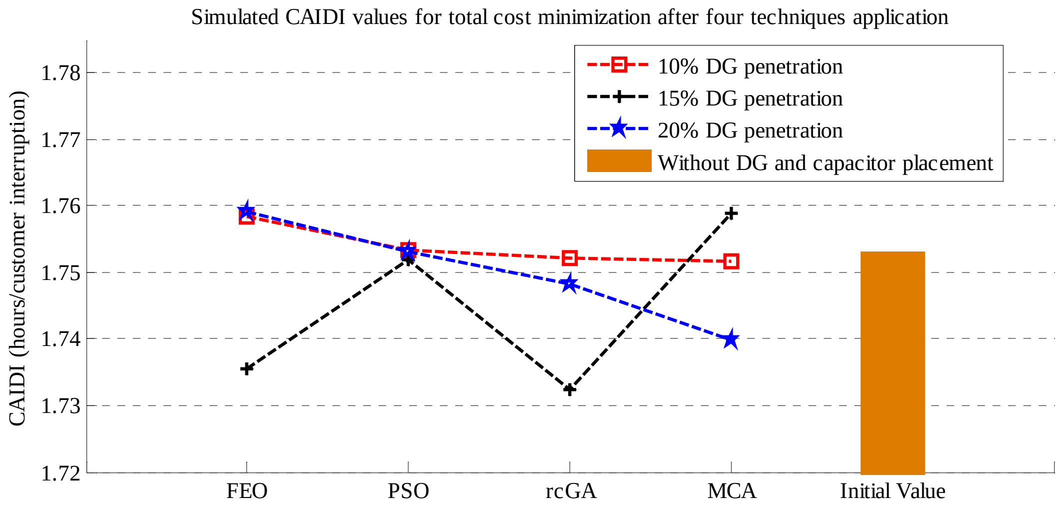

Figure 7.3: Alteration in CAIDI value due to capacitor and DG allocations for total cost minimization considering disconnects with lateral protection in 34 bus microgrid type radial distribution system

Average service unavailability index (ASUI) value has been observed to be changed from its initial value due to capacitor allocation and DG integration for total cost minimization as shown in Figure 7.4. It can be noticed from Figure 7.4 that ASUI value has been found reduced from its initial value at different DG penetration levels by the application of four techniques. The ASUI value has been found increased with the increment in maximum DG penetration level from 10% to 15% by the usage of PSO algorithm in Figure 7.4. The ASUI value achieved by PSO technique has been observed to be decreased at a maximum of 20% DG penetration from earlier values considering DG penetrations up to 10% and 15%. On the other hand, ASUI value has been found reduced while implementing FEO, rcGA and MCA algorithms with the increment of maximum DG penetration level from 10% to 15% as observable in Figure 7.4. The least ASUI value has been obtained by MCA technique amongst all the chosen algorithms at a maximum of 20% DG penetration shown in Figure 7.4.

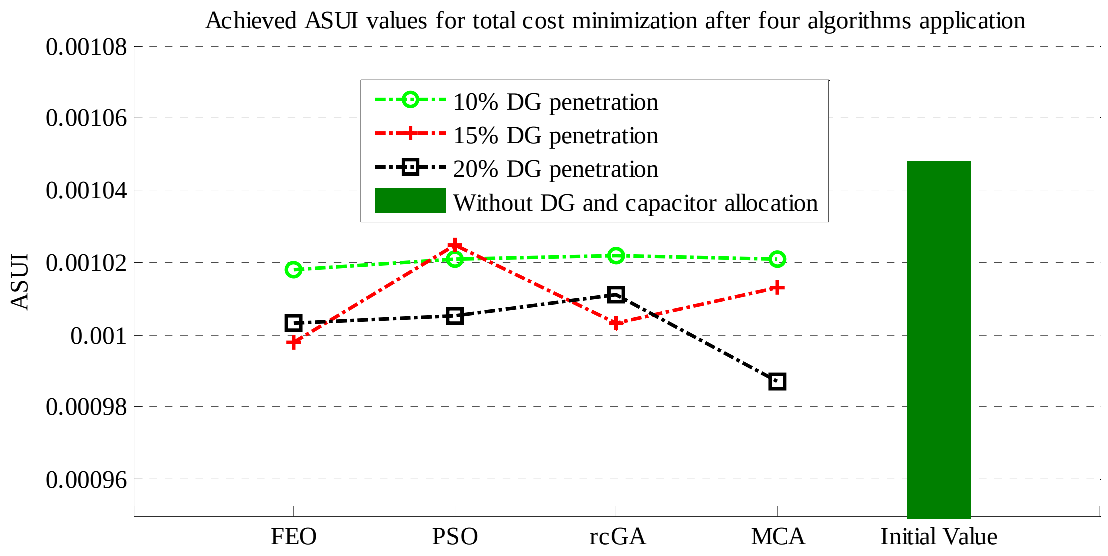

Figure 7.4: Modification in ASUI value due to DG and capacitor placements for total cost minimization considering disconnects with fuse gear protection in 34 bus microgrid type radial distribution system

Average service availability index (ASAI) has been observed to be increased from its initial value due to capacitor allocation and DG integration for total cost minimization as shown in Figure 7.5. The pictorial diagram of Figure 7.5 is the reverse reflection of the previous discussed Figure 7.4. This is due to the reason that ASAI value can be obtained by performing subtraction of ASUI value from one [119].

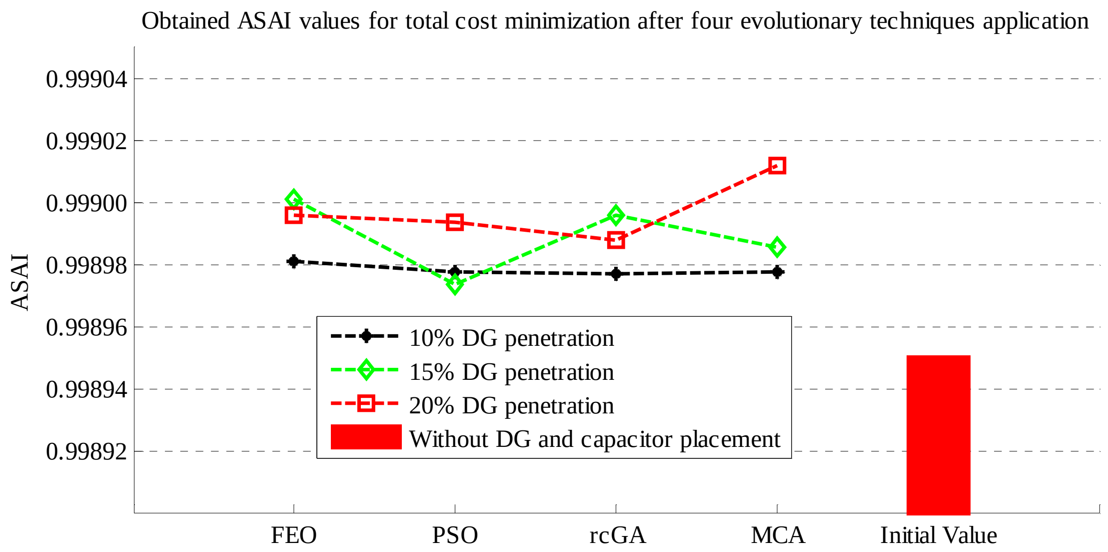

Figure 7.5: Change in ASAI value due to capacitor and DG allocations for total cost minimization considering disconnects with lateral protection in 34 bus microgrid type radial distribution system

The load oriented distribution system reliability index AENS has been observed to be reduced from its initial value after performing capacitor allocation and DG integration for total cost minimization as observable in Figure 7.6. It has been observed from Figure 7.6 that AENS value has been reduced implementing rcGA, FEO and MCA with the increment of maximum DG penetration level from 10% to 15%. On the other hand, AENS value has been found increased applying PSO with the increase of maximum DG penetration level from 10% to 15%. The AENS value has been observed to be increased utilizing FEO and rcGA techniques with the increment of maximum DG penetration level from 15% to 20%. It can be noticed from Figure 7.6 that AENS value has been found reduced implementing PSO and MCA with the increase of maximum DG penetration level from 15% to 20%. The least AENS value has been achieved by MCA technique shown in Figure 7.6.

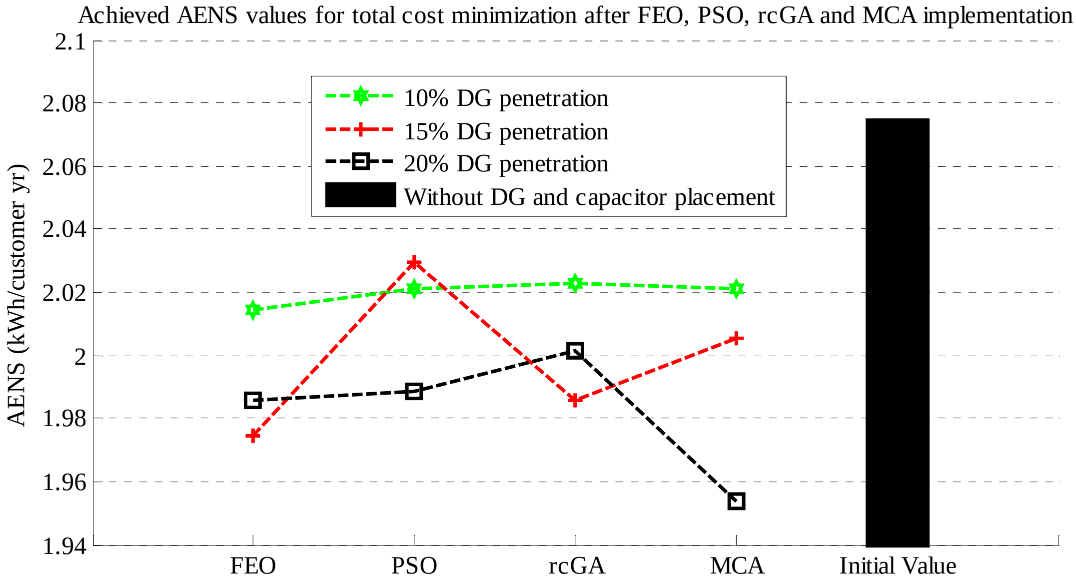

Figure 7.6: Reduction in AENS value due to DG and capacitor allocations for total cost minimization considering disconnects with fuse gear protection in 34 bus microgrid type radial distribution system

It is well known that cost is an integral part of reliability in deregulated scenario. The cost based reliability index (CBRI) has been observed to be increased from its initial value due to DG integration and capacitor placement for total cost minimization which can be observed in Figure 7.7. It can be noticed from Figure 7.7 that CBRI value has been found improved applying FEO, rcGA and MCA techniques with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. The CBRI value has been observed to be reduced after implementing PSO technique with the increment of maximum DG penetration level from 10% to 15%. On the other hand, it has been observed from Figure 7.7 that CBRI value has been found improved after utilizing PSO algorithm with the increase of maximum DG penetration level from 15% to 20%. The CBRI values found by MCA and FEO techniques are nearly equal with each other at a maximum of 20% DG penetration shown in Figure 7.7.

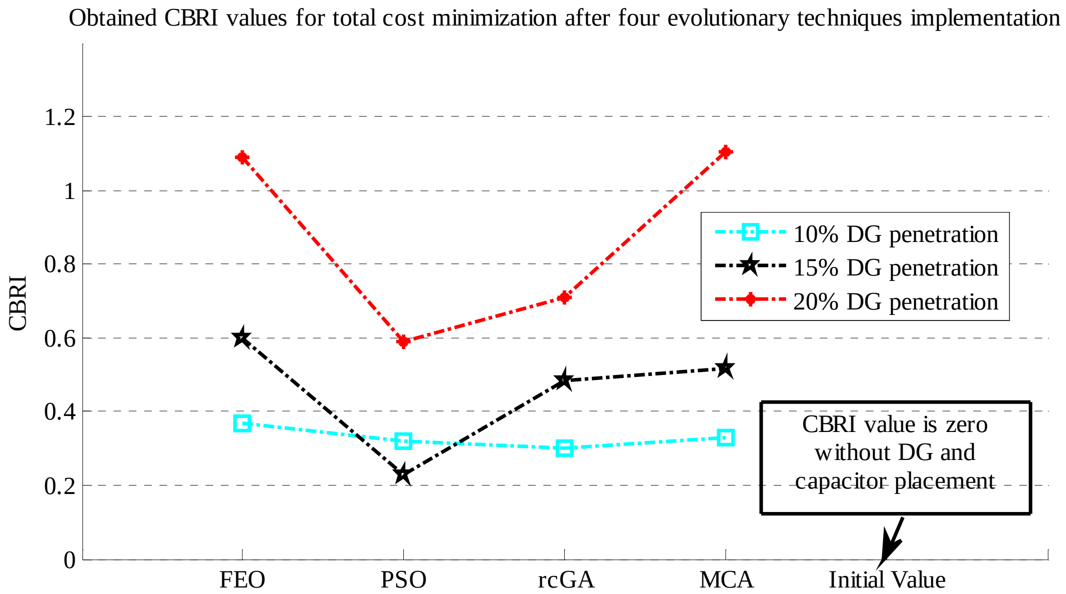

Figure 7.7: Improvement in CBRI value due to capacitor allocation and DG integration for total cost minimization considering disconnects supported by fuse gear in 34 bus microgrid type radial distribution system

Real power loss has been observed to be reduced from its initial value after performing capacitor allocation and DG integration for total cost minimization considering reinforcement scheme applying disconnects with lateral protection shown in Figure 7.8. It has been observed from Figure 7.8 that real power loss values are nearly same at a maximum of 10% and 15% DG penetrations for FEO and rcGA techniques, respectively. The real power loss value has been observed to be increased implementing PSO algorithm with the increment of maximum DG penetration level from 10% to 15%. It can be noticed from Figure 7.8 that real power loss values have been found reduced applying all the techniques with the increase of maximum DG penetration level from 15% to 20%. The least real power loss value has been obtained by FEO technique amongst all the considered algorithms at a maximum of 20% DG penetration as observable in Figure 7.8.

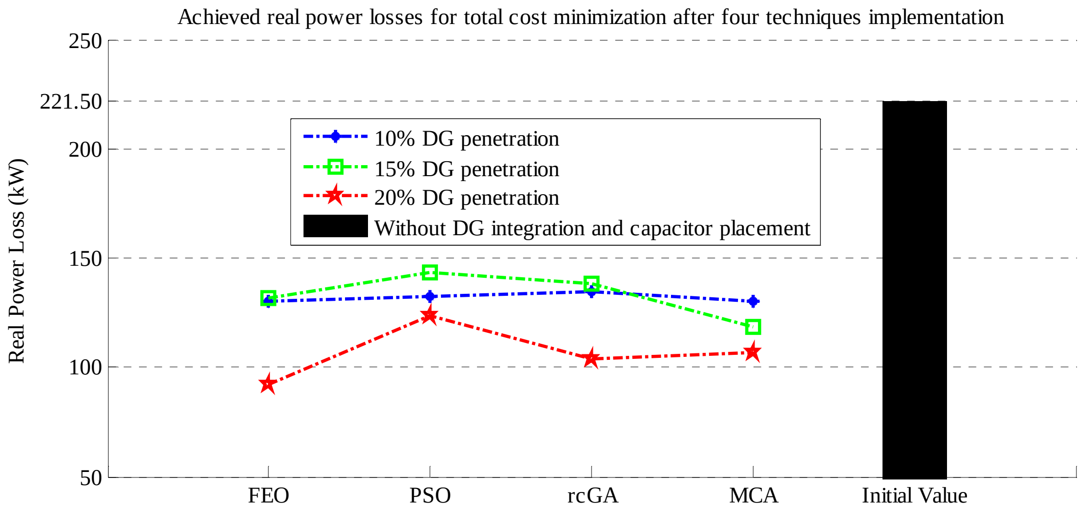

Figure 7.8: Real power loss reduction due to DG and capacitor placements for total cost minimization considering disconnects with lateral protection in 34 bus microgrid type radial distribution system

Total cost minimization considering disconnects with lateral protection has been discussed above. In this regard, reduction of total cost choosing only disconnects between buses is also important to understand.

7.1.1.2 Cost minimization considering only disconnects between buses for 34 bus system

Simultaneous capacitor and DG placements have been performed for total cost reduction considering reinforcement scheme viz. applying disconnects between two buses. The minimization of total cost has been studied for a maximum of 10% and 50% DG penetration levels shown in Table 7.5 and Table 7.6, respectively. The first DG penetration level has been selected considering a common and standard penetration level in different scenarios. On the other hand, the second DG penetration level has been selected considering the futuristic situation as stated earlier. The total cost value has been observed to be reduced from US$ 7919162.52 to US$ 6819698.05 by the application of PSO as observable in Table 7.5. The stated reduction in total cost value has been occurred due to the DG placement at bus location 7 and 23 with DG value of 100 kW and 200 kW, respectively. Shunt capacitor allocation has also been performed at bus number 4, 12, 19, 22, 24 and 30 with installation of 450 kVAR, 450 kVAR, 450 kVAR, 750 kVAR, 450 kVAR and 150 kVAR, respectively. It can be noticed from Table 7.5 that total cost value has been found reduced from US$ 7919162.52 to US$ 6802093.73 with the implementation of rcGA. Distributed generation integration has been performed at bus position 27 and 34 with DG value of 200 kW at every selected location. Shunt capacitor has been placed at bus number 5, 11, 20, 22 and 30. Capacitor values selected at those bus locations are 300 kVAR, 150 kVAR, 600 kVAR, 1350 kVAR and 150 kVAR shown in Table 7.5. Finally it has been observed from Table 7.5 that total cost value has been reduced from US$ 7919162.52 to US$ 6620059.49 with the implementation of FEO. The said reduction in total cost value has been caused due to simultaneous DG and capacitor placement at bus position 24 and 25; and 3, 8, 10, 13, 17, 21, 23, 24 and 27, respectively. Distributed generation and capacitor values selected for those bus locations are 200 kW and 200 kW for DG placement and 300 kVAR, 300 kVAR, 450 kVAR, 150 kVAR, 450 kVAR, 450 kVAR, 150 kVAR, 450 kVAR and 150 kVAR for capacitor allocation, respectively. The total cost value has been observed to be reduced from

US$ 7919162.52 to US$ 6771349.39 by the utilization of MCA. Distributed generation integration has been performed at bus number 22, 33 and 34 with DG value of 200 kW, 100 kW and 100 kW, respectively. Shunt capacitor allocation has also been executed at bus position 8, 19 and 26 with installed capacitor value of 750 kVAR, 1050 kVAR and 750 kVAR, respectively. It can be said from the above discussion that evolutionary technique FEO has found the least total cost value amongst all the chosen meta-heuristic algorithms. The next better position is held by the soft computing technique MCA in finding the total cost value. The study related to the next DG penetration level i.e. at a maximum of 50% of the total active power load has been described in the next paragraph.

Table 7.5: Total cost minimization applying only disconnects at a maximum of 10% DG penetration in 34 bus microgrid type radial distribution system

Methods	Total Cost (US$)	DG placement	DG value (kW)	Capacitor placement	Capacitor Value (kVAR)
PSO	6819698.05	7, 23	100, 200	4, 12, 19, 22, 24, 30	450, 450, 450, 750, 450, 150
rcGA	6802093.73	27, 34	200, 200	5, 11, 20, 22, 30	300, 150, 600, 1350, 150
FEO	6620059.49	24, 25	200, 200	3, 8, 10, 13, 17, 21, 23, 24, 27	300, 300, 450, 150, 450, 450, 150, 450, 150
MCA	6771349.39	22, 33, 34	200, 100, 100	8, 19, 26	750, 1050, 750
Without DG and capacitor placement	7919162.52	-	-	-	-

With a maximum of 50% DG penetration level it can be noticed from Table 7.6 that total cost value has been found reduced from US$ 7919162.52 to US$ 6437648.12 with the implementation of PSO. The total cost value obtained by PSO has been found further reduced as shown in Table 7.6 from the total cost value found by PSO shown in Table 7.5 due to the 40% increment in maximum DG penetration level. Distributed generation integration has been exercised at bus positions 4, 8, 14, 17, 18, 19, 23, 24 and 29 with DG value of 200 kW, 100 kW, 200 kW, 100 kW, 200 kW, 200 kW, 200 kW, 200 kW and 200 kW, respectively. Capacitors have also been placed at bus number 2, 6, 20, 24 and 29 with installed capacitor value of 300 kVAR, 1200 kVAR, 750 kVAR, 450 kVAR and 150 kVAR, respectively. The total cost value has been observed to be reduced from US$ 7919162.52 to US$ 6292065.24 by the utilization of rcGA available in Table 7.6. In this case the total cost value found by rcGA shown in Table 7.6 has been found reduced from the total cost values achieved by rcGA observable in Table 7.5. The reason behind the reduction of cost is the increase in maximum DG penetration level from 10% to 50%. Load bus position 4, 5, 8, 17, 18, 19, 21, 22, 24, 26, 27, 28, 29, 30, 32 and 34 have been chosen by rcGA for allocating 100 kW of DG at every selected location. On the other hand, shunt capacitors have been allocated at bus positions 2, 5, 8, 11, 13, 14, 17, 20, 23, 25, 27, 28, 30, 31 and 33 with installed capacitor value of 150 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 1200 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 300 kVAR and 150 kVAR, respectively shown in Table 7.6. It can be noticed from Table 7.6 that total cost value has been found reduced from US$ 7919162.52 to US$ 6160322.09 with the implementation of FEO. The total cost value achieved by FEO shown in Table 7.6 is lesser in magnitude from the total cost value obtained by FEO available in Table 7.5. This further reduction has been caused due to the DG integrations at bus number 11, 21, 24, 25, 27 and 30 with 200 kW of DG value at every selected location. On the other hand, capacitor placement has also been performed at bus number 2, 3, 10, 17, 21, 22, 25 and 28 with installed capacitor values of 300 kVAR, 150 kVAR, 450 kVAR, 600 kVAR, 300 kVAR, 450 kVAR, 450 kVAR and 150 kVAR, respectively which can be observed in Table 7.5. Finally it can be concluded from Table 7.6 that total cost value has been found reduced from US$ 7919162.52 to US$ 5943928.97 by the utilization of MCA. Distributed generator integration has been performed at bus position 4, 5, 6, 10, 18, 22, 23, 25, 26, 27, 30 and 32. The DG values have been selected as 100 kW, 100 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 100 kW and 200 kW, respectively at those bus locations. Shunt capacitor allocation has been executed at bus number 7, 19 and 24 with installed capacitor value of 1350 kVAR, 750 kVAR and 750 kVAR, respectively as observable in Table 7.6. In this case, the total cost value achieved by MCA technique available in Table 7.6 is lesser than the total cost value obtained by MCA shown in Table 7.5. This is due to the increment in maximum DG penetration level from 10% to 50%. In addition, it can be said from the above discussion that the total cost value found by MCA is the least amongst all the obtained total cost values by other algorithms which can be observed in Table 7.6.

Table 7.6: Minimization of total cost applying only disconnects at a maximum of 50% DG penetration in 34 bus microgrid type radial distribution system

Methods	Total Cost (US$)	DG placement	DG value (kW)	Capacitor placement	Capacitor Value (kVAR)
PSO	6437648.12	4, 8, 14, 17, 18, 19, 23, 24, 29	200, 100, 200, 100, 200, 200, 200, 200, 200	2, 6, 20, 24, 29	300, 1200, 750, 450, 150
rcGA	6292065.24	4, 5, 8, 17, 18, 19, 21, 22, 24, 26, 27, 28, 29, 30, 32, 34	100, 100, 100, 100, 200, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100	2, 5, 8, 11, 13, 14, 17, 20, 23, 25, 27, 28, 30, 31, 33	150, 150, 150, 150, 150, 150, 1200, 150, 150, 150, 150, 150, 150, 300, 150
FEO	6160322.09	11, 21, 24, 25, 27, 30	200, 200, 200, 200, 200, 200	2, 3, 10, 17, 21, 22, 25, 28	300, 150, 450, 600, 300, 450, 450, 150
MCA	5943928.97	4, 5, 6, 10, 18, 22, 23, 25, 26, 27, 30, 32	100, 100, 200, 200, 200, 200, 200, 200, 200, 200, 100, 200	7, 19, 24	1350, 750, 750
Without DG and capacitor placement	7919162.52	-	-	-	-

As discussed in this section total cost value has been reduced from its initial value with the increase in maximum DG penetration level. The techniques MCA and FEO have come out as the effective algorithms in this comparative study. On the other hand, it is evident that the other considered reliability and loss parameters apart from total cost will be modified due to the capacitor allocations and DG integrations considered in Table 7.5 and Table 7.6. This has been pictorially depicted by bar diagram and briefly illustrated in the next section.

7.1.1.2.1 Effect of total cost minimization on real power loss and reliability indices

The considered reliability and loss parameters have been changed from their initial values as stated in the beginning of this chapter due to capacitor allocations and DG integrations for total cost minimization considering reinforcement scheme ‘applying only disconnects’.

Customer oriented distribution system reliability index SAIFI value has been observed to be reduced from its initial value applying four meta-heuristic techniques for total cost minimization shown in Figure 7.9. The SAIFI value found by rcGA is lesser than that value obtained by PSO at a maximum of 10% DG penetration. On the other hand, the SAIFI value achieved by FEO is lower than that value found by rcGA technique. It has been observed from Figure 7.9 that the SAIFI values obtained by rcGA and MCA techniques are almost same. The SAIFI value has been found improved with the increase in maximum DG penetration level from 10% to 50% for all the considered algorithms. The least SAIFI value has been found by MCA technique at a maximum of 50% DG penetration. It can be noticed from Figure 7.9 that the next better position has been achieved by FEO algorithm at a maximum of 50% DG penetration in finding the better SAIFI value.

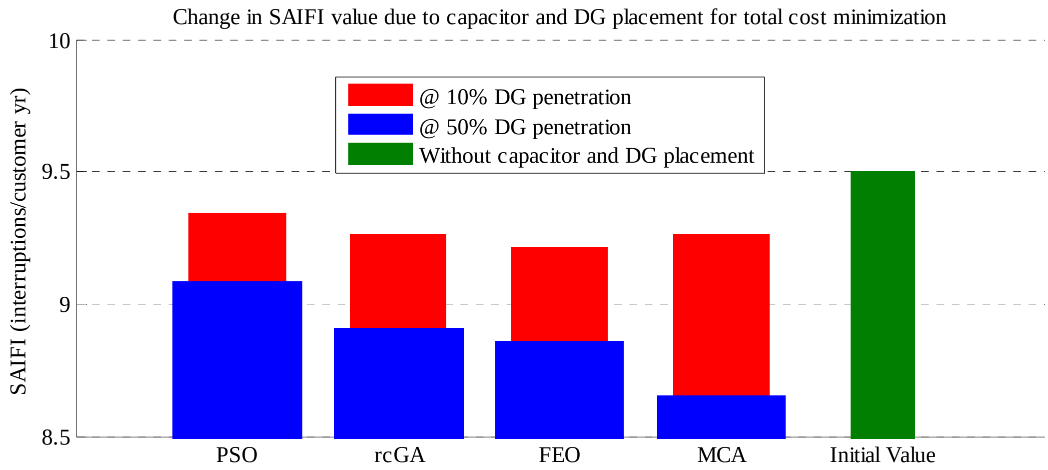

Figure 7.9: Comparative study of SAIFI value modification amongst four techniques with the objective of total cost minimization considering only disconnects in 34 bus microgrid type radial distribution system

Customer oriented distribution system reliability index SAIDI has also been found improved from its initial value due to DG integrations and capacitor allocations for total cost minimization shown in Figure 7.10. It has been observed from Figure 7.10 that the SAIDI value found by FEO algorithm is the least amongst all the chosen techniques at a maximum of 10% DG penetration. On the other hand, MCA technique has obtained the least SAIDI value amongst all the considered algorithms at a maximum of 50% DG penetration. The next better position has been achieved by FEO algorithm in finding the better SAIDI value at a maximum of 50% DG penetration which can be observed in Figure 7.10.

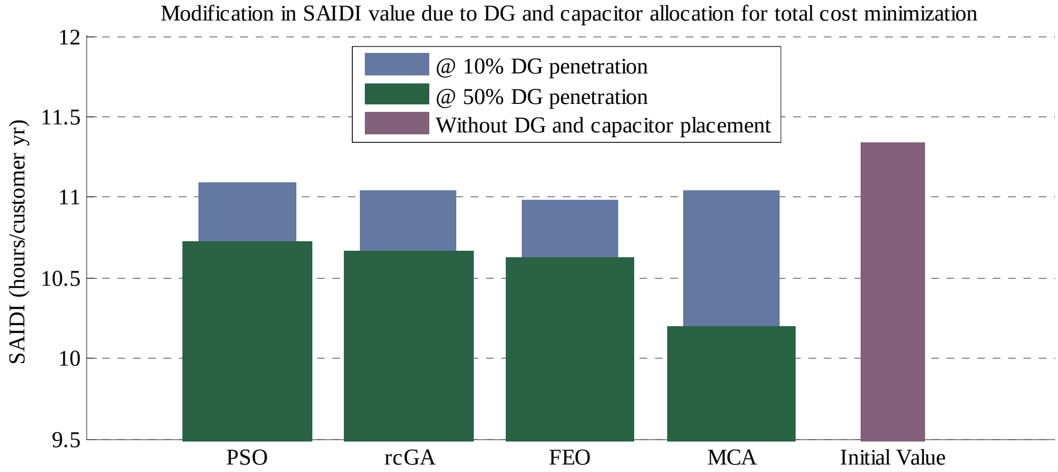

Figure 7.10: SAIDI value reduction by the usage of four algorithms for total cost minimization applying only disconnects in 34 bus microgrid type radial distribution system

Another customer oriented reliability index called average service unavailability index (ASUI) has been observed to be reduced from its initial value after DG integrations and capacitor allocations which can be found in Figure 7.11. It has been observed from Figure 7.11 that ASUI value has been decreased with the increase in maximum DG penetration level from 10% to 50%. The FEO algorithm has found the least ASUI value at a maximum of 10% DG penetration amongst all the considered techniques. On the other hand, MCA technique secures best position in finding better ASUI value at a maximum of 50% DG penetration amongst all the selected algorithms. Consequently another reliability index called average service availability index (ASAI) value can be obtained by performing subtraction of ASUI from unity as stated in Chapter 3 in (3.14). The comparative study of ASAI values found for total cost minimization is one type of reverse reflection of the Figure 7.11. That's why this study has not been performed here.

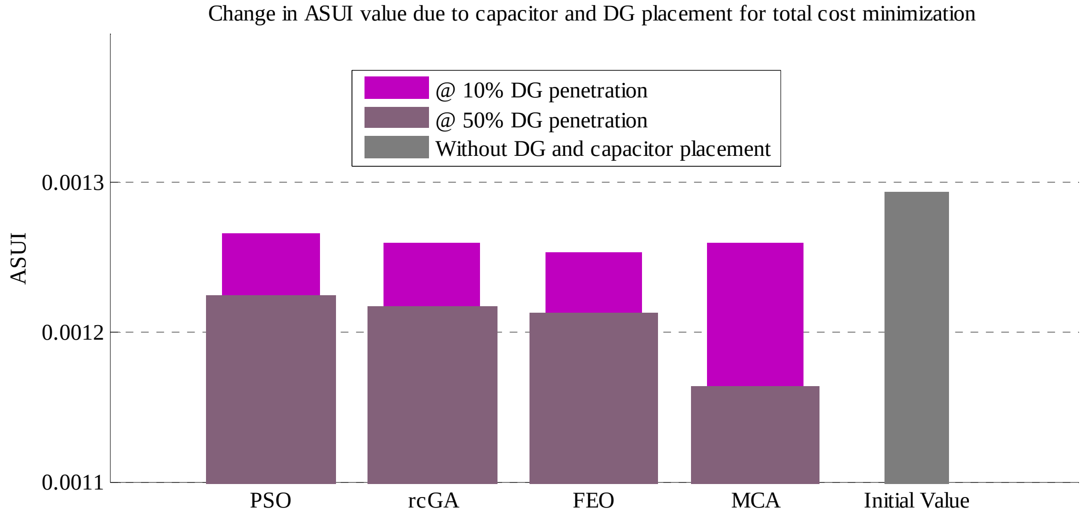

Figure 7.11: Reduction in ASUI value by the usage of four techniques for total cost minimization considering only disconnects in 34 bus microgrid type radial distribution system

The load-oriented distribution system reliability index AENS has been improved from its initial value after DG and capacitor allocations for total cost minimization shown in Figure 7.12. All the AENS values achieved by four techniques are nearly equal at a maximum of 10% DG penetration. That value of AENS at a maximum of 10% DG penetration is close to 2.5 kWh/customer yr for all the considered techniques. It has been observed from Figure 7.12 that the least AENS value has been found by MCA technique amongst all the chosen algorithms considering DG penetration up to 50%. On the other hand, AENS values obtained by rcGA, PSO and FEO techniques are nearly same at a maximum of 50% DG penetration which can be observed in Figure 7.12.

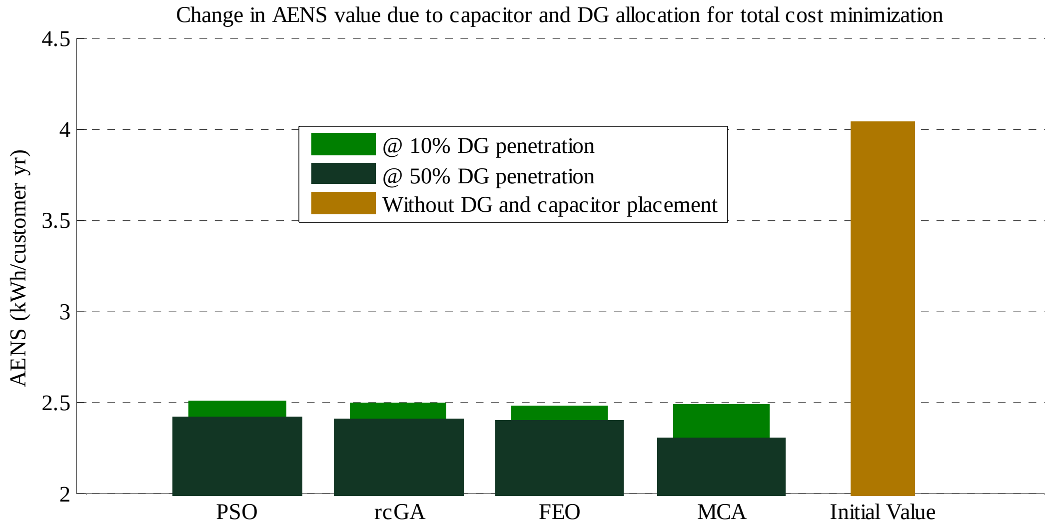

Figure 7.12: Improvement of AENS with the implementation of four techniques for total cost minimization applying only disconnects in 34 bus microgrid type radial distribution system

As discussed in Chapter 3, CBRI is the novel reliability index developed in this thesis. The CBRI has been observed to be increased from its initial value due to capacitor allocations and DG integrations for total cost minimization as observed in Figure 7.13. The CBRI values obtained by four algorithms are more or less same considering DG penetration up to 10%. The CBRI value found by rcGA technique is better than the values obtained by PSO and FEO algorithms at a maximum of 50% DG penetration. But CBRI value found by rcGA technique is lesser than the CBRI value achieved by MCA technique considering DG penetration up to 50%. The FEO technique is observed to be in the third position in finding the improved CBRI value at a maximum of 50% DG penetration whereas it secures the next better position in finding the better total cost value as discussed earlier. This is due to the reason that CBRI is a dimension less quantity and has a cost part and a loss part.

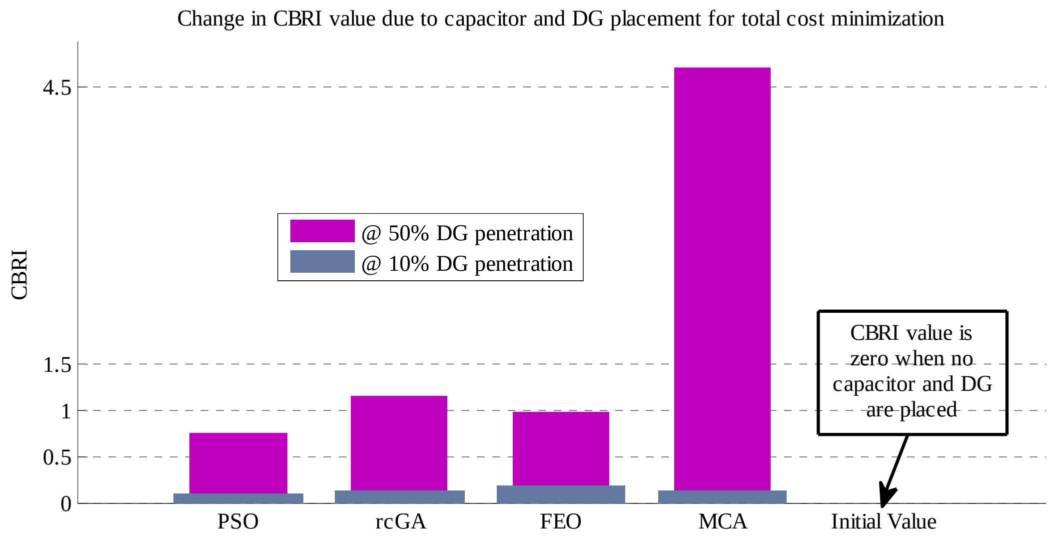

Figure 7.13: Increment in CBRI value by the application of four algorithms for total cost minimization considering only disconnects in 34 bus microgrid type radial distribution system

Real power loss is very important as regard reliability is concerned. Real power loss has been reduced from the initial value after capacitor allocations and DG integrations for total cost minimization shown in Figure 7.14. It has been observed from Figure 7.14 that with the increment of maximum DG penetration level from 10% to 50% the real power loss has been decreased utilizing rcGA, PSO, FEO and MCA. The real power loss found by FEO technique due to capacitor and DG placements is more than that value found by rcGA technique at 50% DG penetration for total cost minimization. The least real power loss has been found by MCA technique amongst all the considered algorithms at a maximum of 50% DG penetration shown in Figure 7.14.

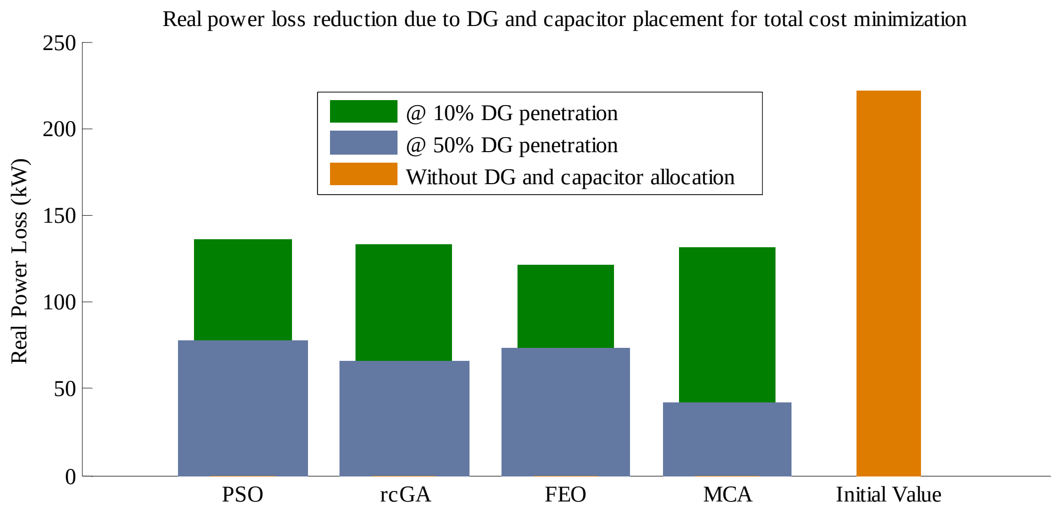

Figure 7.14: Reduction of real power loss by the usage of four techniques for total cost minimization applying only disconnects in 34 bus microgrid type radial distribution system

Minimization of total cost has been the topic of discussion so far considering two reinforcement schemes. Reliability improvement of microgrid type radial distribution system is very crucial like cost reduction. Improvement of reliability indices have been performed considering reinforcement scheme viz. disconnects with lateral protection as stated earlier. In this regard, customer-oriented distribution system reliability index SAIFI improvement has been considered and discussed in the next section.

7.1.2 Improvement of customer-oriented distribution system reliability index SAIFI

Simultaneous capacitor allocations and DG integrations have been performed suitably in 34 bus microgrid type radial distribution system to observe change in SAIFI values. This has been studied by implementing four meta-heuristic techniques on different DG penetration levels. The considered DG penetration levels are up to 10%, 15% and 20% of the total real power load of microgrid type radial distribution system at hand. These penetration levels have been selected considering different scenarios around the world as stated earlier.

7.1.2.1 Illustration of DG penetration and capacitor allocation

Distributed generation integrations have been executed at three levels with the installation of capacitor. The improvement of distribution system reliability index SAIFI has been studied at a maximum of 10%, 15% and 20% DG penetration levels as shown in Table 7.7, Table 7.8 and Table 7.9, respectively. The SAIFI value has been observed to be improved from 5.240010 interruptions/customer yr to 5.112085 interruptions/customer yr by the application of rcGA observable in Table 7.7. The stated reduction in SAIFI value has been occurred due to the DG placement at bus location 12 and 23 with DG value of 100 kW and 200 kW, respectively. On the other hand, shunt capacitor allocations have also been performed at bus number 3, 6, 8, 10, 22, 26 and 27 with installation of 1200 kVAR, 600 kVAR, 150 kVAR, 150 kVAR, 300 kVAR, 300 kVAR and 300 kVAR, respectively. It can be noticed from Table 7.7 that SAIFI value has been found reduced from 5.240010 interruptions/customer yr to 5.098797 interruptions/customer yr with the implementation of PSO. Distributed generation integrations have been performed at bus position 12, 20 and 24 with DG value of 100 kW, 200 kW and 100 kW, respectively. Shunt capacitors have been placed at bus number 4, 9, 12, 22 and 24. Capacitor values selected at those bus locations are 600 kVAR, 450 kVAR, 300 kVAR, 750 kVAR and 450 kVAR. Finally it has been observed from Table 7.7 that SAIFI value has been found improved from 5.240010 interruptions/customer yr to 5.052301 interruptions/customer yr with the implementation of FEO. The said reduction in SAIFI value has been caused due to DG placements at bus position 9 and 15 and capacitor allocations at bus number 2, 4, 6, 10, 14, 18, 20, 24, 26 and 28, respectively. Distributed generation and capacitor values selected for those stated locations are 200 kW and 100 kW for DG and 300 kVAR, 450 kVAR, 300 kVAR, 600 kVAR, 150 kVAR, 150 kVAR, 900 kVAR, 450 kVAR, 450 kVAR and 300 kVAR for capacitors, respectively. The SAIFI value has been observed to be improved from 5.240010 interruptions/customer yr to 5.098118 interruptions/customer yr by the application of MCA. Distributed generation integrations have been performed at bus number 21 and 26 with DG value of 200 kW at every selected location. On the other hand, shunt capacitor allocations have also been executed at bus position 6, 7 and 24 with installed capacitor value of 900 kVAR at every selected location. It can be said from the above discussion that evolutionary technique FEO has found the least SAIFI value amongst all the chosen meta-heuristic algorithms. The next better position is held by MCA in finding the better SAIFI value. The study related to SAIFI value improvement at the next DG penetration level i.e. at a maximum of 15% of the total active power load is also important to understand. This is to ascertain the effect of 5% increment of maximum DG penetration on SAIFI value.

Table 7.7: DG integrations and capacitor placements for SAIFI improvement at a maximum of 10% DG penetration in 34 bus microgrid type radial distribution system

Methods	SAIFI interruptions/customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	5.112085	100, 200	12, 23	1200, 600, 150, 150, 300, 300, 300	3, 6, 8, 10, 22, 26, 27
PSO	5.098797	100, 200, 100	12, 20, 24	600, 450, 300, 750, 450	4, 9, 12, 22, 24
FEO	5.052301	200, 100	9, 15	300, 450, 300, 600, 150, 150, 900, 450, 450, 300	2, 4, 6, 10, 14, 18, 20, 24, 26, 28
MCA	5.098118	200, 200	21, 26	900, 900, 900	6, 7, 24
Without DG and capacitor placement	5.240010	-	-	-	-

Like the previous paragraph, the SAIFI has been observed to be improved from its initial value by the suitable placements of DG and capacitor at the load buses shown in Table 7.8. This time the maximum DG penetration level has been increased by 5% to observe the improvement in SAIFI value. It can be noticed from Table 7.8 that SAIFI value has been found reduced from 5.240010 interruptions/customer yr to 5.091683 interruptions/customer yr with the implementation of rcGA. The SAIFI value obtained by rcGA has been found further reduced as observable in Table 7.8 from the SAIFI value found by rcGA as shown in Table 7.7 due to the 5% increment in maximum DG penetration level. Distributed generation integrations have been exercised at bus positions 6, 12, 21, 22, 26 and 28 with DG value of 100 kW in every selected location. On the other hand, capacitors have also been placed at bus number 18, 25 and 27 with installed capacitor values of 1650 kVAR, 150kVAR and 600 kVAR, respectively. Again the SAIFI value has been observed to be improved from 5.240010 interruptions/customer yr to 5.127165 interruptions/customer yr by the utilization of PSO. In this case the SAIFI value found by PSO available in Table 7.8 has not been found reduced from the SAIFI value achieved by PSO shown in Table 7.7. It is due to the reason that the evolutionary algorithm PSO has been trapped into the local minima while searching for the better SAIFI value. Only load bus number 30 has been selected by PSO for allocating 200 kW of DG. On the other hand, shunt capacitors have been placed at bus positions 2, 3, 5, 10, 27 and 33 with installed capacitor values of 300 kVAR, 750 kVAR, 300 kVAR, 450 kVAR, 450 kVAR and 150 kVAR, respectively in Table 7.8. Finally it can be noticed from Table 7.7 that SAIFI value has been improved from 5.240010 interruptions/customer yr to 5.051077 interruptions/customer yr with the implementation of FEO. This time the SAIFI value obtained by FEO available in Table 7.8 is lesser in magnitude from the SAIFI value achieved by FEO observable in Table 7.7. This further improvement has been caused due to the DG integrations at bus number 7, 23 and 24 with 200 kW of DG value at every selected location. On the other hand, capacitor placements have also been performed at bus number 2, 9, 17, 19, 22, 25 and 28 with installed capacitor values of 1500 kVAR, 600 kVAR, 300 kVAR, 300 kVAR, 450 kVAR, 450 kVAR and 150 kVAR, respectively as shown in Table 7.8. Lastly it has been observed from Table 7.8 that SAIFI value has been improved from 5.240010 interruptions/customer yr to 5.014295 interruptions/customer yr by the utilization of MCA. Distributed generator integrations have been performed at bus position 15, 22, 23, 27 and 32. The DG values have been selected as 100 kW, 100 kW, 100 kW, 200 kW and 100 kW, respectively at those bus locations. On the other hand, shunt capacitor allocations have been executed at bus number 5, 14 and 24 with installed capacitor values of 1800 kVAR, 150 kVAR and 900 kVAR, respectively shown in Table 7.8. In this case, the SAIFI value achieved by MCA available in Table 7.8 is lesser than the SAIFI value obtained by MCA shown in Table 7.7. This improvement in SAIFI value is due to the increase in maximum DG penetration level from 10% to 15%. Furthermore, it can be said from the above discussion that the SAIFI value found by MCA is the least amongst all the obtained SAIFI values by other algorithms. However, further 5% increment in maximum DG penetration level has been exercised to observe the improvement in SAIFI value as shown in Table 7.9.

Table 7.8: Capacitor placements and DG integrations for SAIFI improvement at a maximum of 15% DG penetration in 34 bus microgrid type radial distribution system

Methods	SAIFI interruptions/ customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	5.091683	100, 100, 100, 100, 100, 100	6, 12, 21, 22, 26, 28	1650, 150, 600	18, 25, 27
PSO	5.127165	200	30	300, 750, 300, 450, 450, 150	2, 3, 5,10, 27, 33
FEO	5.051077	200, 200, 200	7, 23, 24	1500, 600, 300, 300, 450, 450, 150	2, 9, 17, 19, 22, 25, 28
MCA	5.014295	100, 100, 100, 200, 100	15, 22, 23, 27, 32	1800, 150, 900	5, 14, 24
Without DG and capacitor placement	5.240010	-	-	-	-

It can be noticed from Table 7.9 that SAIFI value has been found reduced from 5.240010 interruptions/customer yr to 5.035698 interruptions/customer yr with the implementation of rcGA. The SAIFI value obtained by rcGA has been further reduced as shown in Table 7.9 from the SAIFI value found by rcGA available in Table 7.8 due to the 5% increment in maximum DG penetration level. Distributed generation integrations have been exercised at bus positions 4, 7, 12, 14, 25, 27, 30 and 34 with DG value of 100 kW in every selected location. On the other hand, capacitors have also been placed at bus number 2, 6, 8, 25 and 29 with installed capacitor values of 600 kVAR, 1950 kVAR, 150 kVAR, 750 kVAR and 300 kVAR, respectively. Again the SAIFI value has been observed to be improved from 5.240010 interruptions/customer yr to 5.048160 interruptions/customer yr by the application of PSO. In this case the SAIFI value found by PSO shown in Table 7.9 has been found reduced from the SAIFI values achieved by PSO as observable in Table 7.7 and Table 7.8 due to the increase in maximum DG penetration level. Load bus position 3, 5, 11, 24, 29 and 34 have been selected by PSO for allocating 200 kW, 100 kW, 100 kW, 200 kW, 200 kW and 100 kW of DG. On the other hand, shunt capacitors have been placed at bus positions 11 and 24 with installed capacitor values of 900 kVAR and 1200 kVAR, respectively as shown in Table 7.9. Finally it can be noticed from Table 7.9 that SAIFI value has been found improved from 5.240010 hours/customer yr to 4.971100 hours/customer yr with the implementation of FEO. The SAIFI value obtained by FEO shown in Table 7.9 is lesser in magnitude from the SAIFI value achieved by FEO as observable in Table 7.8. This further improvement has been caused due to the DG integrations at bus number 3, 11, 30, 32 and 34 with DG values of 100 kW, 200 kW, 200 kW, 200 kW and 200 kW at those selected locations. On the other hand, capacitor placements have also been performed at bus number 3, 5, 9, 11, 12, 18, 19, 21, 23, 24 and 28 with installed capacitor values of 300 kVAR, 300 kVAR, 300 kVAR, 300 kVAR, 150 kVAR, 150 kVAR, 1650 kVAR, 600 kVAR, 150 kVAR, 150 kVAR and 150 kVAR, respectively. Finally it has been observed from Table 7.9 that SAIFI value has been found improved from 5.240010 interruptions/customer yr to 4.951034 interruptions/customer yr by the utilization of MCA. Distributed generator integrations have been performed at bus position 10, 12, 14, 22, 29 and 30. The DG values have been selected as 100 kW, 200 kW, 100 kW, 200 kW, 200 kW and 100 kW, respectively at those bus locations. On the other hand, shunt capacitor allocations have been executed at bus number 6, 22, 28 and 31 with installed capacitor values of 750 kVAR, 1050 kVAR, 150 kVAR and 750 kVAR, respectively. In this case, the SAIFI value achieved by MCA shown in Table 7.9 is lesser than the SAIFI value obtained by MCA observable in Table 7.8 due to increment in maximum DG penetration level.

Table 7.9: DG integrations and capacitor placements for SAIFI improvement at a maximum of 20% DG penetration in 34 bus microgrid type radial distribution system

Methods	SAIFI interruptions/ customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	5.035698	100, 100, 100, 100, 100, 100, 100, 100	4, 7, 12, 14, 25, 27, 30, 34	600, 1950, 150, 750, 300	2, 6, 8, 25, 29
PSO	5.048160	200, 100, 100, 200, 200, 100	3, 5, 11, 24, 29, 34	900, 1200	11, 24
FEO	4.971100	100, 200, 200, 200, 200	3, 11, 30, 32, 34	300, 300, 300, 300, 150, 150, 1650, 600, 150, 150, 150	3, 5, 9, 11, 12, 18, 19, 21, 23, 24, 28
MCA	4.951034	100, 200, 100, 200, 200, 100	10, 12, 14, 22, 29, 30	750, 1050, 150, 750	6, 22, 28, 31
Without DG and capacitor placement	5.240010	-	-	-	-

In addition, it can be said from the above discussion that the SAIFI value found by MCA is the least amongst all the obtained SAIFI values by other algorithms as observable in Table 7.9. It has been already discussed that capacitor allocation and DG integration reduces resistive line loss. This in turn reduces failure rate and improves the reliability index SAIFI. The failure rate modification and resitive line loss is connected with the current magnitude flowing in the branches of feeder. This current magnitude variation has been studied in Table 7.10 for mostly DG connected branches to understand the reliability enhancement phenomena properly. It can be noticed from Table 7.10 that DG value of 100 kW, 200 kW, 100 kW, 200 kW, 200 kW and 100 kW have been placed at bus number 10, 12, 14, 22, 29 and 30 by the application of MCA technique. Capacitors have also been placed by MCA technique as observable in Table 7.9. The current magnitude in branches 10-11, 11-12, 13-14 and 21-22, have been found reduced from 0.0409 p.u to 0.0262 p.u, from 0.0151 p.u to 0.0098 p.u, from 0.0171 p.u to 0.0103 p.u and from 0.1462 p.u to 0.1066 p.u, respectively as shown in Table 7.10. It has been observed from Table 7.10 that current magnitudes in brances 9-10, 22-23, 28-29 and 29-30 have been found reduced from 0.0670 p.u to 0.0463 p.u, from 0.1202 p.u to 0.1182 p.u, from 0.0168 p.u to 0.0164 p.u and from 0.0083 p.u to 0.0050 p.u, respectively. These reduction in current magnitude is due to the fact that distributed generator locally cater the load which in turn reduces the current flow in line. It can be noticed from Table 7.10 that current value in branch 10-31 has been found increased from 0.0256 p.u to 0.0612 p.u. This is not a desired phenomenon. This will enhance the failure rate. This increment in current magnitude has been caused due the capacitor allocation of 750 kVAR at bus location 31 as observable in Table 7.9. Though this reactive power compensation by capacitor increases failure rate of that particular line but system resitive line loss decreases. It can be noticed that system line loss has been found reduced from 221.5 kW to 110.05 kW. This in turn helps to reduce the failure rates of other branches in feeder. It has also been observed from Table 7.10 that current magnitudes in branches 1-2 and 18-19 have been found reduced from 0.5193 p.u to 0.3541 p.u and from 0.2237 p.u to 0.1697 p.u due to the effect of DG integrations and capacitor allocations.

Table 7.10: Study of current magnitude for SAIFI improvement by implementing MCA technique in 34 bus microgrid type radial distribution system at a maximum of 20% DG penetration

Branch	Current in p.u without DG and capacitor placement	Current in p.u after DG and capacitor placement	Loss in kW without DG and capacitor allocation	Loss in kW after DG and capacitor allocation	DG placement chosen by MCA technique	DG value in kW selected by MCA technique
1-2	0.5193	0.3541	221.5	110.05	10, 12, 14, 22, 29, 30	100, 200, 100, 200, 200, 100
9-10	0.0670	0.0463				
10-11	0.0409	0.0262				
10-31	**0.0256**	**0.0612**				
11-12	0.0151	0.0098				
13-14	0.0171	0.0103				
21-22	0.1462	0.1066				
22-23	0.1202	0.1182				
28-29	0.0168	0.0164				
29-30	0.0083	0.0050				
18-19	0.2237	0.1697				

As discussed in this section SAIFI value has been improved from its initial value with the increase in maximum DG penetration level. The techniques MCA and FEO have come out as the effective algorithms in this comparative study. Nevertheless there is always a chance of further improvement in SAIFI value with the increase in DG penetration level. This has been studied later for a maximum of 50% DG penetration level considering futuristic plan. On the other hand, it is evident that the other considered reliability, cost and loss parameters apart from SAIFI will be modified due to the capacitor allocations and DG integrations considered in Table 7.7, Table 7.8 and Table 7.9. This has been briefly illustrated in the next section.

7.1.2.2 Consequence of SAIFI improvement on total cost, other reliability indices and real power loss

Suitable capacitor and DG positions and values have been selected by four meta-heuristic techniques for performing SAIFI improvement. This has been discussed in previous section. However, the other considered reliability indices apart from SAIFI did also change from its initial value due to the placements of DG and capacitor. The total cost and real power loss have also been reduced from its initial values due the said allocations of capacitor and DG. This modification or changes in the stated reliability, cost and loss parameters apart from SAIFI have been illustrated in the following section.

Total cost has been found reduced from initial value after capacitor allocations and DG integrations for SAIFI improvement as shown in Figure 7.15. It has been observed from Figure 7.15 that total cost values are close to each other at a maximum of 10%, 15% and 20% DG penetrations implementing rcGA and MCA techniques. However, the total cost value has been found increased with the increase of maximum DG penetration level from 10% to 15% utilizing PSO. It can be noticed from Figure 7.15 that total cost values achieved by PSO technique are very close to each other at a maximum of 10% and 20% DG penetrations. On the other hand, it has been observed that total cost value has been found decreased with the increase in maximum DG penetration level from 10% to 15% upon applying FEO technique. On the other hand, the total cost value has been increased with the increase in maximum DG penetration level from 15% to 20% after implementing FEO technique.

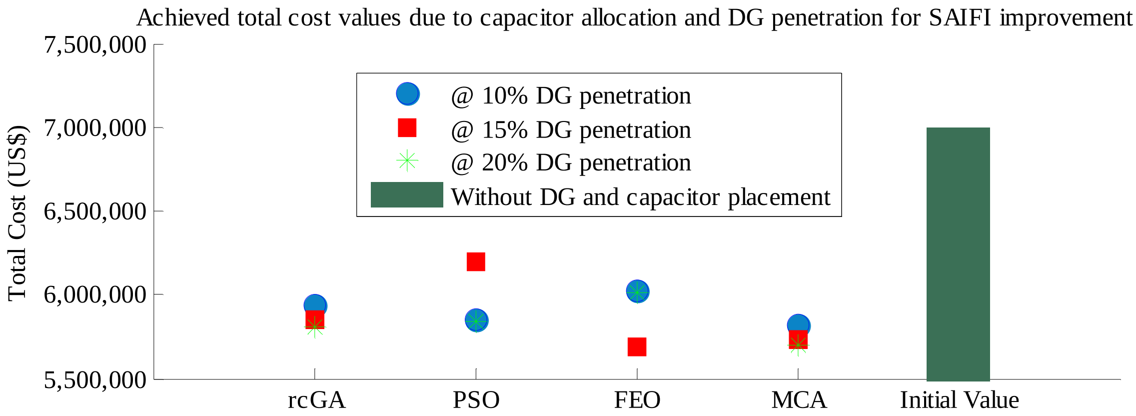

Figure 7.15: Comparative study amongst four techniques related to total cost values for SAIFI improvement in 34 bus microgrid type radial distribution system

Customer oriented distribution system reliability index SAIDI has also been observed to be reduced from its initial value due to capacitor allocations and DG integrations for SAIFI improvement as can be observed in Figure 7.16. It is visible from Figure 7.16 that SAIDI value has been found reduced by the application of rcGA technique with the increase of maximum DG penetration level from 10% to 15% and from 15% to 20%. But the SAIDI value has been observed to be increased applying PSO algorithm with the increment of maximum DG penetration level from 10% to 15%. This is due to the reason that the main objective of the optimization is to improve the SAIFI not the SAIDI. Similarly, the SAIDI value has been observed to be increased implementing FEO technique with the increment of maximum DG penetration level from 10% to 15%. It can also be noticed from Figure 7.16 that SAIDI values found by MCA technique are almost same at a maximum of 15% and 20% DG penetration level.

It has also been observed from Figure 7.16 that the SAIDI values found by FEO technique at a maximum of 10% and 20% DG penetrations are almost equal. The least SAIDI value has been achieved by MCA technique amongst all the considered algorithms.

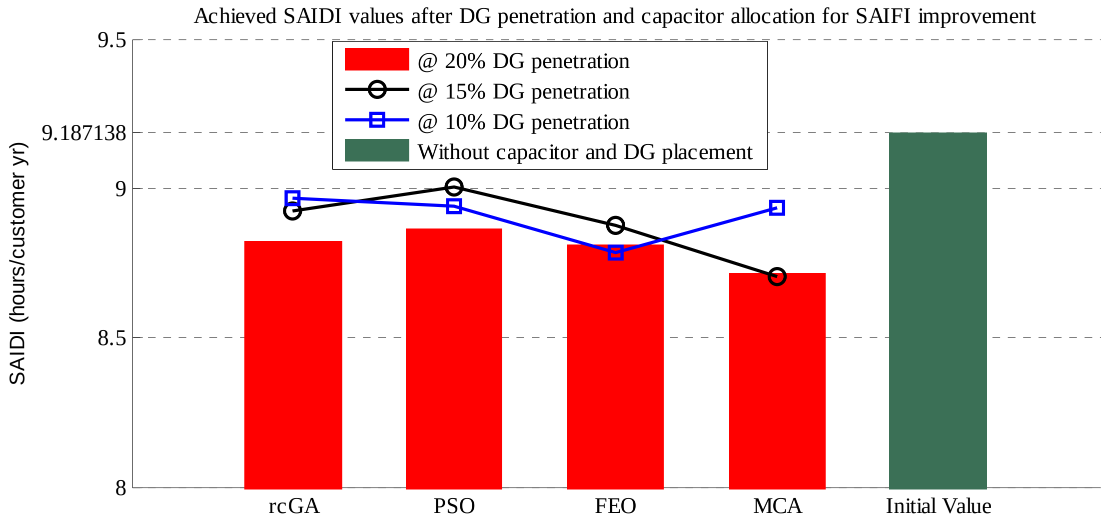

Figure 7.16: Modification in SAIDI value due to capacitor and DG placements for SAIFI improvement in 34 bus microgrid type radial distribution system

Interruption duration is important as regard reliability is concerned. Customer average interruption duration index (CAIDI) value has been observed to be changed from its initial value after capacitor and DG placements for SAIFI improvement shown in Figure 7.17. It can be noticed from Figure 7.17 that CAIDI values found by rcGA and PSO techniques remain more or less equal to initial values at a maximum of 10%, 15% and 20% DG penetration levels. The CAIDI value has been observed to be reduced from initial value implementing FEO algorithm at a maximum of 10% DG penetration. With the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%, the CAIDI values have been observed to be increased after applying FEO algorithm. On the other hand, the CAIDI value has been observed to be decreased implementing MCA technique with the increase of maximum DG penetration level from 10% to 15%. Furthermore the CAIDI value has been found increased utilizing MCA technique with the increment of maximum DG penetration level from 15% to 20%.

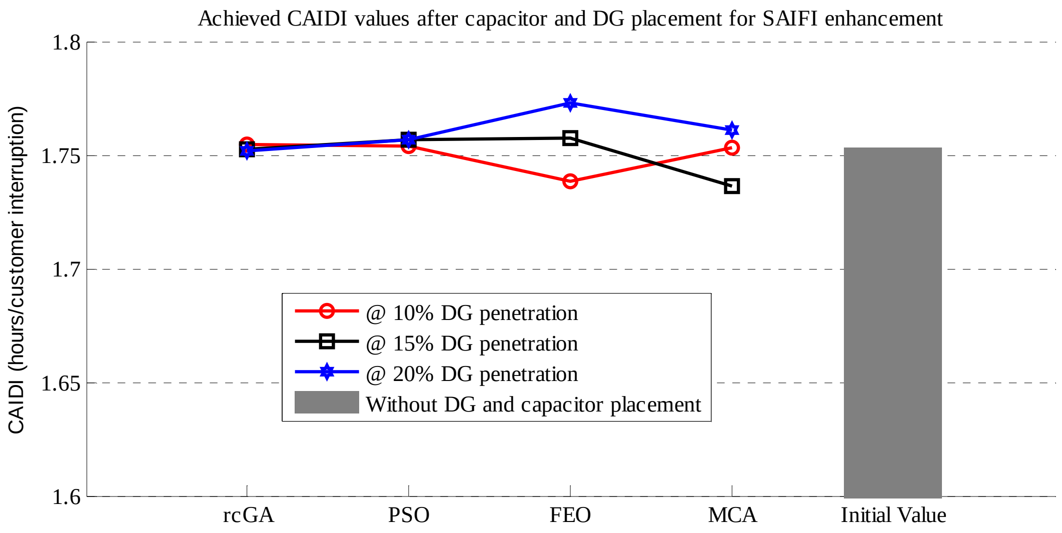

Figure 7.17: Change in CAIDI value as outcome of DG and capacitor allocations for SAIFI improvement in 34 bus microgrid type radial distribution system

As regard deregulation is concerned, service availability is an important issue. The reliability index ASUI is connected to this issue. The ASUI value has been found reduced from its initial value due to capacitor allocation and DG integration for SAIFI improvement shown in Figure 7.18. It can be observed from Figure 7.18 that ASUI value has been found reduced after implementing rcGA technique with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. The ASUI value on the other hand has been observed to be increased applying PSO algorithm with the increase of maximum DG penetration level from 10% to 15%. It can be noticed from Figure 7.18 that ASUI value has been decreased applying PSO technique with the increment of maximum DG penetration level from 15% to 20%. The ASUI value has been observed to be increased utilizing FEO technique with the increase of maximum DG penetration level from 10% to 15%. It has been again observed from Figure 7.18 that ASUI values found by FEO technique are nearly equal at a maximum of 15% and 20% DG penetrations. The ASUI value has been observed to be reduced upon applying MCA technique with the increase of maximum DG penetration level from 10% to 15%. It can be noticed from Figure 7.18 that ASUI value has been found increased very insignificantly after implementing MCA technique with the increase of maximum DG penetration level from 15% to 20%.

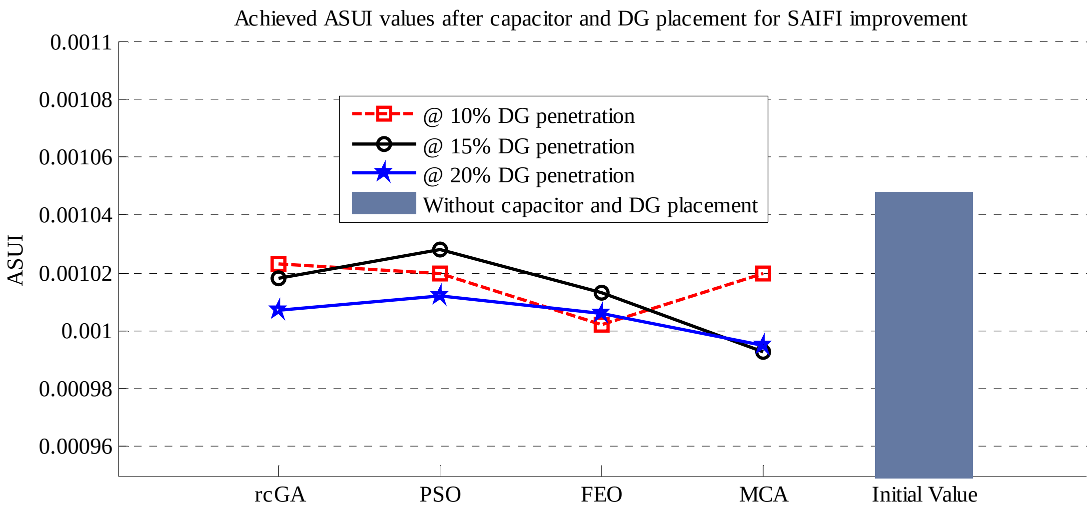

Figure 7.18: Change in ASUI value due to capacitor and DG allocations for SAIFI improvement in 34 bus microgrid type radial distribution system

Uninterrupted energy supply is crucial as regard to business continuity. The load oriented distribution system reliability index AENS has been found reduced from its initial value after DG integrations and capacitor allocations while SAIFI improvement was manifested. It is shown in Figure 7.19. It can be noticed from Figure 7.19 that AENS value has been found reduced upon implementing rcGA technique with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. The AENS value has also been observed to be increased after applying PSO and FEO algorithms with the increase of maximum DG penetration from 10% to 15%. On the other hand, with further 5% increase in maximum DG penetration level from 15%, the AENS value has been found decreased and increased after utilizing PSO and FEO techniques, respectively. It has been observed from Figure 7.19 that AENS value has been reduced after implementing MCA technique with the increase of maximum DG penetration level from 10% to 15%. It can also be noticed from Figure 7.19 that the AENS value has been found more or less same at a maximum of 15% and 20% DG penetration levels implementing MCA technique. This AENS value obtained by MCA technique is the least amongst all the considered soft computing techniques.

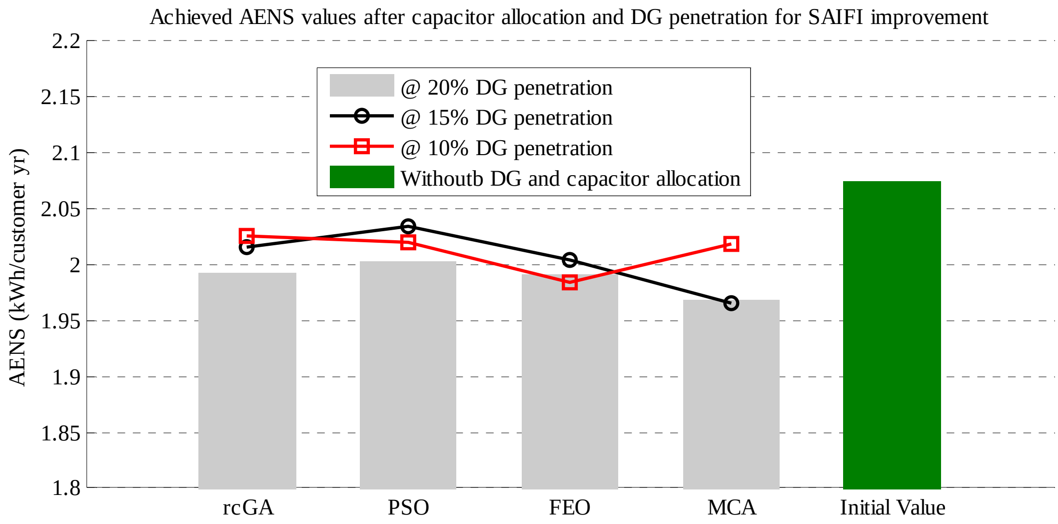

Figure 7.19: Modification in AENS value as a result of capacitor and DG placements for SAIFI improvement in 34 bus microgrid type radial distribution system

The cost based reliability index (CBRI) has been observed to be increased from its initial value due to DG integration and capacitor placement applied for SAIFI improvement shown in Figure 7.20. It has been observed from Figure 7.20 that CBRI value has been found increased and decreased upon implementing rcGA and PSO algorithms, respectively with the increase of maximum DG penetration level from 10% to 15%. With further 5% increase of maximum DG penetration from 15% DG penetration level, the CBRI value has been observed to be decreased and increased after applying rcGA and PSO techniques, respectively. On the other hand, it can be noticed from Figure 7.20 that CBRI value has been found increased utilizing FEO and MCA techniques with the increase of maximum DG penetration level from 10% to 15%. But it has been observed from Figure 7.20 that CBRI value has been found reduced after applying MCA and FEO algorithms with further 5% increase of maximum DG penetration from 15% DG penetration level.

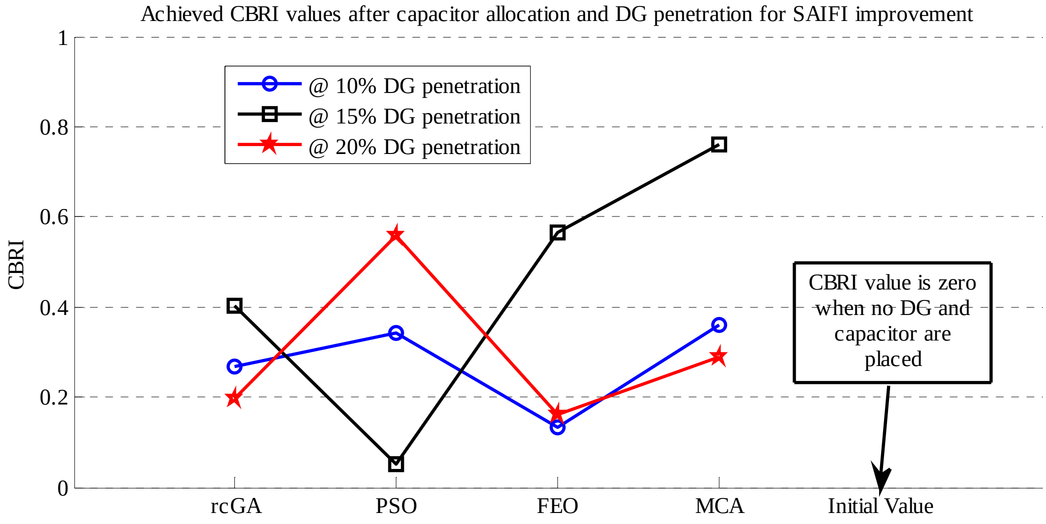

Figure 7.20: CBRI value change due to DG and capacitor allocation for SAIFI improvement in 34 bus microgrid type radial distribution system

Reliability has a significant interconnection with real power loss. The real power loss has been observed to be reduced from its initial value after performing capacitor allocation and DG integration for SAIFI improvement shown in Figure 7.21. It can be noticed from Figure 7.21 that real power loss has been found reduced after implementing rcGA technique with the increase of maximum DG penetration level from 10% to 15% and from 15% to 20%. Real power loss has been observed to be increased applying PSO technique with the increment of maximum DG penetration level from 10% to 15%. In addition, it can be noticed from Figure 7.21 that real power loss has been found reduced after implementing PSO algorithm with the increase of maximum DG penetration level from 15% to 20%. On the other hand, it has been observed from Figure 7.21 that real power loss has been found decreased applying FEO and MCA technique with the increase of maximum DG penetration level from 10% to 15%. It can be noticed from Figure 7.21 that real power loss has been increased and decreased upon implementing FEO and MCA techniques, respectively with the increase of maximum DG penetration level from 15% to 20%.

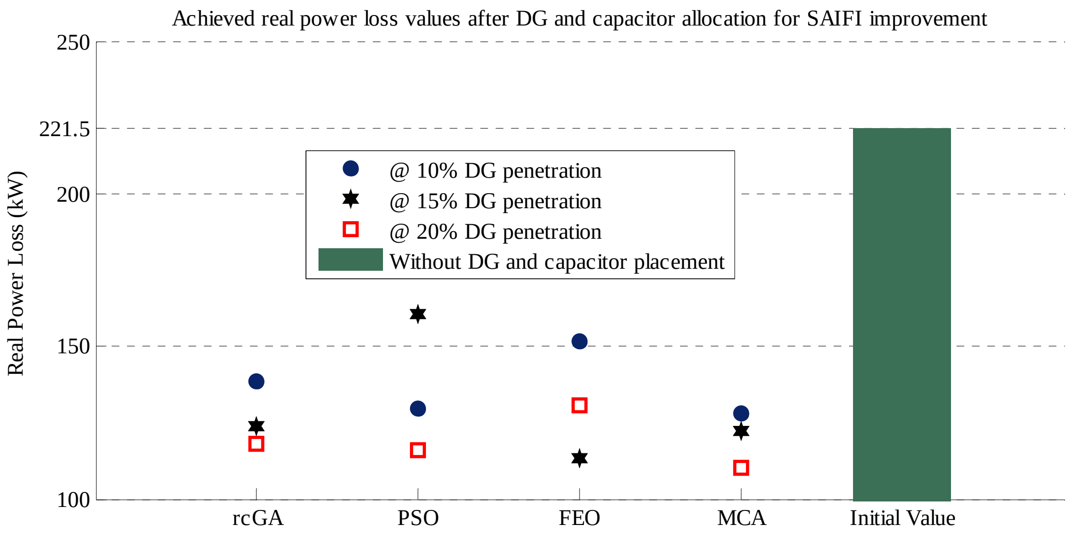

Figure 7.21: Real power loss reduction due to capacitor and DG placements for SAIFI improvement in 34 bus microgrid type radial distribution system

Appropriate simultaneous DG and capacitor placements can also improve another customer oriented distribution system reliability index called SAIDI. The study related to the improvement of SAIDI also draws special attention like the above stated reliability enhancement performed by SAIFI minimization.

7.1.3 Customer-oriented distribution system reliability index SAIDI improvement

Simultaneous DG integrations and capacitor allocations have been executed suitably in 34 bus microgrid type radial distribution system for improvement of SAIDI value. This has been studied by implementing four evolutionary techniques on different DG penetration levels. The stated DG penetrations are up to 10%, 15% and 20% of the total real power load concerning to the microgrid type radial distribution system at hand. These penetration levels have been considered assessing different situations as stated earlier.

7.1.3.1 Description of capacitor placement and DG integration

Distributed generation integrations have been performed at three levels along with the installation of capacitors. The improvement of distribution system reliability index SAIDI has been studied at a maximum of 10%, 15% and 20% DG penetration levels shown in Table 7.11, Table 7.12 and Table 7.13, respectively. The SAIDI value has been observed to be improved from 9.187138 hours/customer yr to 8.783708 hours/customer yr by the application of rcGA as observable in Table 7.11. The stated reduction in SAIDI value has been occurred due to the DG placements at bus location 11, 14, 17 and 25 with DG value of 100 kW at every selected location. On the other hand, shunt capacitor allocations have also been performed at bus number 2, 3, 4, 5, 9, 12, 15, 17, 19, 21, 23, 24, 28 and 33 with installation of 900 kVAR, 750 kVAR, 300 kVAR, 300 kVAR, 300 kVAR, 150 kVAR, 150 kVAR, 300 kVAR, 150 kVAR, 300 kVAR, 150 kVAR, 600 kVAR, 300 kVAR and 150 kVAR, respectively. It can be noticed from Table 7.11 that SAIDI value has been found reduced from 9.187138 hours/customer yr to 8.959402 hours/customer yr with the implementation of PSO. Distributed generation integrations have been performed at bus position 4 and 25 with DG value of 200 kW at every selected position. Shunt capacitors have been placed at bus number 2, 7, 12, 17, 22 and 26. Capacitor values selected at those bus locations are 600 kVAR, 600 kVAR, 300 kVAR, 300 kVAR, 450 kVAR and 600 kVAR. Finally it has been observed from Table 7.11 that SAIDI value has been improved from 9.187138 hours/customer yr to 8.777764 hours/customer yr with the implementation of FEO. The said reduction in SAIDI value has been caused due to DG allocations at bus position 10, 15 and 27 and capacitor placements at bus number 6, 14, 17, 20, 21, 31 and 32, respectively. Distributed generation and capacitor values selected for those bus locations are 100 kW, 100 kW and 200 kW and 150 kVAR, 150 kVAR, 300 kVAR, 150 kVAR, 2100 kVAR, 150 kVAR and 300 kVAR, respectively. Finally the SAIDI value has been observed to be improved from 9.187138 hours/customer yr to 8.767885 hours/customer yr by the application of MCA. Distributed generation integrations have been performed at bus number 15, 20 and 27 with DG values of 100 kW, 100 kW and 200 kW. On the other hand, shunt capacitor allocations have also been executed at bus position 14, 18 and 21 with installed values of 150 kVAR, 1350 kVAR and 900 kVAR. It can be said from the above discussion that evolutionary technique MCA has found the least SAIDI value amongst all the chosen meta-heuristic algorithms. The next position is held by the soft computing technique FEO in finding the better SAIDI value. The study related to the next maximum DG penetration level i.e. 15% of the total active power load has been described in the next paragraph.

Table 7.11: DG integrations and capacitor placements for SAIDI improvement at a maximum of 10% DG penetration in 34 bus microgrid type radial distribution system

Methods	SAIDI hours/customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	8.783708	100, 100, 100, 100	11, 14, 17, 25	900, 750, 300, 300, 300, 150, 150, 300, 150, 300, 150, 600, 300, 150	2, 3, 4, 5, 9, 12, 15, 17, 19, 21, 23, 24, 28, 33
PSO	8.959402	200, 200	4, 25	600, 600, 300, 300, 450, 600	2, 7, 12, 17, 22, 26
FEO	8.777764	100, 100, 200	10, 15, 27	150, 150, 300, 150, 2100,150, 300	6, 14, 17, 20, 21, 31, 32
MCA	8.767885	100, 100, 200	15, 20, 27	150, 1350, 900	14, 18, 21
Without DG and capacitor placement	9.187138	-	-	-	-

Like the above discussed paragraph, the SAIDI value has been observed to be improved from its initial value by the suitable placements of DG and capacitor at the load buses shown in Table 7.12. This time the maximum DG penetration level has been increased by 5% to observe the change in SAIDI value. It can be noticed from Table 7.12 that SAIDI value has been found reduced from 9.187138 hours/customer yr to 8.825259 hours/customer yr with the implementation of rcGA. The SAIDI value obtained by rcGA has been further increased in Table 7.12 from the SAIDI value found by rcGA shown in Table 7.9. Though there is 5% increment in DG penetration level, the meta-heuristic technique rcGA has been trapped in local minima. That’s why the value of SAIDI obtained by rcGA as observable in Table 7.12 has not been improved from the SAIDI value achieved by rcGA shown in Table 7.11. Distributed generation integrations have been exercised at bus positions 11, 14 and 28 with DG values of 200 kW, 100 kW and 200 kW, respectively. On the other hand, capacitors have also been placed at bus number 14, 17 and 26 with installed capacitor values of 150 kVAR, 300 kVAR and 300 kVAR, respectively. Again the SAIDI value has been observed to be improved from 9.187138 hours/customer yr to 8.986909 hours/customer yr by the application of PSO. In this case the SAIDI value found by PSO as observable in Table 7.12 has not been found reduced from the SAIDI value achieved by PSO available in Table 7.11. It is due to the reason that the evolutionary algorithm PSO is trapped into the local minima while searching for the better SAIDI value. Only load bus number 8 has been selected by PSO technique for allocating 200 kW of DG. On the other hand, shunt capacitors have been placed at bus position 4, 20, 23, 26, 30 and 31 with installed capacitor values of 450 kVAR, 450 kVAR, 300 kVAR, 600 kVAR, 150 kVAR and 600 kVAR, respectively. Finally it can be noticed from Table 7.12 that SAIDI value has been found improved from 9.187138 hours/customer yr to 8.760713 hours/customer yr with the implementation of FEO. This time the SAIDI value obtained by FEO shown in Table 7.12 is lesser in magnitude from the SAIDI value achieved by FEO as observable in Table 7.11. This further improvement has been caused due to the DG integrations at bus number 15, 20 and 30 with 200 kW of DG value at every selected location. On the other hand, capacitor placements have also been performed at bus number 2, 4, 5, 6, 8, 9, 14, 21, 24, 25 and 32 with installed capacitor values of 2250 kVAR, 150 kVAR, 1500 kVAR, 150 kVAR, 300 kVAR, 150 kVAR, 150 kVAR, 300 kVAR, 150 kVAR, 300 kVAR and 150 kVAR, respectively. Finally it has been observed from Table 7.12 that SAIDI value has been found improved from 9.187138 hours/customer yr to 8.756572 hours/customer yr by the application of MCA. Distributed generator integrations have been performed at bus position 12, 15, 31 and 34. The DG values have been selected as 200 kW, 100 kW, 200 kW and 100 kW, respectively at those bus locations. Shunt capacitor allocations have also been executed at bus number 14 and 23 with installed capacitor values of 150 kVAR and 1350 kVAR, respectively. In this case, the SAIDI value achieved by MCA shown in Table 7.12 is lesser than the SAIDI value obtained by MCA observable in Table 7.11. In addition, it can be said from the above discussion that the SAIDI value found by MCA is the least amongst all the obtained SAIDI values by other algorithms. However, further 5% increment in maximum DG penetration level has been exercised to observe the improvement in SAIDI value as shown in Table 7.13.

Table 7.12: Capacitor allocations and DG integrations for SAIDI improvement at a maximum of 15% DG penetration in 34 bus microgrid type radial distribution system

Methods	SAIDI hours/customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	8.825259	200, 100, 200	11, 14, 28	150, 300, 300	14, 17, 26
PSO	8.986909	200	8	450, 450, 300, 600, 150, 600	4, 20, 23, 26, 30, 31
FEO	8.760713	200, 200, 200	15, 20, 30	2250, 150, 1500, 150, 300, 150, 150, 300, 150, 300, 150	2, 4, 5, 6, 8, 9, 14, 21, 24, 25, 32
MCA	8.756572	200, 100, 200, 100	12, 15, 31, 34	150, 1350	14, 23
Without DG and capacitor placement	9.187138	-	-	-	-

It can be noticed from Table 7.13 that SAIDI value has been found reduced from 9.187138 hours/customer yr to 8.853253 hours/customer yr with the implementation of rcGA. The SAIDI value obtained by rcGA has been further increased as can be observed in Table 7.13 from the SAIDI value found by rcGA shown in Table 7.12. This is due to the entrapment of rcGA algorithm in local minima. Distributed generation integrations have been exercised at bus position 7, 10, 13 and 24 with DG values of 200 kW in every selected location. Capacitors have also been placed at bus number 11 and 21 with installed capacitor values of 1050 kVAR and 750 kVAR, respectively. The SAIDI value has been observed to be improved from 9.187138 hours/customer yr to 8.824094 hours/customer yr by the application of PSO technique. In this case the SAIDI value found by PSO as shown in Table 7.13 has been reduced from the SAIDI values achieved by PSO available in Table 7.11 and Table 7.12 due to increase in DG penetration level. Load bus position 15 and 21 have been selected by PSO algorithm for allocating 100 kW and 200 kW of DG. On the other hand, shunt capacitors have been placed at bus position 2, 11, 14 and 22 with installed capacitor values of 150 kVAR, 1650 kVAR, 150 kVAR and 600 kVAR, respectively. Finally it can be noticed from Table 7.13 that SAIDI value has been improved from 9.187138 hours/customer yr to 8.624611 hours/customer yr with the implementation of FEO. This time the SAIDI value obtained by FEO shown in Table 7.13 is lesser in magnitude from the SAIDI value achieved by FEO which can be found in Table 7.10. This further improvement has been caused due to the DG integrations at bus number 15, 18, 21, 25 and 30 with DG values of 100 kW, 200 kW, 200 kW, 200 kW and 200 kW at those selected locations. On the other hand, capacitor placements have also been performed at bus number 5, 7, 14, 19, 21, 25 and 31 with installed capacitor values of 300 kVAR, 150 kVAR, 150 KVAR, 150 kVAR, 750 kVAR, 750 kVAR and 300 kVAR, respectively. Finally it has been observed from Table 7.13 that SAIDI value has been found improved from 9.187138 hours/customer yr to 8.739185 hours/customer yr by the application of MCA. Distributed generator integrations have been performed at bus position 9, 10, 12, 15 and 22. The DG values have been selected as 200 kW, 200 kW, 200 kW, 100 kW and 200 kW, respectively at those bus locations. On the other hand, shunt capacitor allocations have been executed at bus number 10 and 18 with installed capacitor values of 600 kVAR and 1950 kVAR, respectively. In this case, the SAIDI value achieved by MCA shown in Table 7.13 is lesser than the SAIDI value obtained by MCA as observable in Table 7.12. In addition, it can be said from the above discussion that the SAIDI value found by FEO is the least amongst all the obtained SAIDI values by other algorithms.

Table 7.13: DG integrations and capacitor placements for SAIDI improvement at a maximum of 20% DG penetration in 34 bus microgrid based radial distribution system

Methods	SAIDI hours/customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	8.853253	200, 200, 200, 200	7, 10, 13, 24	1050, 750	11, 21
PSO	8.824094	100, 200	15, 21	150, 1650, 150, 600	2, 11,14, 22
FEO	8.624611	100, 200, 200, 200, 200	15, 18, 21, 25, 30	300, 150, 150, 150, 750, 750, 300	5, 7, 14, 19, 21, 25, 31
MCA	8.739185	200, 200, 200, 100, 200	9, 10, 12, 15, 22	600, 1950	10, 18
Without DG and capacitor placement	9.187138	-	-	-	-

The evolutionary techniques FEO and MCA have come out as the effective techniques noticeable in Table 7.11, Table 7.12 and Table 7.13 in comparison to other algorithms considered here. The improvement patterns of SAIDI by the application of FEO and MCA techniques have been shown in Figure 7.22 and Figure 7.23, respectively.

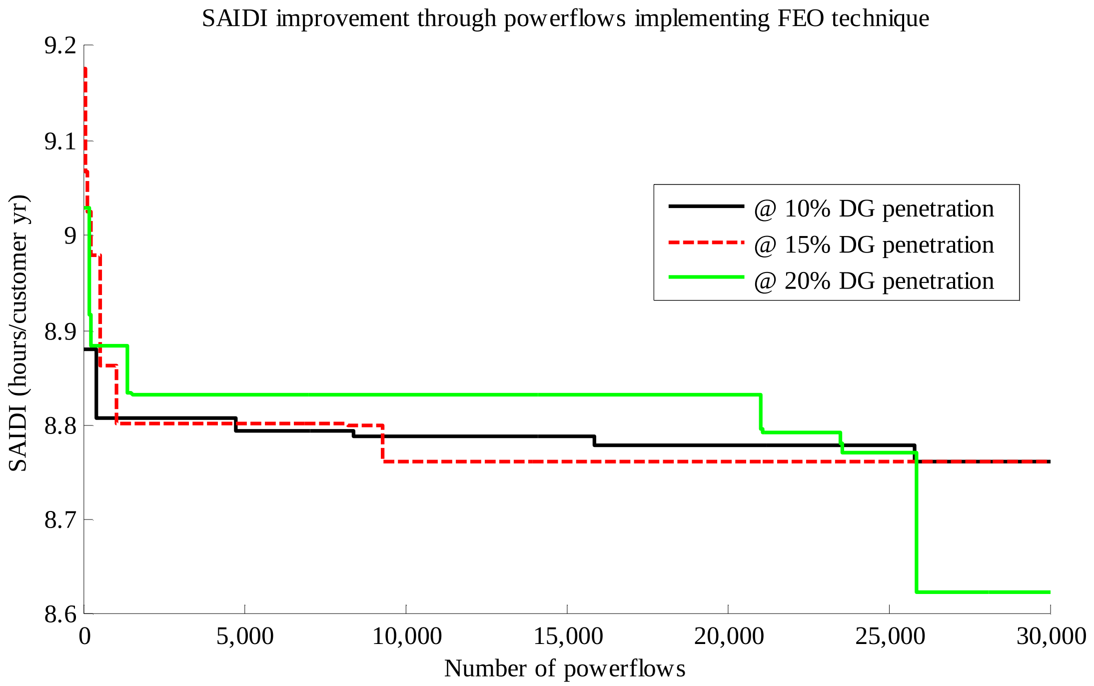

Figure 7.22: Improvement of SAIDI through power flows due to capacitor allocation and DG integration implementing FEO technique in 34 bus microgrid type radial distribution system

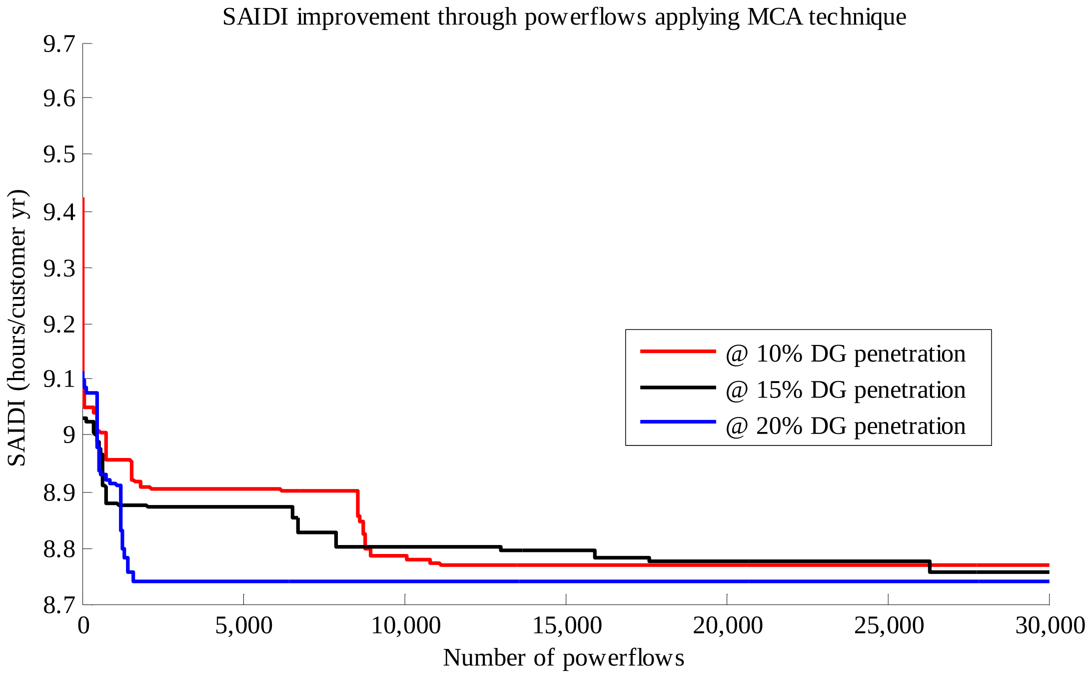

Figure 7.23: Improvement of SAIDI through power flows after DG integration and capacitor placement applying MCA technique in 34 bus microgrid type radial distribution system

As discussed in this section SAIDI value has been found improved from its initial value with the increase in maximum DG penetration level. The techniques MCA and FEO have also come out as the effective algorithms in this comparative study. Nevertheless there is always a chance of further improvement in SAIDI value with the increase in maximum DG penetration level. This has been studied later for a maximum of 50% DG penetration level considering futuristic plan. On the other hand, it is evident that the other considered reliability, cost and loss parameters apart from SAIDI will be modified due to the capacitor allocations and DG integrations considered in Table 7.11, Table 7.12 and Table 7.13. This has been briefly illustrated in the next section.

7.1.3.2 Effect of SAIDI improvement on total cost, reliability indices and real power loss

Suitable DG and capacitor positions and values have been selected by four evolutionary techniques for performing SAIDI improvement. This has been discussed in earlier section. Although, the other considered reliability indices apart from SAIDI has been changed from its initial value due to the placements of DG and capacitor. The total cost and real power loss have also been found reduced from its initial values due the said allocations of DG and capacitor. This modification or change in the stated reliability, cost and loss parameters apart from SAIDI has been discussed in the following section.

Total cost has been found reduced from initial value after performing DG integrations and capacitor allocations for SAIDI improvement shown in Figure 7.24. It has been observed from Figure 7.24 that total cost has been found increased implementing rcGA and PSO techniques with the increase of maximum DG penetration level from 10% to 15%. The total cost values found by FEO algorithm at a maximum of 10% and 15% DG penetrations are very close to each other. It can be noticed from Figure 7.24 that total cost has been increased applying MCA technique with the increase of maximum DG penetration level from 10% to 15%. The total cost value has been observed to be reduced applying rcGA, FEO and MCA techniques with the increase of maximum DG penetration level from 15% to 20%. On the other hand, it can be noticed from Figure 7.24 that total cost value has been increased utilizing PSO technique with the increase of maximum DG penetration level from 15% to 20%.

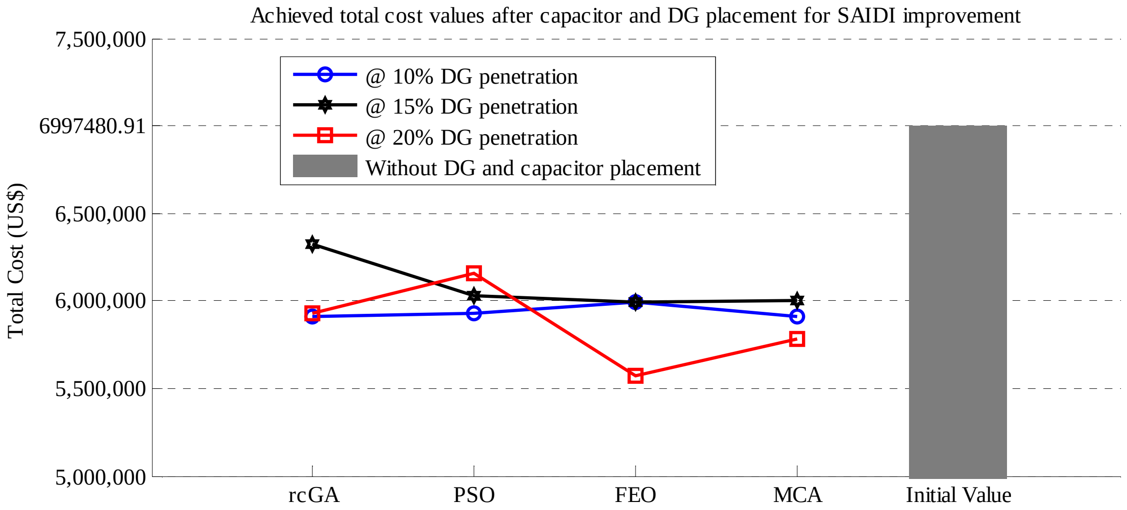

Figure 7.24: Total cost reduction due to capacitor allocations and DG penetrations for SAIDI improvement in 34 bus microgrid type radial distribution system

The customer oriented distribution system reliability index SAIFI has been observed to be reduced from its initial value after DG integration and capacitor placement for SAIDI improvement shown in Figure 7.25. It can be noticed from Figure 7.25 that SAIFI value has been increased after implementing rcGA technique with the increase of maximum DG penetration level from 10% to 15% and from 15% to 20%. It has also been observed from Figure 7.25 that SAIFI value has been increased and decreased applying PSO technique with the increase of maximum DG penetration level from 10% to 15% and from 15% to 20%, respectively. Unlike the SAIFI value change by the application of rcGA technique, the SAIFI value has been observed to be reduced upon implementing FEO and MCA techniques separately with the increase of maximum DG penetration level from 10% to 15% and from 15% to 20%.

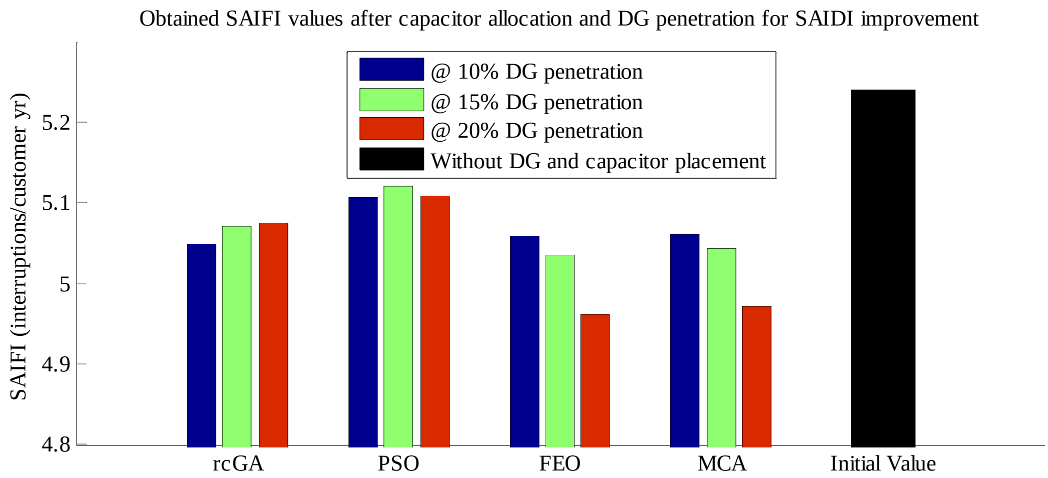

Figure 7.25: Change in SAIFI value due to capacitor and DG placements for SAIDI improvement in 34 bus microgrid type radial distribution system

The customer oriented distribution system reliability index CAIDI has been observed to be changed from its initial value due to capacitor placement and DG integration for SAIDI improvement shown in Figure 7.26. Random changes have occurred after capacitor allocation and DG integration for SAIFI improvement. Figure 7.26 shows a comparative study amongst rcGA, PSO, FEO and MCA techniques concerning to CAIDI value modification. However, the cause behind this random change is that the main objective is to reduce the SAIDI value. On the other hand, CAIDI is the ratio of SAIDI and SAIFI. The reliability index CAIDI is therefore dependent on the stated two parameters.

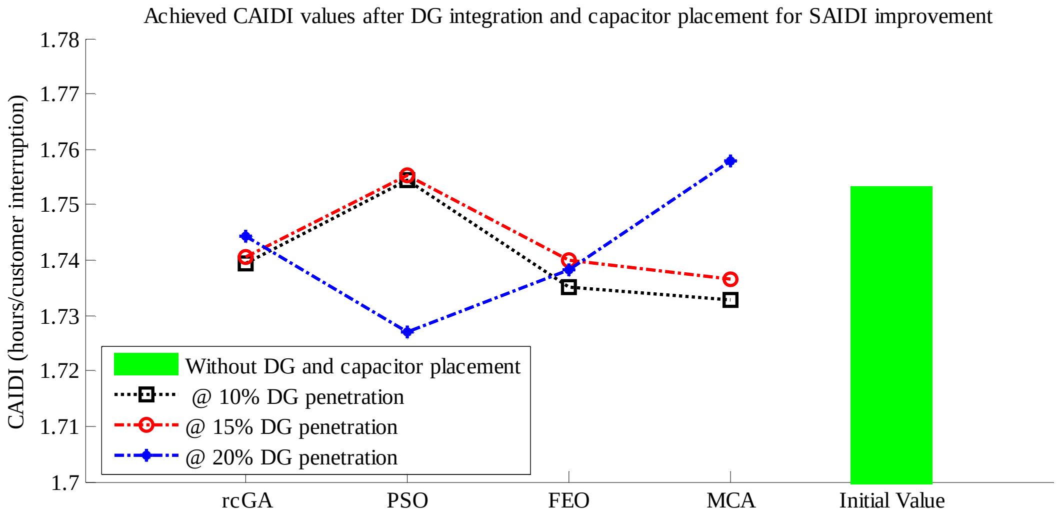

Figure 7.26: Modification in CAIDI value due to capacitor and DG allocations for SAIDI improvement in 34 bus microgrid type radial distribution system

The distribution system reliability index ASUI has been observed to be reduced from its initial value due to DG integration and capacitor allocation for SAIDI improvement shown in Figure 7.27. It has been observed from Figure 7.27 that ASUI value has been found increased after implementing rcGA and PSO techniques with the increment of maximum DG penetration level from 10% to 15%. It can also be noticed from Figure 7.27 that the ASUI value has been increased and decreased applying rcGA and PSO techniques, respectively with the increase of maximum DG penetration level from 15% to 20%. On the other hand, it has been observed from Figure 7.27 that ASUI value has also been found reduced after implementing FEO and MCA techniques with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. The least ASUI value has been found by FEO algorithm amongst all of the considered techniques.

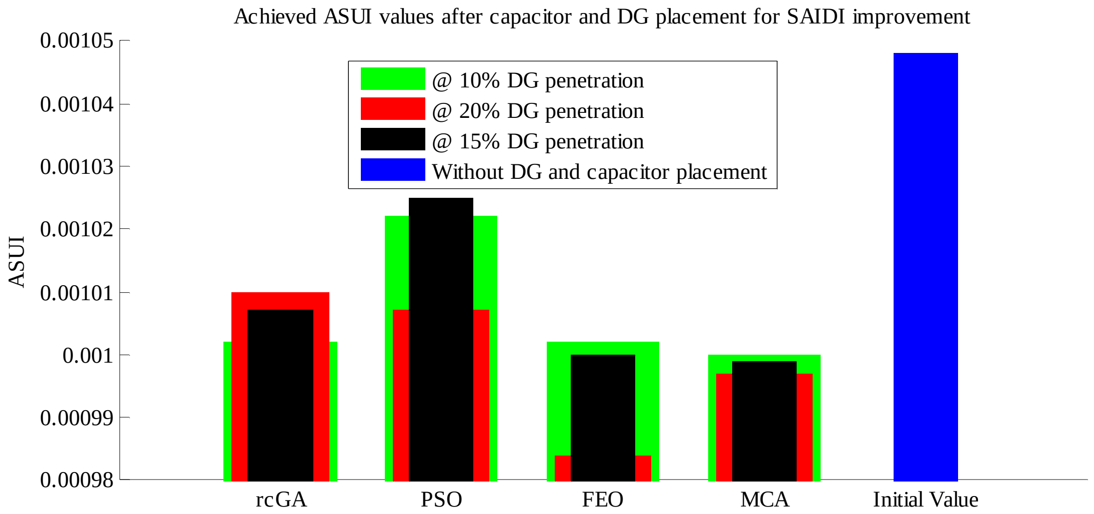

Figure 7.27: Change in ASUI value due to DG and capacitor placements for SAIDI improvement in 34 bus microgrid type radial distribution system

The load oriented distribution system reliability index AENS has been observed to be reduced from its initial value due to DG integration and capacitor placement for SAIDI improvement shown in Figure 7.28. It has been observed from Figure 7.28 that AENS value has been found increased after implementing rcGA technique with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. The AENS value has been observed to be increased and decreased applying PSO algorithm with the increase of maximum DG penetration level from 10% to 15% and from 15% to 20%, respectively. It can be noticed from Figure 7.28 that AENS value has been found reduced applying FEO and MCA techniques with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. The AENS values found by FEO technique at a maximum of 10% and 15% DG penetrations are very close to each other. On the other hand, it has been observed from Figure 7.28 that AENS values achieved by MCA technique at a maximum of 10%, 15% and 20% DG penetrations are close to each other. The least AENS value has been obtained by FEO algorithm amongst all the considered techniques.

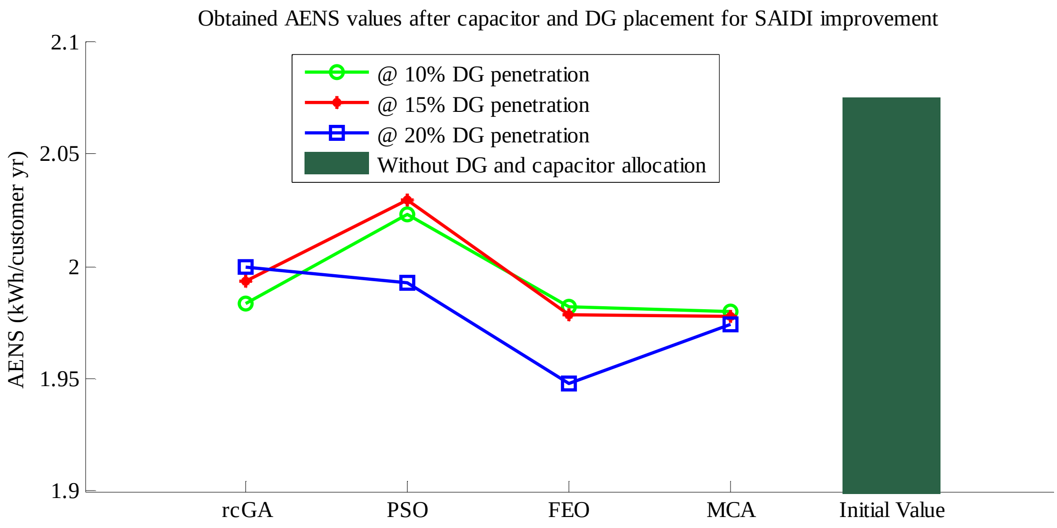

Figure 7.28: Modification in AENS value due to DG and capacitor allocations for SAIDI improvement in 34 bus microgrid type radial distribution system

The cost based reliability index (CBRI) has been observed to be increased from its initial value after capacitor placement and DG integration for SAIDI improvement shown in Figure 7.29. It can be noticed from Figure 7.29 that CBRI value has been reduced after implementing rcGA technique with the increment of maximum DG penetration level from 10% to 15%. Like the case of rcGA technique, PSO algorithm has also found decreased CBRI value with the increment of maximum DG penetration level from 10% to 15%. The CBRI value has been observed to be improved after applying FEO algorithm with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. On the other hand, the CBRI values found by MCA technique are nearly same at a maximum of 10% and 15% DG penetrations. The same scenario has been observed in the case of rcGA technique while finding the CBRI values at a maximum of 10% and 20% DG penetrations. The highest CBRI value has been found applying FEO technique amongst all the chosen algorithms at a maximum of 20% DG penetration.

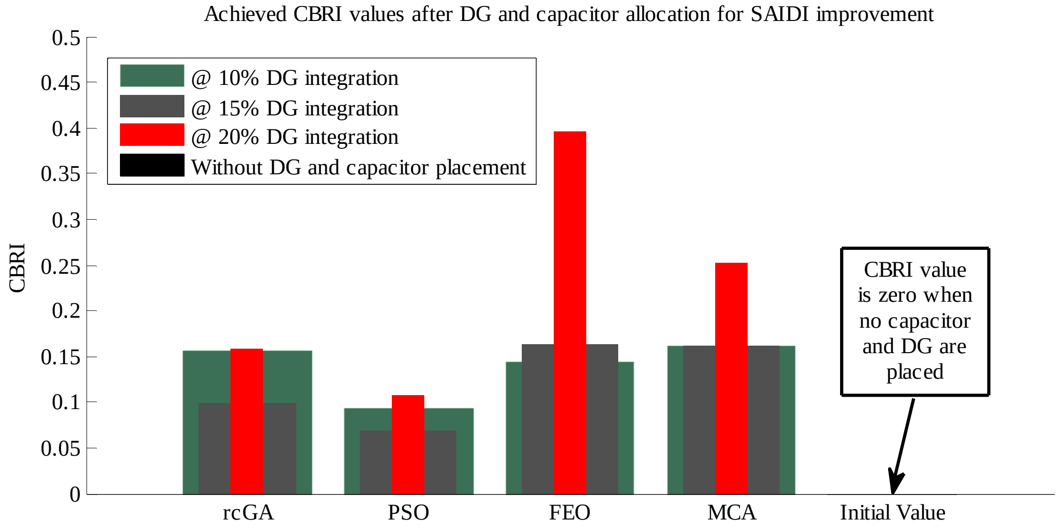

Figure 7.29: Change in CBRI value due to capacitor and DG placements for SAIDI improvement in 34 bus microgrid type radial distribution system

Real power loss values have been observed to be reduced from initial value after capacitor allocation and DG integration for SAIDI improvement shown in Figure 7.30. It has been observed from Figure 7.30 that real power loss values have been reduced upon applying FEO with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. On the other hand, real power loss value has been observed to be increased implementing PSO with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. This is due to the reason that the main objective is to improve SAIDI value not the reduction of real power loss. Again, the real power loss value has been observed to be increased implementing rcGA technique with the increment of maximum DG penetration level from 10% to 15%. On the other hand, the real power loss values have been found nearly same implementing MCA technique at a maximum of 10% and 15% DG penetrations. The least real power loss value has been achieved by FEO algorithm amongst all the considered techniques at a maximum of 20% DG penetration.

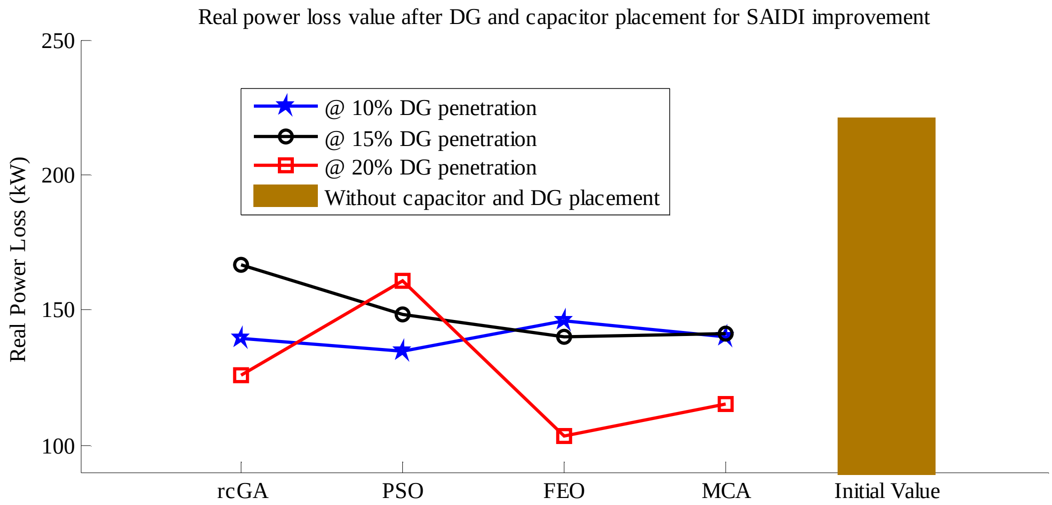

Figure 7.30: Real power loss reduction due to capacitor and DG allocations for SAIDI improvement in 34 bus microgrid type radial distribution system

Improvement of load oriented distribution system reliability index called average energy not supply (AENS) is also significant for study purpose like the earlier discussed reliability indices' improvements. The simulation studies concerning to this load-oriented reliability index improvement. These have been discussed in the next section.

7.1.4 Improvement of load-oriented distribution system reliability index AENS

Simultaneous capacitor placements and DG integrations have been executed suitably in 34 bus radial distribution system resembling microgrid for improvement of AENS value. This has been studied by implementing four evolutionary techniques on different DG penetration levels. The DG penetrations are up to 10%, 15% and 20% of the total active power load of the microgrid type radial distribution system at hand. These penetration levels have been selected considering different scenarios around the domain business level.

7.1.4.1 Discussion of DG integration and capacitor allocation

Distributed generation integrations have been performed at three levels along with the installation of capacitors. The improvement of distribution system load-oriented reliability index AENS has been studied at DG penetration levels up to 10%, 15% and 20% shown in Table 7.14, Table 7.15 and Table 7.16, respectively. The AENS value has been observed to be improved from 2.074900 kWh/customer yr to 2.008326 kWh/customer yr by the application of rcGA in Table 7.14. The stated reduction in AENS value has been occurred due to the DG placements at bus location 15 and 23 with DG values of 200 kW and 100 kW. Shunt capacitor allocation has also been performed at bus number 4, 14, 23 and 25 with installation of 150 kVAR, 150 kVAR, 1200 kVAR and 1050 kVAR, respectively. It can be noticed from Table 7.14 that AENS value has been found reduced from 2.074900 kWh/customer yr to 2.019738 kWh/customer yr with the implementation of PSO. Distributed generation integrations have been performed at bus position 18 and 21 with DG value of 200 kW at every selected location. Shunt capacitors have also been placed at bus number 3, 13, 19, 25 and 32. Capacitor values selected at those bus locations are 300 kVAR, 150 kVAR, 900 kVAR, 600 kVAR and 900 kVAR. Finally it has been observed from Table 7.14 that AENS value has been found improved from 2.074900 kWh/customer yr to

1.981444 kWh/customer yr with the implementation of FEO. The said reduction in AENS value has been caused due to simultaneous DG and capacitor placement at bus position 15 and 26; and 2, 3, 5, 8, 11, 14, 17, 22, 24 and 25, respectively. Distributed generation and capacitor values chosen for those selected locations are 200 kW and 200 kW; and 450 kVAR, 450 kVAR, 300 kVAR, 300 kVAR, 600 kVAR, 150 kVAR, 300 kVAR, 300 kVAR, 300 kVAR and 300 kVAR, respectively. The AENS value has been observed to be improved from 2.074900 kWh/customer yr to 1.991726 kWh/customer yr by the utilization of MCA. Distributed generation integration has been performed at bus number 14 and 31 with DG value of 200 kW at every selected location. Shunt capacitor allocation has also been executed at bus position 12, 13 and 22 with installed capacitor value of 750 kVAR, 150 kVAR and 1350 kVAR, respectively. It can be said from the above discussion that evolutionary technique FEO has found the least AENS value amongst all the chosen meta-heuristic algorithms. The next better position is held by the soft computing technique MCA in finding the better AENS value. The study related to the next DG penetration level i.e. up to 15% of the total active power load is also necessary to observe the improvement in AENS value.

Table 7.14: Capacitor installations and DG incorporations for AENS improvement at a maximum of 10% DG penetration in 34 bus microgrid type radial distribution system

Methods	AENS kWh/customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	2.008326	200, 100	15, 23	150, 150, 1200, 1050	4, 14, 23, 25
PSO	2.019738	200, 200	18, 21	300, 150, 900, 600, 900	3, 13, 19, 25, 32
FEO	1.981444	200, 200	15, 26	450, 450, 300, 300, 600, 150, 300, 300, 300, 300	2, 3, 5, 8, 11, 14, 17, 22, 24, 25
MCA	1.991726	200, 200	14, 31	750,150, 1350	12, 13, 22
Without DG and capacitor placement	2.074900	-	-	-	-

Like the above discussed paragraph, the AENS value has been observed to be improved from its initial value by the suitable placement of DG and capacitor at the load buses shown in Table 7.15. This time the maximum DG penetration level has been increased by 5% to observe the improvement in AENS value. It can be noticed from Table 7.15 that AENS value has been reduced from 2.074900 kWh/customer yr to 1.987160 kWh/customer yr with the implementation of rcGA. The AENS value obtained by rcGA has been further reduced as shown in Table 7.15 from the AENS value found by rcGA which can be observed in Table 7.14 due to the 5% increment in maximum DG penetration level. Distributed generation integration has been exercised at bus positions 13, 19 and 22 with DG value of 200 kW in every selected location. Capacitors are also placed at bus number 2, 9, 14, 20, 23, 28 and 33 with installed capacitor value of 300 kVAR, 450 kVAR, 150 kVAR, 600 kVAR, 750 kVAR, 300 kVAR and 600 kVAR, respectively. The AENS value has been observed to be improved from 2.074900 kWh/customer yr to 2.016453 kWh/customer yr by the utilization of PSO shown in Table 7.15. In this case the

AENS value found by PSO observable in Table 7.15 has also been found reduced from the AENS value achieved by PSO available in Table 7.14. Load bus number 10 and 30 have been chosen by PSO for allocating 200 kW of DG in each place. Shunt capacitors have been placed at bus positions 6, 13, 26 and 31 with installed capacitor value of 600 kVAR, 150 kVAR, 600 kVAR and 900 kVAR, respectively. It can be noticed from Table 7.15 that AENS value has been improved from 2.074900 kWh/customer yr to 1.970762 kWh/customer yr with the implementation of FEO. This time the AENS value obtained by FEO shown in Table 7.15 is lesser in magnitude from the AENS value achieved by FEO which can be found in Table 7.14. This further improvement has been caused due to the DG placements at bus number 8, 15, 23 and 28 with 100 kW, 100 kW, 200 kW and 200 kW of DG value. Capacitor placement has also been performed at bus number 4, 7, 13, 20 and 23 with installed capacitor value of 1800 kVAR, 450 kVAR, 150 kVAR, 300 kVAR and 750 kVAR, respectively. Finally it has been observed from Table 7.15 that AENS value has been found improved from 2.074900 kWh/customer yr to 1.980875 kWh/customer yr by the utilization of MCA. Distributed generator integration has been performed at bus position 15, 31 and 34. The DG value has been chosen as 100 kW, 200 kW and 200 kW, respectively at those selected locations. Shunt capacitor allocation has been executed at bus number 2, 14 and 22 with installed capacitor value of 1050 kVAR, 150 kVAR and 1500 kVAR, respectively. In this case, the AENS value achieved by MCA shown in Table 7.15 is lesser than the AENS value obtained by MCA noticeable in Table 7.14. In addition, it can be said from the above discussion that the AENS value found by FEO is the least amongst all the obtained AENS values by other algorithms. However, further 5% increment in maximum DG penetration level has been exercised to observe the improvement in AENS value which can be observed in Table 7.16.

Table 7.15: DG integrations and capacitor allocations for AENS improvement at a maximum of 15% DG penetration in 34 bus microgrid based radial distribution system

Methods	AENS kWh/customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	1.987160	200, 200, 200	13, 19, 22	300, 450, 150, 600, 750, 300, 600	2, 9, 14, 20, 23, 28, 33
PSO	2.016453	200, 200	10, 30	600, 150, 600, 900	6, 13, 26, 31
FEO	1.970762	100, 100, 200, 200	8, 15, 23, 28	1800, 450, 150, 300, 750	4, 7, 13, 20, 23
MCA	1.980875	100, 200, 200	15, 31, 34	1050, 150, 1500	2, 14, 22
Without DG and capacitor placement	2.074900	-	-	-	-

It can be noticed from Table 7.16 that AENS value has been found reduced from 2.074900 kWh/customer yr to 1.960456 kWh/customer yr with the implementation of rcGA. The AENS value obtained by rcGA has been further found reduced in Table 7.16 from the AENS value found by rcGA in Table 7.15 due to the 5% increment in maximum DG penetration level. Distributed generation integration has been exercised at bus positions 8, 14, 21, 22, 24, 28 and 33 with DG value of 100 kW in every selected location. Capacitors are also placed at bus number 3, 4, 5, 6, 7, 11, 14, 18, 21, 22, 25, 30 and 33 with installed capacitor value of 750 kVAR, 150 kVAR, 600 kVAR, 1050 kVAR, 300 kVAR, 150 kVAR, 150 kVAR, 450 kVAR, 150 kVAR, 450 kVAR, 150 kVAR, 150 kVAR and 300 kVAR, respectively.

Table 7.16: Capacitor placements and DG incorporations for AENS improvement at a maximum of 20% DG penetration in 34 bus microgrid type radial distribution system

Methods	AENS kWh/customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	1.960456	100, 100, 100, 100, 100, 100, 100	8, 14, 21, 22, 24, 28, 33	750, 150, 600, 1050, 300, 150, 150, 450, 150, 450, 150, 150, 300	3, 4, 5, 6, 7, 11, 14, 18, 21, 22, 25, 30, 33
PSO	1.983312	200, 100, 200, 200, 200	14, 17, 19, 27, 34	600, 1050, 150, 600, 450	4, 18, 21, 25, 34
FEO	1.956178	200, 200, 200, 100, 100	7, 8,11,15, 27	450, 150, 150, 300, 1050, 900	5, 9, 15, 18, 21, 31
MCA	1.958514	200, 200, 100, 200, 200	10, 14, 15, 30, 31	1050, 150, 750, 900	9, 14, 22, 25
Without DG and capacitor placement	2.074900	-	-	-	-

The AENS value has been observed to be improved from 2.074900 kWh/customer yr to 1.983312 kWh/customer yr by the utilization of PSO. In this case the AENS value found by PSO shown in Table 7.16 has been found reduced from the AENS values achieved by PSO observable in Table 7.14 and Table 7.15. Load bus position 14, 17, 19, 27 and 34 have been chosen by PSO for allocating 200 kW, 100 kW, 200 kW, 200 kW and 200 kW of DG. Shunt capacitors have been placed at bus positions 4, 18, 21, 25 and 34 with installed capacitor value of 600 kVAR, 1050 kVAR, 150 kVAR, 600 kVAR and 450 kVAR, respectively. It can be noticed from Table 7.16 that AENS value has been found improved from 2.074900 kWh/customer yr to 1.956178 kWh/customer yr with the implementation of FEO. This time the AENS value obtained by FEO which can be found in Table 7.16 is lesser in magnitude from the AENS value achieved by FEO as observable in Table 7.15. This further improvement has been caused due to the DG integrations at bus number 7, 8, 11, 15 and 27 with 200 kW, 200 kW, 200 kW, 100 kW and 100 kW of DG value at those selected locations. Capacitor placement has also been performed at bus number 5, 9, 15, 18, 21 and 31 with installed capacitor value of 450 kVAR, 150 kVAR, 150 kVAR, 300 kVAR, 1050 kVAR and 900 kVAR, respectively. Finally it has been observed from Table 7.16 that AENS value has been found improved from 2.074900 kWh/customer yr to 1.958514 kWh/customer yr by the utilization of MCA. Distributed generator integration has been performed at bus position 10, 14, 15, 30 and 31. The DG value has been chosen as 200 kW, 200 kW, 100 kW, 200 kW and 200 kW, respectively at those selected locations. Shunt capacitor allocation has been executed at bus number 9, 14, 22 and 25 with installed capacitor value of 1050 kVAR, 150 kVAR, 750 kVAR and 900 kVAR, respectively. In this case, the AENS value achieved by MCA available in Table 7.16 is lesser than the AENS value obtained by MCA shown in Table 7.15. In addition, it can be said from the above discussion that the AENS value found by FEO is the least amongst all the obtained AENS values by other algorithms.

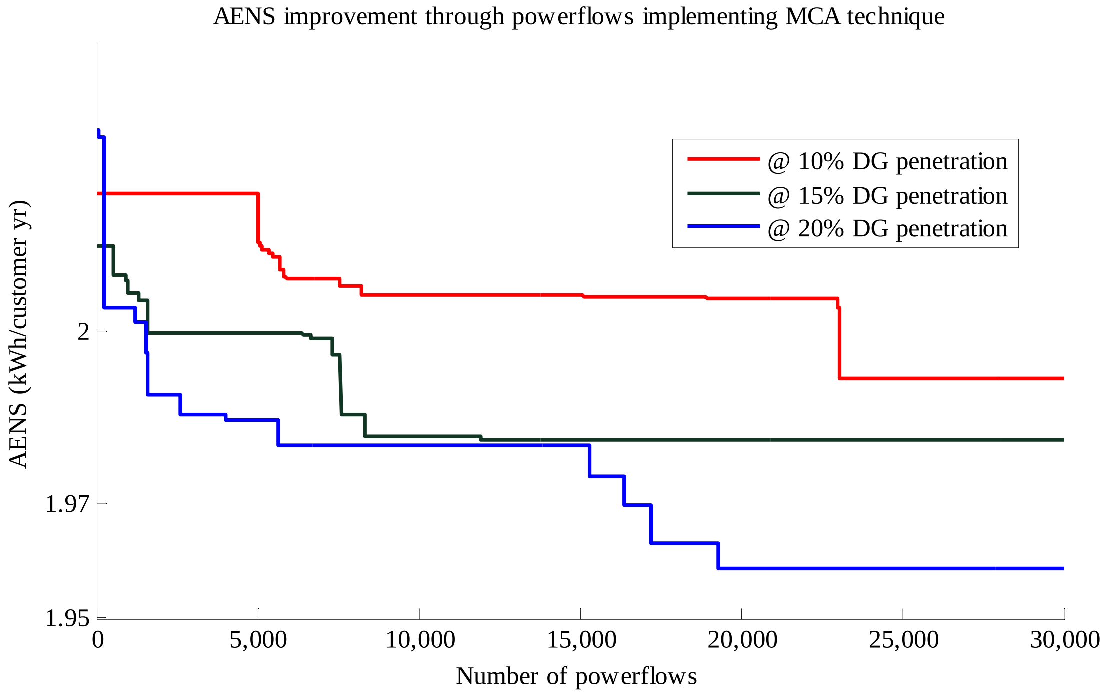

Figure 7.31: Improvement of AENS through power flows after capacitor allocations and DG integrations applying MCA technique in 34 bus microgrid type radial distribution system

As discussed in this section AENS value has been found improved from its initial value with the increase in maximum DG penetration level. The techniques MCA and FEO have come out as the effective algorithms in this comparative study. The improvement pattern of AENS through power flows (iterations) implementing MCA technique has been depicted in Figure 7.31. Nevertheless there is always a chance of further improvement in AENS value with the increase in DG penetration level. This has been studied later for a maximum of 50% DG penetration level considering futuristic plan. On the other hand, it is evident that the other considered cost, reliability and loss parameters apart from AENS will be modified due to the capacitor allocations and DG integrations considered in Table 7.14, Table 7.15 and Table 7.16. This has been briefly illustrated in the next section.

7.1.4.2 Modification in total cost, reliability indices and real power loss due to AENS improvement

Suitable DG and capacitor positions and values have been selected by four evolutionary techniques for performing AENS improvement. This has been discussed in earlier section. Although, the other considered reliability indices apart from AENS has been found changed from its initial value due to the placements of DG and capacitor. The total cost and real power loss have also been reduced from its initial values due the said allocations of DG and capacitor. This modification or change in the stated reliability, cost and loss parameters apart from AENS has been discussed in the following section.

Total cost has been found reduced from initial value after performing capacitor allocations and DG integrations for AENS improvement. The reduction of total cost due to the mentioned AENS improvement implementing four meta-heuristic techniques has been depicted in Figure 7.32. It has been observed from Figure 7.32 that total cost values obtained by rcGA, PSO, FEO and MCA are comparatively lesser in magnitude at a maximum of 20% DG penetration from other total cost values considering DG penetrations up to 10% and 15%, respectively. The total cost value obtained by rcGA at a maximum of 10% DG penetration is the highest amongst all the obtained total cost values. On the other hand, it can be noticed from Figure 7.32 that the achieved total cost values applying rcGA are almost same for a maximum of 15% and 20% DG penetrations. Similarly, in the case of MCA technique the total cost values are nearly same in magnitude for a maximum of 10% and 15% DG penetrations. It can also be noticed from Figure 7.32 that all the three total cost values at a maximum of 10%, 15% and 20% DG penetrations are close to each other for the case of FEO algorithm. Surprisingly, the total cost value is higher at a maximum of 15% DG penetration in comparison to DG penetration up to 10% for the case of PSO technique. This is due to the reason that the primary aim is to reduce the AENS value and not the total cost value. Nevertheless, the least total cost value has been obtained by PSO algorithm at a maximum of 20% DG penetration amongst all the considered techniques for AENS improvement.

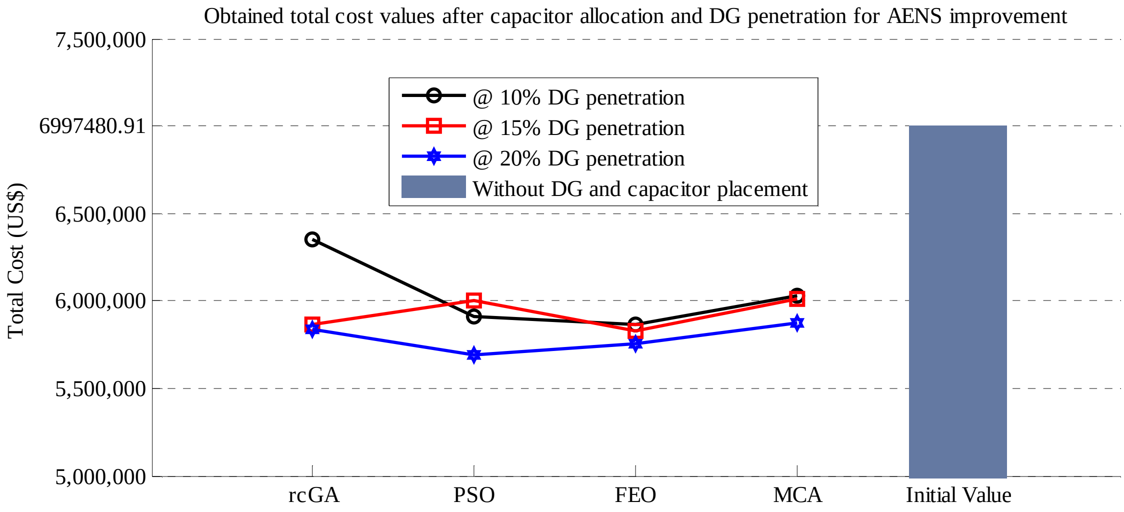

Figure 7.32: Total cost reduction due to capacitor and DG allocations for AENS improvement in 34 bus microgrid type radial distribution system

Distribution system reliability index SAIFI value has been observed to be improved from initial value due to capacitor and DG placements for AENS improvement in Figure 7.33. The least SAIFI values have been found by FEO technique at a maximum of 10% and 15% DG penetrations amongst all the chosen algorithms. On the other hand, the rcGA technique has obtained the least SAIFI value amongst all the considered techniques at a maximum of 20% DG penetration. It can be noticed from Figure 7.33 that the SAIFI values found implementing FEO and MCA techniques are close to each other at a maximum of 20% DG penetration. The PSO algorithm performs poorly in finding better SAIFI values at a maximum of 15% and 20% DG penetrations amongst all the considered techniques as shown in Figure 7.33.

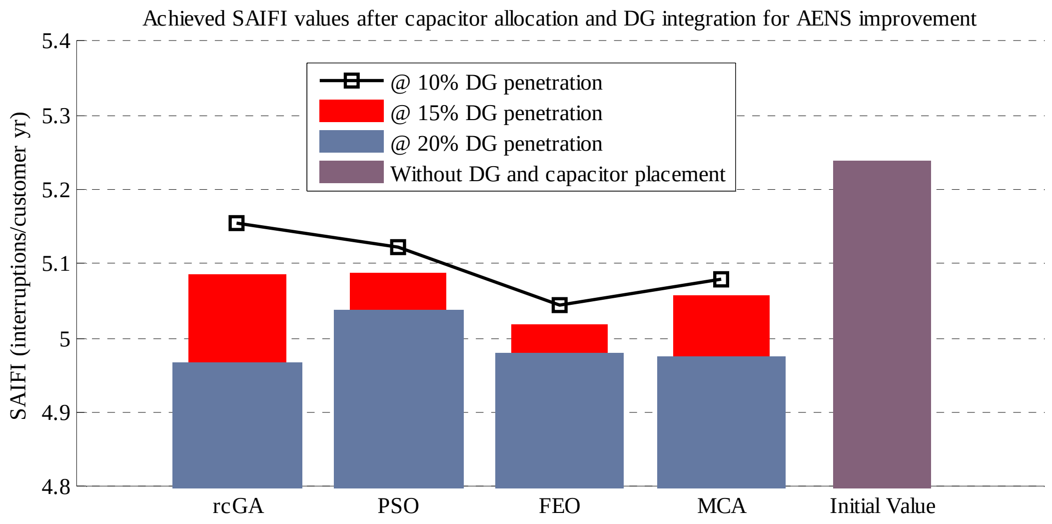

Figure 7.33: Change in SAIFI value due to capacitor and DG placement for AENS minimization in 34 bus microgrid type radial distribution system

Customer oriented distribution system reliability index SAIDI has been observed to be reduced from its initial value due to capacitor allocation and DG integration for AENS improvement shown in Figure 7.34. It has been observed from Figure 7.34 that SAIDI values have been found decreased with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20% for all the considered techniques. The least SAIDI value has been obtained by FEO technique amongst all the chosen techniques at a maximum of 10%, 15% and 20% DG penetrations. The next better position is secured by MCA technique in finding the better SAIDI value at all the three DG penetration levels. It has been observed from Figure 7.34 that the worst SAIDI values have been found by PSO algorithm at all the three DG penetration levels.

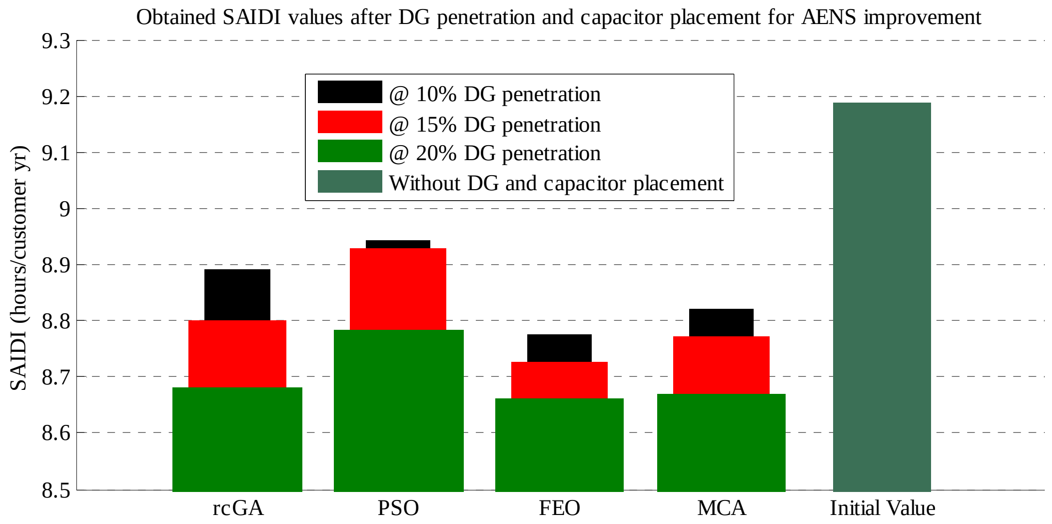

Figure 7.34: Modification in SAIDI value due to DG and capacitor allocation for AENS improvement in 34 bus microgrid type radial distribution system

Customer average interruption duration index (CAIDI) value has been observed to be changed after DG integration and capacitor placement for AENS improvement as observable in Figure 7.35. A random change has occurred in CAIDI value implementing all the four algorithms. This is due to the reason that the main objective is to improve the AENS value not the CAIDI value. On the other hand, CAIDI value is the ratio of SAIDI and SAIFI. So, it is dependent on the change of SAIDI and SAIFI.

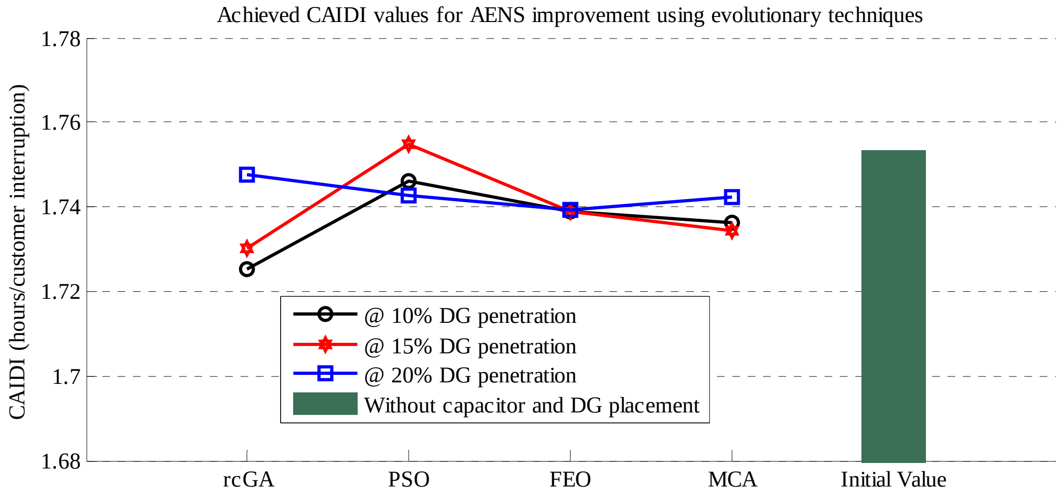

Figure 7.35: Change in CAIDI value due to DG and capacitor placement for AENS minimization in 34 bus microgrid type radial distribution system

The ASUI values found by rcGA, PSO, FEO and MCA techniques have been found reduced from initial value due to capacitor allocation and DG penetration for AENS improvement shown in Figure 7.36. It has been observed from Figure 7.36 that ASUI values obtained by four algorithms have been decreased with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. The least ASUI values at a maximum of 10% and 15% DG penetrations have been achieved by FEO technique amongst all the chosen algorithms. It can be noticed from Figure 7.36 that ASUI values obtained by rcGA, FEO and MCA techniques are nearly same at a maximum of 20% DG penetration. Only the ASUI value found by PSO technique is higher than that value obtained by other three algorithms. The ASAI values have not been enumerated here as it can easily be found out by subtracting the ASUI values from unity as stated earlier.

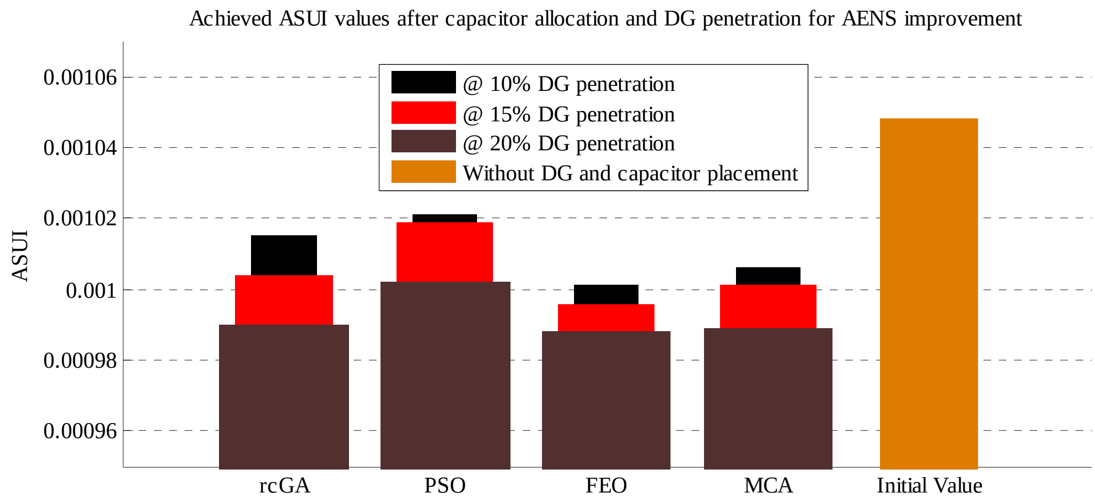

Figure 7.36: Modification in ASUI value due to capacitor and DG allocation for AENS improvement in 34 bus microgrid type radial distribution system

The newly developed reliability index CBRI has also been observed to be increased from its initial value after DG penetration and capacitor allocation for AENS improvement as shown in Figure 7.37. The CBRI values have been found increased upon applying rcGA, FEO and MCA with the increment of maximum DG penetration level from 10% to 15% and from 15% to 20%. It can be noticed from Figure 7.37 that the CBRI values found by PSO technique are close to each other at a maximum of 10% and 15% DG penetrations. The highest CBRI value has been achieved by FEO technique at a maximum of 20% DG penetration.

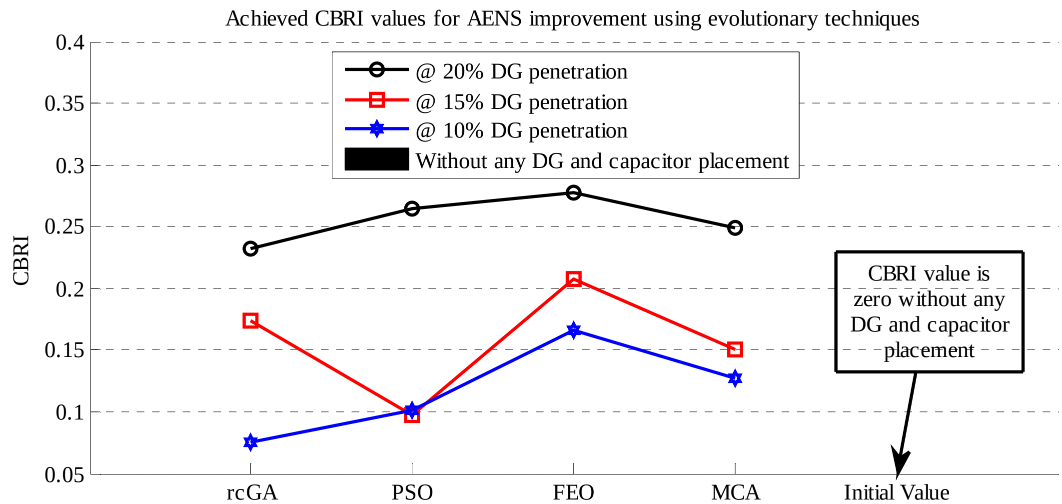

Figure 7.37: Change in CBRI value due to capacitor and DG allocation for AENS improvement in 34 bus microgrid type radial distribution system

Real power loss has been observed to be reduced from its initial value after capacitor allocation and DG integration for AENS improvement shown in Figure 7.38. It can be noticed from Figure 7.38 that real power loss value found by rcGA technique has been reduced with the increment of maximum DG penetration level from 10% to 15%. But the real power loss obtained after implementing rcGA at a maximum of 20% DG penetration is close to the value at a maximum of 15% DG penetration noticeable in Figure 7.38. On the other hand, it can be noticed from Figure 7.38 that real power loss value has been increased applying PSO with the increase in maximum DG penetration level from 10% to 15%. This is due to the reason that the main objective is to improve AENS not the real power loss. The least real power loss value has been achieved by PSO algorithm at a maximum of 20% DG penetration amongst all the chosen techniques. The real power loss values found by FEO and MCA techniques at a maximum of 10% and 15% DG penetrations are nearly same. In addition, the real power loss values have been found reduced after implementing MCA and FEO algorithms with the increase in maximum DG penetration level from 15% to 20%.

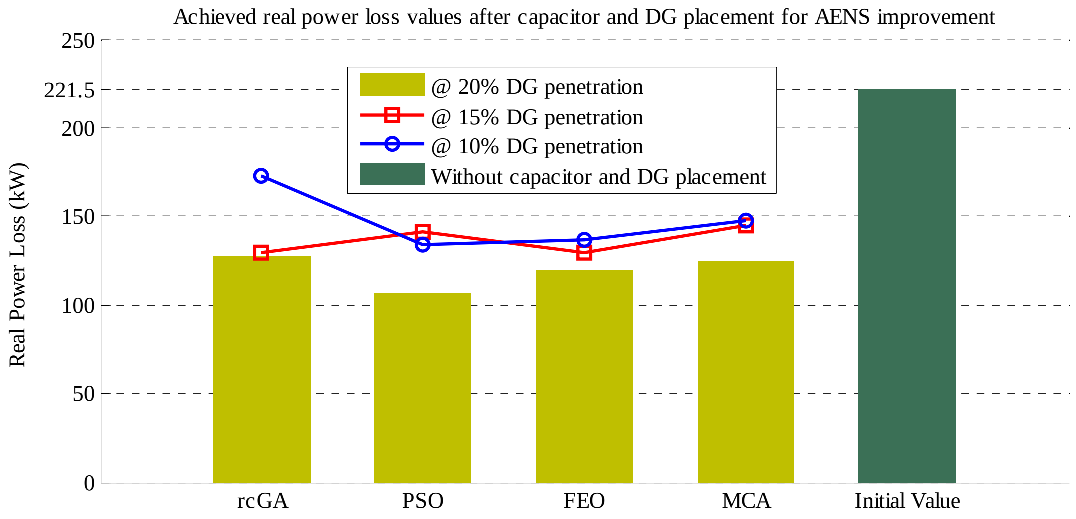

Figure 7.38: Real power loss reduction due to capacitor and DG placement for AENS improvement in 34 bus microgrid type radial distribution system

Total cost minimization and improvement of three important distribution system reliability indices viz. SAIFI, SAIDI and AENS have been discussed so far. All the considered situations are single objective. Nevertheless, multi-objective optimization is crucial for distribution system planning purpose. This is due to the reason that consideration of multiple conflicting objectives will provide a choice for the decision makers to select a particular solution. The multi-objective optimizations leading to appropriate planning have been performed after single objective optimizations considering a maximum of 50% DG penetration for futuristic scenario in the next section.

7.2 Appropriate futuristic planning considering capacitor allocation and DG integration

Single objective optimizations have been performed on thirty four bus microgrid type radial distribution system incorporating capacitor and distributed generation (DG) considering DG penetration up to 50%. The DG penetration level has been selected up to 50% of the total active power load keeping the futuristic situation in mind. The 50% DG penetration by simulation has been performed to analyze the corresponding reliability enhancement, loss reduction and total cost minimization individually and simultaneously leading to appropriate planning. The DG values have been selected as 100 kW and 200 kW, respectively as discussed earlier [244]. The DG sizes have been selected considering the load values of the microgrid based radial distribution system at hand. The reinforcement scheme for the distribution network has been considered as lateral protection supported by disconnects as this is standard and common. All the bus and line data and capacitor value and cost concerning to the chosen distribution system have been taken from elsewhere as stated earlier [242].

7.2.1 Real power loss minimization after enhanced (50%) DG integration

Real power loss has been reduced by performing DG integration and reactive power compensation by shunt capacitor. The DGs and shunt capacitors have been suitably selected and placed in the considered microgrid type radial distribution system by the four evolutionary computation techniques. The comparative study has been shown in Figure 7.39 and Table 7.17, respectively. It has been observed from Figure 7.39 and Table 7.17 that real power loss has been found reduced from 221.5 kW to 68.42 kW after placing DG at bus locations 4, 12, 13, 16, 20, 22, 23, 27, 31 and 34, respectively by the soft computing technique PSO. The DG values chosen at those particular bus positions are 200 kW, 100 kW, 200 kW, 100 kW, 100 kW, 200 kW, 200 kW, 200 kW, 200 kW and 200 kW, respectively. Reactive power compensations by shunt capacitor at bus locations 11, 17, 18 and 25 have also been performed by PSO. The capacitor values selected at those bus positions are 600 kVAR, 450 kVAR, 750 kVAR and 600 kVAR, respectively. It can be noticed from Figure 7.39 that real power loss has been found diminished from 221.5 kW to 59.95 kW by the implementation of rcGA. Distributed generator integration has been performed at bus location 3, 5, 6, 7, 8, 14, 15, 19, 20, 21, 22, 23, 25, 26, 29, 30 and 32, respectively shown in Table 7.17. The DG value chosen by rcGA for those selected locations are 100 kW, 100 kW, 100 kW, 200 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 200 kW, 100 kW, 200 kW, 100 kW, 200 kW, 100 kW, 200 kW and 200 kW, respectively. Shunt capacitor value chosen by rcGA at bus number 15, 16, 21, 25, 27 and 29 are 300 kVAR, 750 kVAR, 300 kVAR, 750 kVAR, 750 kVAR and 450 kVAR, respectively. Finally it has been observed from Figure 7.39 that real power loss has been found reduced from 221.5 kW to 57.41 kW by the application of FEO. The distributed generators have been placed at bus number 2, 4, 5, 12, 19, 22, 25, 26, 28, 29 and 32 shown in Table 7.17. The DG value chosen at those bus locations are 200 kW, 100 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW and 200 kW, respectively. Shunt capacitor values selected at bus locations 9, 14, 21 and 27 are 450 kVAR, 1200 kVAR, 900 kVAR and 450 kVAR, respectively. Lastly it has been observed from Figure 7.39 that real power loss has been found decreased from 221.5 kW to 41.98 kW by the implementation of MCA. The DG values have been selected by MCA. The bus numbers are 6, 8, 9, 13, 17, 18, 19, 20, 21, 24, 27, 29, 31 and 32 with values 100 kW, 200 kW, 200 kW, 100 kW, 200 kW, 100 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 100 kW and 100 kW, respectively. This can be observed in Table 7.17. Shunt capacitor values chosen at bus number 8, 21, 27 and 28 are 750 kVAR, 600 kVAR, 900 kVAR and 450 kVAR, respectively. It can be said from the above discussion that soft computing technique MCA has generated the least real power loss value amongst all the considered evolutionary techniques. Cost due to real power loss has an influence on total cost. The study of total cost minimization is very important to understand as it is connected with reliability worth [119].

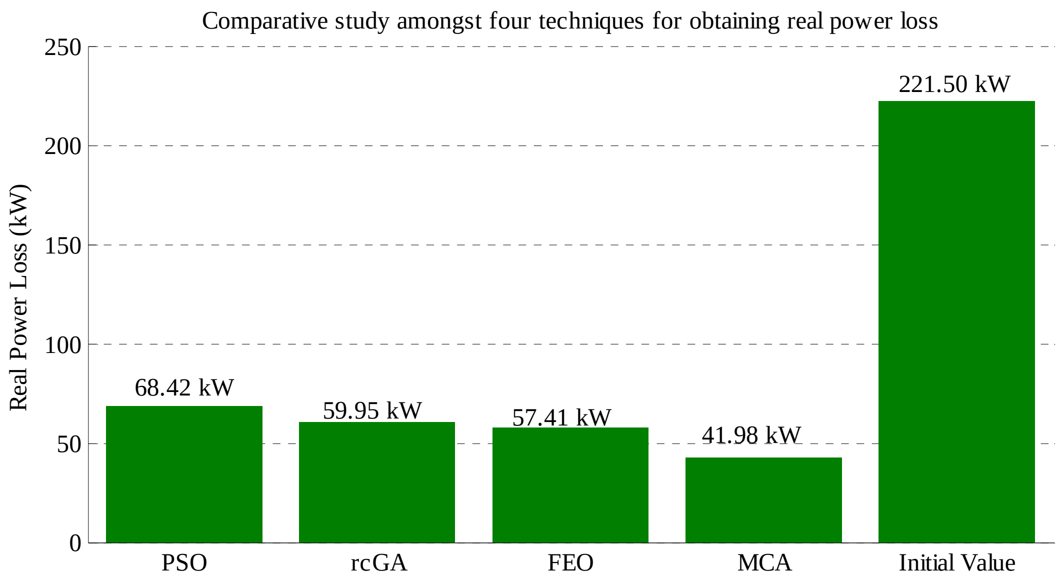

Figure 7.39: Comparison of real power loss values for thirty four bus microgrid type radial distribution system at a maximum of 50% DG penetration

Table 7.17: Simulation results of DG integration and capacitor placement for real power loss minimization in 34 bus microgrid type radial distribution system considering a maximum of 50% DG penetration

Methods	DG placement	DG value (kW)	Capacitor placement	Capacitor value (kVAR)
PSO	4,12, 13, 16, 20, 22, 23, 27, 31, 34	200, 100, 200, 100, 100, 200, 200, 200, 200, 200	11, 17, 18, 25	600, 450, 750, 600
rcGA	3, 5, 6, 7, 8,14, 15, 19, 20, 21, 22, 23, 25, 26, 29, 30, 32	100, 100, 100, 200, 100, 100, 100, 100, 100, 200, 100, 200, 100, 200, 100, 200, 200	15, 16, 21, 25, 27, 29	300, 750, 300, 750, 750, 450
FEO	2, 4, 5, 12, 19, 22, 25, 26, 28, 29, 32	200, 100, 200, 200, 200, 200, 200, 200, 200, 200, 200	9, 14, 21, 27	450, 1200, 900, 450
MCA	6, 8, 9,13, 17, 18, 19, 20, 21, 24, 27, 29, 31, 32	100, 200, 200, 100, 200, 100, 200, 200, 200, 200, 200, 200, 100, 100	8, 21, 27, 28	750, 600, 900, 450

7.2.2 Simulation results for total cost minimization for a maximum of 50% DG integration

Like the previously discussed section of single objective simulation dealing with real power loss, the total cost in this case has been found reduced from its original value i.e. without DG and capacitor connectivity by the application of the selected four soft computing techniques. The simulation result for this specific study is shown in Table 7.18. It has been observed from Table 7.18 that total cost has been found reduced from US$ 6997480.91 to US$ 5468756.17 by the implementation of PSO. The DG values chosen by PSO at bus locations 9, 20, 23, 24, 26 and 31 are 100 kW, 200 kW, 100 kW, 200 kW, 200 kW and 200 kW, respectively. Reactive power compensation has also been performed by allocating shunt capacitors by PSO at bus positions 4, 10, 20, 22 and 28. The capacitor values selected at those bus locations are 600 kVAR, 600 kVAR, 150 kVAR, 1200 kVAR and 150 kVAR, respectively. It can be noticed from Table 7.18 that the total cost has been found reduced from US$ 6997480.91 to US$ 5355163.65 by the application of rcGA. The DG integration has been performed by rcGA at bus number 6, 9, 10, 12, 13, 19, 21, 22, 25, 26, 27, 29, 32 and 33. The DG value selected by rcGA for every bus position is 100 kW. Shunt capacitors have been allocated at bus number 3, 4, 7, 8, 10, 13, 17, 19, 20, 22, 23, 24, 25, 26, 30, 32, 33 and 34. Capacitor values chosen by rcGA at those stated locations are 300 kVAR, 150 kVAR, 150 kVAR, 300 kVAR, 150 kVAR, 150 kVAR, 450 kVAR, 150 kVAR, 150 kVAR, 300 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 150 kVAR, 150 kVAR and 150 kVAR, respectively. Finally it has been observed from Table 7.18 that total cost has been found reduced from US$ 6997480.91 to US$ 5349990.64 by the implementation of FEO. Distributed generators have been placed at bus locations 5, 10, 12, 18, 21, 24, 25, 27 and 34. The DG value chosen at those mentioned bus positions are 200 kW, 100 kW, 100 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW and 200 kW, respectively. Furthermore, shunt capacitors have been sited at the bus number 5, 9 and 25. Capacitor values selected by FEO at those bus positions are 150 kVAR, 750 kVAR and 1350 kVAR, respectively. Lastly it has been noticed from Table 7.18 that the total cost has been found diminished from US$ 6997480.91 to US$ 5101151.83 with the implementation of MCA. Distributed generators have been placed at bus position 5, 7, 9, 11, 15, 19, 20, 23, 24, 27 and 29. The DG values chosen at those selected locations are 100 kW, 200 kW, 200 kW, 200 kW, 100 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW and 200 kW, respectively. Reactive power compensation has also been performed by sitting shunt capacitor at bus location 12, 19 and 22. Capacitor values chosen at those selected bus positions are 750 kVAR, 600 kVAR and 1050 kVAR, respectively.

Table 7.18: Comparative study amongst PSO, rcGA, FEO and MCA for total cost minimization in 34 bus microgrid type radial distribution system considering a maximum of 50% DG penetration

Methods	Total cost (US$)	DG placement	DG value (kW)	Capacitor placement	Capacitor value (kVAR)
PSO	5468756.17	9, 20, 23, 24, 26, 31	100, 200, 100, 200, 200, 200	4, 10, 20, 22, 28	600, 600, 150, 1200, 150
rcGA	5355163.65	6, 9, 10,12, 13, 19, 21, 22, 25, 26, 27, 29, 32, 33	100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100	3, 4, 7, 8, 10, 13, 17, 19, 20, 22, 23, 24, 25, 26, 30, 32, 33, 34	300, 150, 150, 300, 150, 150, 450, 150, 150, 300, 150, 150, 150, 150, 150, 150, 150, 150
FEO	5349990.64	5, 10, 12, 18, 21, 24, 25, 27, 34	200, 100, 100, 200, 200, 200, 200, 200, 200	5, 9, 25	150, 750, 1350
MCA	5101151.83	5, 7, 9, 11, 15, 19, 20, 23, 24, 27, 29	100, 200, 200, 200, 100, 200, 200, 200, 200, 200, 200	12, 19, 22	750, 600, 1050
Without any DG and capacitor placement	6997480.91	-	-	-	-

It can be concluded from the above discussion that MCA has outperformed other algorithms in finding the least total cost value as observable in Table 7.18. Total cost has a part termed power interruption cost as stated earlier. Power interruption cost is connected with the failure rate of load point. This cost reduces as the failure rate decreases in line. Failure rate is reduced with the reduction of resitive line loss as this has heating and melting effect on electric line. It is a known fact that resitive line loss is proportional to the square of current magnitude. So with the reduction of current magnitude in branches failure rate improves and this in turn reduces the cost. The study of current magnitude variation after DG and capacitor placements has been shown in Table 7.19. It has been observed from Table 7.19 that current magnitudes in branches 4-5, 5-6, 6-7 and 8-9 have been found reduced from 0.4442 p.u to 0.1938 p.u, from 0.4189 p.u to 0.1820 p.u, from 0.1438 p.u to 0.0468 p.u and from 0.0926 p.u to 0.0468 p.u, respectively. This reduction in current magnitude has been caused due to the DG integrations of 100 kW, 200 kW and 200 kW at bus location 5, 7 and 9 as observable in Table 7.19. Distributed generation integration locally caters the load and reduces the circuit current. It has also been observed from Table 7.18 and Table 7.19 that distributed generator has been placed at bus number 11, 15, 19, 20, 23, 24, 27 and 29. It can be noticed from Table 7.19 that current values in branches 14-15, 18-19, 19-20, 22-23, 23-24 and 28-29 have been found reduced from initial values i.e. without DG and capacitor connectivity. It has been observed from Table 7.19 that current magnitudes in branches 10-11 and 11-12 have been found increased from 0.0409 p.u to 0.0509 p.u and from 0.0151 p.u to 0.0628 p.u, respectively. This is not a desirable phenomenon. It is shown in bold format in Table 7.19. Though DG value of 200 kW has been placed at bus number 11 by MCA technique as observable in Table 7.19 but capacitor value of 750 kVAR has been selected by MCA technique at bus location 12. This capacitor allocation increases the reactive component of current. This in turn increases the current magnitude which is a combination of active and reactive component. Though increase in current magnitude augments the failure rate and resitive line loss for those branches but system line loss and failure rates of other lines get reduced due to the effect of capacitor allocation and DG integration. It has been observed from Table 7.19 that resistive line loss has been found reduced from 221.5 kW to 49.73 kW. The current values in other branches such as 1-2, 2-3 and 3-13 have been found reduced from 0.5193 p.u to 0.2518 p.u, from 0.4945 p.u to 0.2290 p.u and from 0.0249 p.u to 0.1938 p.u, respectively. These reductions in current magnitudes in most of the branches help to reduce failure rates and eventually decrease the total cost.

Table 7.19: Study of current magnitude for total cost minimization by applying MCA technique in 34 bus microgrid type radial distribution system considering DG penetration up to 50%

Branch	Current in p.u without DG and capacitor allocation	Current in p.u after DG and capacitor allocation	Loss in kW without DG and capacitor placement	Loss in kW after DG and capacitor placement	DG placement chosen by MCA technique	DG value in kW selected by MCA technique
1-2	0.5193	0.2518	221.5	49.73	5, 7, 9, 11, 15, 19, 20, 23, 24, 27, 29	100, 200, 200, 200, 100, 200, 200, 200, 200, 200, 200
2-3	0.4945	0.2290				
3-13	0.0249	0.0176				
4-5	0.4442	0.1938				
5-6	0.4189	0.1820				
6-7	0.1438	0.0465				
8-9	0.0926	0.0468				
10-11	**0.0409**	**0.0509**				
11-12	**0.0151**	**0.0628**				
14-15	0.0092	0.0049				
18-19	0.2237	0.1003				
19-20	0.1979	0.0893				
22-23	0.1202	0.0746				
23-24	0.0942	0.0624				
24-25	0.0680	0.0508				
26-27	0.0154	0.0099				
28-29	0.0168	0.0099				
29-30	0.0083	0.0081				

Reliability enhancement by performing minimization of reliability indices has also been considered here. In this regard, a comparative study regarding customer oriented reliability index SAIFI improvement is important to understand.

7.2.3 Discussion of results related to SAIFI improvement for enhanced DG integration

For futuristic situations effect of enhanced DG integration on customer oriented reliability index SAIFI (system average interruption frequency index) has to be understood thoroughly. It can be observed from Figure 7.40 and Table 7.20 that SAIFI has been found improved from the initial value i.e. without DG and capacitor integration. This is achieved after optimal implementation of four evolutionary computation techniques. It has been observed from Figure 7.40 that SAIFI value has been found improved from 5.240010 interruptions/customer yr to 5.012375 interruptions/customer yr by the application of PSO. The distributed generators have been placed at bus number 6, 15, 27, 29 and 31 shown in Table 7.20. The DG values selected by PSO at those mentioned bus positions are 200 kW, 100 kW, 200 kW, 200 kW and 100 kW, respectively. Shunt capacitors have been allocated by PSO at bus locations 5, 11, 20 and 27. Capacitor values chosen at those mentioned bus positions are 600 kVAR, 600 kVAR, 1050 kVAR and 450 kVAR, respectively. It can be noticed from Figure 7.40 that SAIFI value has been found reduced from

5.240010 interruptions/customer yr to 4.790627 interruptions/customer yr with the implementation of rcGA. The distributed generators have been allocated after applying rcGA at bus number 9, 12, 14, 20, 21, 23, 24, 25, 26, 27 and 34 shown in Table 7.20. The chosen DG values for those selected bus positions are 100 kW, 200 kW, 100 kW, 100 KW, 200 kW, 100 kW, 200 kW, 100 kW, 200 kW, 200 kW and 200 kW. Reactive power compensation has also been performed by rcGA placing shunt capacitors at bus number 2, 6, 9, 21 and 27. Capacitor values selected at those stated bus locations are 750 kVAR, 1950 kVAR, 600 kVAR, 150 kVAR and 600 kVAR, respectively. Finally it has been observed from Figure 7.40 that SAIFI value has been found improved from 5.240010 interruptions/customer yr to 4.733468 interruptions/customer yr by the application of FEO. The DG integrations have been performed by utilizing FEO at bus locations 5, 6, 7, 9, 10, 11, 14, 21, 27, 28 and 30. The chosen DG values at those selected locations are 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW and 100 kW, respectively. Reactive power compensations have been performed by FEO placing shunt capacitors at bus locations 2, 4, 12, 19, 20, 21, 23, 26, 30 and 32. Capacitor values have been chosen for those mentioned bus numbers are 150 kVAR, 150 kVAR, 450 kVAR, 300 kVAR, 300 kVAR, 300 kVAR, 600 kVAR, 450 kVAR, 150 kVAR and 450 kVAR, respectively. Lastly it can be noticed from Figure 7.40 that customer oriented reliability index SAIFI value has been found reduced from 5.240010 interruptions/customer yr to 4.754224 interruptions/customer yr with the implementation of MCA. Distributed generators have been placed after applying MCA at bus locations 7, 8, 15, 21, 23, 24, 26, 27, 28 and 30 shown in Table 7.20. The DG values chosen by MCA at those selected positions are 200 kW, 200 kW, 100 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW and 200 kW, respectively. Shunt capacitors have been allocated by MCA at bus locations 3, 20, 22, 27 and 32. Capacitor values have been chosen for those stated positions are 900 kVAR, 300 kVAR, 1200 kVAR, 450 kVAR and 600 kVAR, respectively.

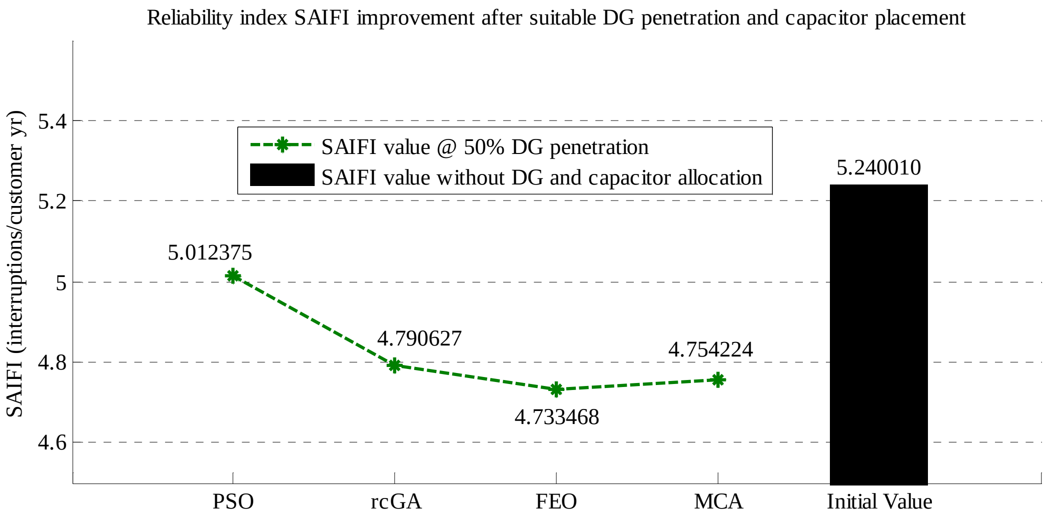

Figure 7.40: Comparative study amongst four algorithms for SAIFI improvement in 34 bus microgrid type radial distribution system at a maximum of 50% DG penetration

Table 7.20: Simulation results of DG integration and capacitor allocation for SAIFI improvement in 34 bus microgrid type radial distribution system at a maximum of 50% DG penetration

Methods	DG placement	DG value (kW)	Capacitor placement	Capacitor value (kVAR)
PSO	6, 15, 27, 29, 31	200, 100, 200, 200, 100	5, 11, 20, 27	600, 600, 1050, 450
rcGA	9, 12, 14, 20, 21, 23, 24, 25, 26, 27, 34	100, 200, 100, 100, 200, 100, 200, 100, 200, 200, 200	2, 6, 9, 21, 27	750, 1950, 600, 150, 600
FEO	5, 6, 7, 9, 10, 11, 14, 21, 27, 28, 30	200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 100	2, 4,12, 19,20, 21, 23, 26, 30, 32	150, 150, 450, 300, 300, 300, 600, 450, 150, 450
MCA	7, 8, 15, 21, 23, 24, 26, 27, 28, 30	200, 200, 100, 200, 200, 200, 200, 200, 200, 200	3, 20, 22, 27, 32	900, 300, 1200, 450, 600

It can be said from the above discussion that soft computing technique FEO has outperformed all the selected algorithms in finding the best SAIFI value as observable in Figure 7.40. Reliability index SAIFI is dependent on the failure rate of electric line which has been expressed in Chapter 3. The failure rate of electric line gets modified after capacitor allocation and DG integration. This is due to the reason that capacitor allocation indirectly reduces the resitive line loss and DG integration also decreases real power loss by locally catering the load demand as stated in Chapter 4. Heating or melting effect which causes the failure of electric line or cable reduces with the decrement of real power loss. This power loss is proportional with the square of current flowing through the branches. So, reduction in current magnitude will improve the failure rate which in turn improves the reliability index SAIFI. The study of current magnitude variation before and after capacitor allocations and DG integrations has been shown in Table 7.21 in mostly DG connected branches. It has been observed from Table 7.21 that current values in branches 5-6, 6-7, 7-8, 8-9 and 9-10 have been found reduced from 0.4189 p.u to 0.2025 p.u, from 0.1438 p.u to 0.0308 p.u, from 0.1182 p.u to 0.0495 p.u, from 0.0926 p.u to 0.0429 p.u and from 0.0670 p.u to 0.0534 p.u, respectively. It can also be noticed from Table 7.21 that current magnitudes in branches 7-28, 10-11, 13-14, 20-21, 26-27 and 28-29 have been found reduced from initial values i.e. without DG and capacitor placement. Surprisingly it has been observed that current value in branch 29-30 has been found increased from 0.0083 p.u to 0.0096 p.u. This is not a favorable development. It is shown in bold format in Table 7.21. Though there is a DG placement of 100 kW at bus location 30 but there is also a capacitor allocation of 150 kVAR at the same bus position as observable in Table 7.20 and Table 7.21. This capacitor allocation augments the reactive component of current flowing in that particular branch which in turn increases the absolute value of current magnitude. This augmentation in current value increases the failure rate and real power loss of that particular branch but system real power loss and failure rates of other branches reduces due to the combined effect of capacitor allocation and DG integration. It has been observed from Table 7.21 that system real power loss has been found reduced from 221.5 kW to 64 kW. Current values in other branches where DG is not connected such as 1-2 and 17-18 have been found reduced from 0.5193 p.u to 0.2435 p.u and from 0.2494 p.u to 0.1783 p.u, respectively as shown in Table 7.21. These reductions in current values have helped to reduce the failure rates of electric lines and improved the reliability index SAIFI from initial value i.e. without capacitor and DG connectivity.

Table 7.21: Study of current magnitude for SAIFI improvement by the application of FEO algorithm in 34 bus microgrid type radial distribution system at a maximum of 50% DG penetration

Branch	Current in p.u without DG and capacitor allocation	Current in p.u after DG and capacitor allocation	Loss in kW without DG and capacitor placement	Loss in kW after DG and capacitor placement	DG placement chosen by FEO technique	DG value in kW selected by FEO technique
1-2	0.5193	0.2435	221.5	64	5, 6, 7, 9, 10, 11, 14, 21, 27, 28, 30	200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 100
4-5	0.4442	0.2016				
5-6	0.4189	0.2025				
6-7	0.1438	0.0308				
7-8	0.1182	0.0495				
8-9	0.0926	0.0429				
9-10	0.0670	0.0534				
10-11	0.0409	0.0258				
13-14	0.0171	0.0095				
20-21	0.1721	0.1121				
26-27	0.0154	0.0100				
7-28	0.0253	0.0067				
28-29	0.0168	0.0068				
29-30	**0.0083**	**0.0096**				
17-18	0.2494	0.1783				

In the next section, another customer oriented reliability index SAIDI has been considered to observe reliability enhancement.

7.2.4 Illustration of enumerated values for SAIDI improvement at a maximum of 50% DG incorporation

System interruption duration is very important for commercial purposes. Customer oriented reliability index SAIDI (system average interruption duration index) has been minimized by opting DG and capacitor placement considering a maximum of 50% DG penetration. Likewise the study for SAIFI improvement, four evolutionary algorithms have been considered for this purpose shown in Figure 7.41 and Table 7.22. It has been observed from Figure 7.41 that SAIDI value has been found improved from 9.187138 hours/customer yr to 8.725616 hours/customer yr by the application of PSO. Distributed generator placements have been performed by PSO at bus locations 4, 5, 11, 12, 15 and 34 shown in Table 7.22. The DG value chosen for every selected bus is 200 kW. Shunt capacitors have been allocated at bus locations 2, 4, 11, 19 and 22. Capacitor values chosen for those buses are 150 kVAR, 150 kVAR, 600 kVAR, 1350 kVAR and 600 kVAR, respectively. It can be noticed from Figure 7.41 that reliability index SAIDI has been found improved from 9.187138 hours/customer yr to 8.462286 hours/customer yr with the implementation of rcGA. The DG placements have been performed by rcGA at bus number 3, 4, 5, 8, 10, 12, 15, 17, 20, 21, 23, 26, 31and 32, respectively. The DG values chosen at those selected bus positions are 200 kW, 200 kW, 200 kW, 200 kW, 100 kW, 100 kW, 100 kW, 100 kW, 200 kW, 100 kW, 100 kW, 100 kW, 200 kW and 200 kW, respectively. Reactive power compensations have been exercised by allocating shunt capacitors at bus location 5, 23 and 29. Capacitor values selected for those three buses are 150 kVAR, 1800 kVAR and 450 kVAR, respectively. Finally it has been observed from Figure 7.41 that SAIDI value has been found improved from 9.187138 hours/customer yr to 8.217452 hours/customer yr by the application of FEO. Distributed generation integrations have been performed by FEO at bus location 7, 9, 11, 12, 14, 18, 19, 21, 22, 24, 27, 30 and 34 shown in Table 7.22. The selected DG values for those bus positions are 200 kW, 200 kW, 200 kW, 200 kW, 100 kW, 100 kW, 200 kW, 100 kW, 200 kW, 200 kW, 200 kW, 200 kW and 100 kW. Shunt capacitors have been allocated at bus number 3, 4, 14, 24, 25 and 26. Chosen capacitor values for those mentioned buses are 2400 kVAR, 600 kVAR, 150 kVAR, 450 kVAR, 450 kVAR and 300 kVAR, respectively. Lastly it can be noticed from Figure 7.41 that SAIDI value has been found reduced from 9.187138 hours/customer yr to 8.138697 hours/customer yr with the implementation of MCA. The DG placements have been performed by MCA at bus location 3, 7, 8, 9, 11, 14, 19, 21, 23, 25, 26 and 29. The chosen DG values for those stated buses are 100 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 200 kW, 100 kW, 200 kW, 200 kW, 200 kW and 100 kW, respectively. Reactive power compensations have been executed by allocating shunt capacitors at bus number 3, 6, 27 and 34. Chosen capacitor values at those bus positions are 150 kVAR, 1800 kVAR, 1050 kVAR and 450 kVAR, respectively.

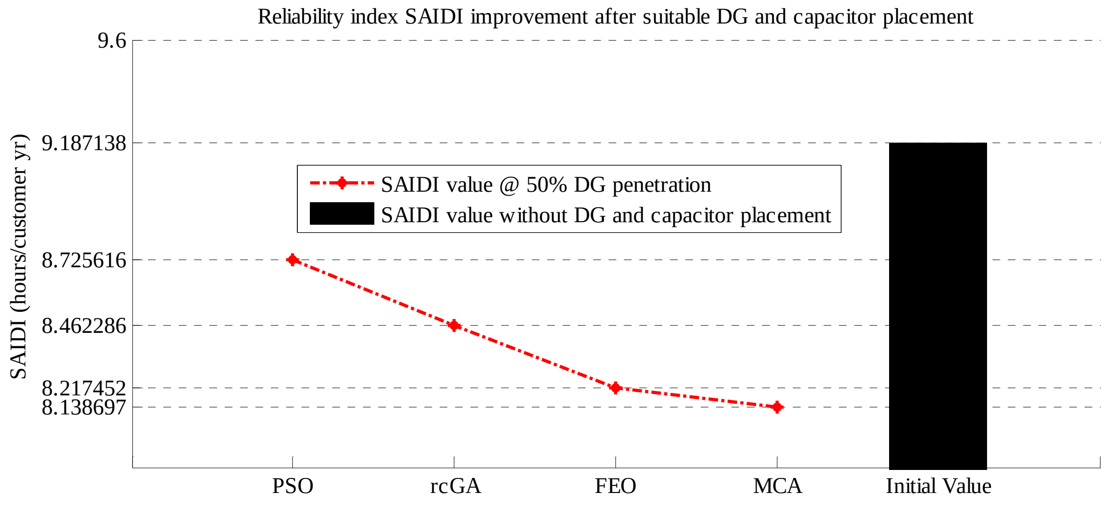

Figure 7.41 Comparative study amongst four techniques for SAIDI improvement in 34 bus microgrid type radial distribution system at a maximum of 50% DG penetration

Table 7.22: Capacitor placement and DG integration for SAIDI improvement in 34 bus microgrid type radial distribution system considering DG penetration up to 50%

Methods	DG placement	DG value (kW)	Capacitor placement	Capacitor value (kVAR)
PSO	4, 5, 11, 12, 15, 34	200, 200, 200, 200, 200, 200	2, 4, 11, 19, 22	150, 150, 600, 1350, 600
rcGA	3, 4, 5, 8, 10, 12, 15, 17, 20, 21, 23, 26, 31, 32	200, 200, 200, 200, 100, 100, 100, 100, 200, 100, 100, 100, 200, 200	5, 23, 29	150, 1800, 450
FEO	7, 9,11, 12, 14, 18, 19, 21, 22, 24, 27, 30, 34	200, 200, 200, 200, 100, 100, 200, 100, 200, 200, 200, 200, 100	3, 4, 14, 24, 25, 26	2400, 600, 150, 450, 450, 300
MCA	3, 7, 8, 9, 11, 14, 19, 21, 23, 25, 26, 29	100, 200, 200, 200, 200, 200, 200, 100, 200, 200, 200, 100	3, 6, 27, 34	150, 1800, 1050, 450

It can be concluded from the above discussion that the technique MCA has outperformed amongst all the selected soft computing techniques in finding the least SAIDI value as shown in Figure 7.41. The reliability index SAIDI is dependent on annual outage time and number of customer. The number of customer is a fixed parameter as it is connected to the load demand. On the other hand, annual outage time is dependent on failure rate and repair time. Failure rate gets modified with the change in current flow in the circuit. This is due to the reason that resistive line loss causes heating or melting effect of line and augments failure rate as discussed earlier. So study of current magnitude after DG integration and capacitor allocation is important to observe to understand the improvement in reliability index SAIDI. This has been shown in Table 7.23. The study of current varation before and after DG and capacitor placement has been shown in mostly DG connected branches. This is to observe the current reduction as distributed generator locally cater the load and reduces the line current. It can be noticed from Table 7.23 that current magnitudes in branches 2-3, 6-7, 7-8 and 8-9 have been found reduced from 0.4945 p.u to 0.2282 p.u, 0.1438 p.u to 0.0481 p.u, 0.1182 p.u to 0.0469 p.u and 0.0962 p.u to 0.0409 p.u, respectively. Distributed generator of 100 kW, 200 kW, 200 kW and 200 kW have been placed at bus location 3, 7, 8 and 9, respectively by MCA technique as shown in Table 7.22 and Table 7.23. It has also been observed that current magnitudes in branches 9-10, 10-11, 13-14, 18-19, 20-21, 22-23, 24-25 and 28-29 have been found reduced from the initial values i.e. without DG and capacitor connectivity. Distributed generators have been placed in one of the node point of those stated branches as observable in Table 7.23. Surprisingly current magnitudes in branches 25-26, 26-27 and 32-33 have been found increased from 0.0417 p.u to 0.0783 p.u, from 0.0154 p.u to 0.0907 p.u and from 0.0127 p.u to 0.0368 p.u, respectively. This is not a desirable phenomenon. It is shown in bold format in Table 7.23. These augmentations in current values increase the failure rates and resistive line losses of thoses branches. Though DG integration of 200 kW has been performed at bus location 25 and 26 but capacitor values of 1050 kVAR and 450 kVAR have been allocated at bus number 27 and 34 as observable in Table 7.22 and Table 7.23. The capacitor allocation increases the reactive component of current in line which in turn agments the current magnitude. It is quite evident fact that these increments in current magnitudes will increase failure rate but the combination of the stated capacitor allocation and

DG integration has beneficial effect on system reliability. This improves the failure rates of other branches and decreases the real power loss of the 34 bus microgrid type radial distribution system. It can be noticed from Table 7.23 that real power loss has been found reduced from 221.5 kW to 55.36 kW. It has been observed from Table 7.23 that current values of other branches where DG is not connected such as 1-2 and 17-18 have been found reduced from 0.5193 p.u to 0.2453 p.u and from 0.2494 p.u to 0.1263 p.u, respectively. These reductions in current values have helped to improve the reliability index SAIDI.

Table 7.23: Study of current magnitude for SAIDI improvement by implementing MCA technique in 34 bus microgrid type radial distribution system considering DG penetration up to 50%

Branch	Current in p.u without DG and capacitor allocation	Current in p.u after DG and capacitor allocation	Loss in kW without DG and capacitor placement	Loss in kW after DG and capacitor placement	DG placement chosen by MCA technique	DG value in kW selected by MCA technique
1-2	0.5193	0.2453	221.5	55.36	3, 7, 8, 9, 11, 14, 19, 21, 23, 25, 26, 29	100, 200, 200, 200, 200, 200, 200, 100, 200, 200, 200, 100
2-3	0.4945	0.2282				
6-7	0.1438	0.0481				
7-8	0.1182	0.0469				
8-9	0.0962	0.0409				
9-10	0.0670	0.0386				
10-11	0.0409	0.0260				
13-14	0.0171	0.0095				
18-19	0.2237	0.1027				
20-21	0.1721	0.0779				
22-23	0.1202	0.0571				
24-25	0.0680	0.0662				
25-26	**0.0417**	**0.0783**				
26-27	**0.0154**	**0.0907**				
28-29	0.0168	0.0099				
29-30	0.0083	0.0081				
17-18	0.2494	0.1263				
32-33	**0.0127**	**0.0368**				

However, the simulation study concerning to the load oriented reliability index AENS improvement is also important to understand reliability issues.

7.2.5 Simulation results for AENS improvement after enhanced DG connectivity

Energy and load oriented reliability index AENS (average energy not supplied) has been improved from the initial value i.e. without capacitor and DG connectivity after proper selection and placement of DG and shunt capacitor. The comparative study amongst the four soft computing techniques has been performed considering a maximum of 50% DG penetration. It has been observed from Figure 7.42 that AENS value has been found improved from 2.074900 kWh/customer yr to 1.969807 kWh/customer yr with the implementation of PSO. On the other hand, it can be noticed from Figure 7.42 that reliability index AENS value has been found reduced from 2.074900 kWh/customer yr to 1.938987 kWh/customer yr by the application of rcGA. Finally it has been observed from Figure 7.42 that AENS value has been found improved from 2.074900 kWh/customer yr to 1.879504 kWh/customer yr with the implementation of FEO. Lastly it can be noticed from Figure 7.42 that AENS value has been found reduced from 2.074900 kWh/customer yr to 1.836213 kWh/customer yr by the application of MCA.

Simultaneous DG and capacitor placement have been performed by four evolutionary techniques as stated earlier. The DG sitting and sizing for four techniques has been depicted in Figure 7.43. On the other hand, capacitor value selection and allocation has been illustrated for PSO, rcGA, FEO and MCA, respectively and shown in Figure 7.44.

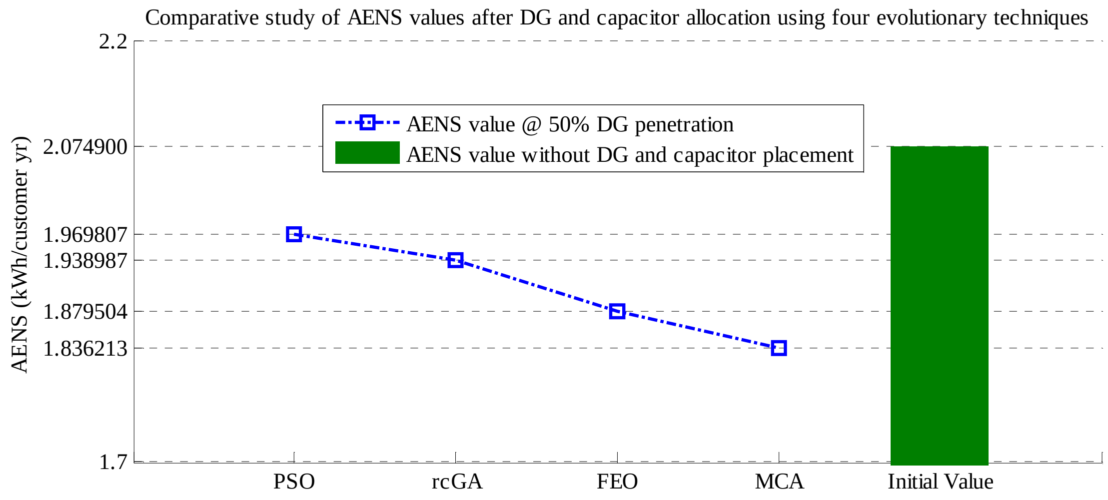

Figure 7.42: Comparative study for AENS improvement after suitable DG integration and capacitor placement in 34 bus microgrid type radial distribution system considering DG penetration up to 50%

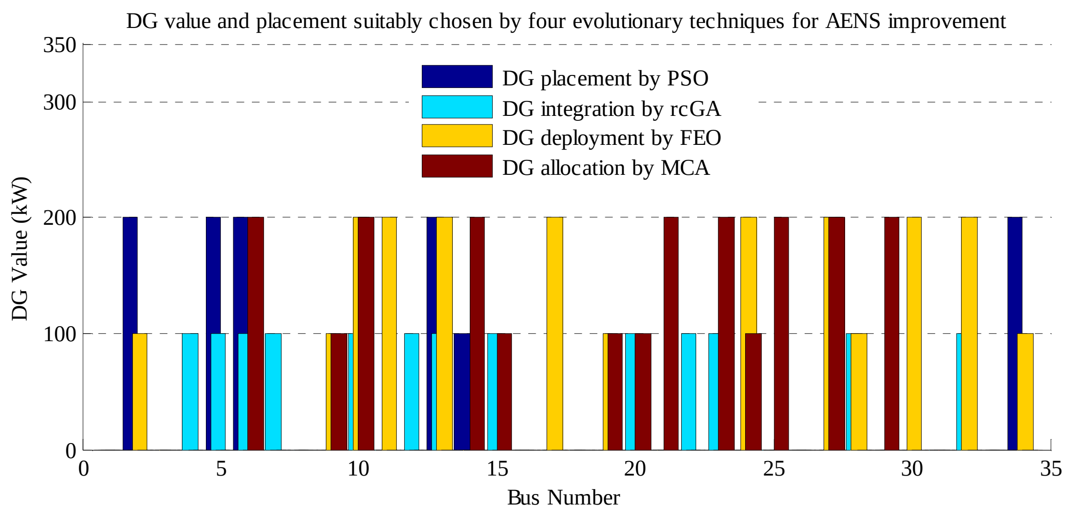

Figure 7.43: DG value and placement data selected by four algorithms for AENS improvement in 34 bus microgrid type radial distribution system at a maximum of 50% DG penetration

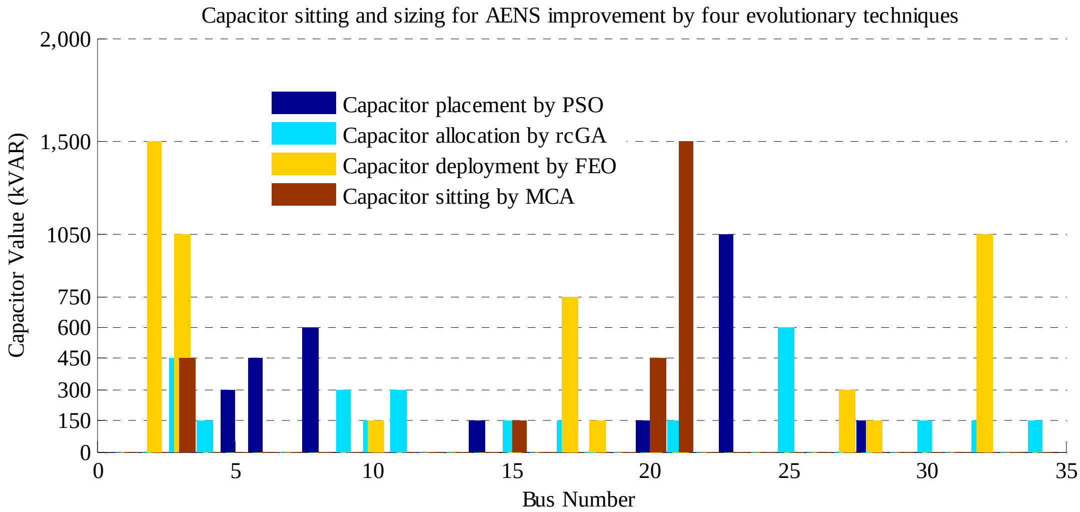

Figure 7.44: Capacitor sitting and sizing data chosen by four techniques for AENS improvement in 34 bus microgrid type radial distribution system

It can be said from the above discussion that MCA technique has achieved the least load oriented reliability index AENS value amongst the all chosen algorithm. This MCA technique has also achieved the least real power loss, total cost and SAIDI values. This has already been illustrated earlier. The FEO technique has obtained the least SAIFI value. But the considered objectives are conflicting objectives. These conflicting objectives should be taken care of simultaneously for the multi-objective situations.

7.2.6 Cost based multi-objective capacitor allocation and DG integration for decision making

Multi-objective optimization has been performed considering real power loss, total cost, SAIFI, SAIDI and AENS. The multi-objective optimization has been exercised considering a maximum of 50% DG penetration keeping the futuristic situation in mind. Soft computing techniques MCA and FEO have been implemented to study the pareto-optimal solutions. Non-dominated solutions achieved after MCA application are shown in Table 7.24. It has been observed from Table 7.24 that five pareto-optimal solutions have been obtained by the implementation of MCA. The bold solutions are notified as the least values. The italics solutions are the worst solutions as shown in Table 7.19. It has been observed from Table 7.24 that least real power loss value obtained by MCA is 43.27 kW. It has also been observed from Table 7.24 that least total cost, SAIFI, SAIDI and AENS values achieved by MCA technique are US$ 5054468.18, 4.646906 interruptions/customer yr, 8.054546 hours/customer yr and 1.818457 kWh/customer yr, respectively. The worst total cost, SAIFI, SAIDI and AENS values obtained by MCA are US$ 5226544.67, 4.723650 interruptions/customer yr, 8.240774 hours/customer yr and 1.861264 kWh/customer yr respectively. On the other hand, the pareto-optimal solutions obtained by fish electrolocation optimization are shown in Table 7.25.

Table 7.24: Pareto optimal solution after modified cultural algorithm implementation considering five objectives

Sl. No.	Parameters				
	Real power loss (kW)	Total cost (US$)	SAIFI interruptions/ customer yr	SAIDI hours/customer yr	AENS kWh/customer yr
1	49.99	5162889.81	4.661606	8.152207	1.840671
2	**43.27**	5156874.31	4.691568	*8.240774*	*1.861264*
3	*52.32*	*5226544.67*	**4.646906**	8.131539	1.836164
4	48.32	**5054468.18**	4.665226	**8.054546**	**1.818457**
5	45.86	5134930.02	*4.723650*	8.212367	1.854323

It has been observed from Table 7.25 that eleven non-dominated solutions have been achieved after implementing fish electrolocation optimization. The least real power loss, total cost, SAIFI, SAIDI and AENS values are 59.45 kW, US$ 5404371.75, 4.886962 interruptions/customer yr, 8.536557 hours/customer yr and 1.927632 kWh/customer yr respectively shown in Table 7.20. The worst real power loss, total cost, SAIFI, SAIDI and AENS values obtained by FEO are 88.52 kW, US$ 5765936.68, 5.184810 interruptions/customer yr, 9.111578 hours/customer yr and 2.060789 kWh/customer yr respectively in Table 7.25. It has been observed from Table 7.24, Table 7.25 that solutions achieved by MCA are comparatively better than the solutions obtained by FEO. It can be noticed from Table 7.24 that a set of non-dominated solutions obtained by MCA are nearer to the real power loss and total cost value of 40 kW and US$ 5,000,000, respectively. On the other hand, the non-dominated solutions obtained by FEO in Table 7.20 are at the farthest corner from the mentioned values of real power loss and total cost. It has also been observed from Table 7.24 that non-dominated solutions obtained by MCA are nearer to the SAIFI, SAIDI and AENS values of 4.6 interruptions/customer yr, 8.5 hours/customer yr and 1.8 kWh/customer yr respectively. Interestingly the pareto-optimal solutions obtained by FEO are mostly at the farthest corner from those mentioned values of SAIFI, SAIDI and AENS shown in Table 7.25. From the above discussion it can be concluded that MCA has outperformed soft computing technique FEO. That’s why non-dominated solutions obtained by MCA have been chosen for decision making purpose.

Table 7.25: Non-dominated solutions after fish electrolocation optimization implementation considering five objectives

Sl. No.	Parameters				
	Real power loss (kW)	Total cost (US$)	SAIFI interruptions /customer yr	SAIDI hours/customer yr	AENS kWh/customer yr
1	**59.45**	5676468.65	*5.184810*	*9.111578*	*2.060789*
2	80.88	**5404371.75**	4.911715	**8.536557**	**1.927632**
3	79.81	5443032.61	4.928997	8.560544	1.933165
4	71.99	5461585.93	4.950567	8.644270	1.952108
5	77.27	5493791.17	4.946936	8.653504	1.954359
6	71.44	5501256.03	4.993239	8.748258	1.975823
7	77.86	5579484.62	4.894622	8.544816	1.930131
8	*88.52*	*5765936.68*	**4.886962**	8.645633	1.953201
9	76.49	5645904.33	4.929661	8.639977	1.951398
10	78.96	5678396.18	4.892926	8.637992	1.951371
11	77.62	5626648.20	4.933604	8.564707	1.934840

The decision making has been done by giving pseudo weights to all the obtained non-dominated solutions by MCA technique. There are five conflicting objectives in the multi-objective optimization problem. Therefore, five pseudo weights viz. W_1, W_2, W_3, W_4 and W_5 are considered for every solution. This is shown in Table 7.26. The higher pseudo weight value signifies the minimum or reduced parameter value. But the minimum parameter value based solution is not the chosen solution by the decision maker. In this research work, the decision maker chooses such solution which provides equal importance to real power loss, total cost, SAIFI, SAIDI and AENS as stated earlier. This equal importance phenomenon has been conceptualized for urban type of customer who wants uninterruptible power supply, reduced electricity price and improved power quality. That's why a specific weight value is selected for providing equal importance to all the five conflicting objectives. The specific weight value is 0.2 as summation of all the weights is equal to one as a thumb rule. This has also been discussed earlier in Chapter 4. The deviation of calculated pseudo weight from the specific weight value gives the deterioration value from the wanted solution by the decision maker. In this regard, the least deviation value will give the wanted solution by the decision maker. The deviation values viz. *dev(1), dev(2), dev(3), dev(4) and dev(5)* for the five solutions are depicted in Figure 7.45 as bar chart. It has been observed from Figure 7.45 that solution number 2, 3 and 5 are competitive to each other. But one amongst the solutions is the least. That is depicted in Figure 7.46. It can be noticed from Figure 7.46 that the solution number 4 outperforms the solution 1 in competition. The tower height of solution 4 is lowest amongst all the five non-dominated solutions. That's why the solution 4 is chosen as the wanted solution in this simulation study related to multi-objective optimization. The real power loss, total cost, SAIFI, SAIDI and AENS values concerning to solution 4 are 48.32 kW, US$ 5054468.18, 4.665226 interruptions/customer yr, 8.054546 hours/customer yr and 1.818457 kWh/customer yr respectively. Distributed generators have been placed at bus locations 5, 6, 10, 15, 20, 21, 23, 24, 26, 27, 32 and 34 to achieve that particular solution. The DG values chosen for those bus positions are 200 kW, 200 kW, 100 kW, 100 kW, 200 kW, 100 kW, 200 kW, 100 kW, 200 kW, 200 kW, 200 kW and 200 kW, respectively. Reactive power compensation has also been performed by allocating shunt capacitors at bus locations 3, 6, 8, 14, 17 and 27. The shunt capacitor values selected at those bus positions are 600 kVAR, 300 kVAR, 900 kVAR, 150 kVAR, 450 kVAR and 750 kVAR, respectively.

Table 7.26: Pseudo weight of non-dominated solutions obtained by MCA

Solution No.	Pseudo Weights				
	W_1	W_2	W_3	W_4	W_5
1	0.1076	0.1546	0.3379	0.1987	0.2010
2	0.5485	0.2221	0.2293	0	0
3	0	0	0.4602	0.2699	0.2698
4	0.1051	0.2379	0.1811	0.2379	0.2379
5	0.4573	0.3410	0	0.0977	0.1038

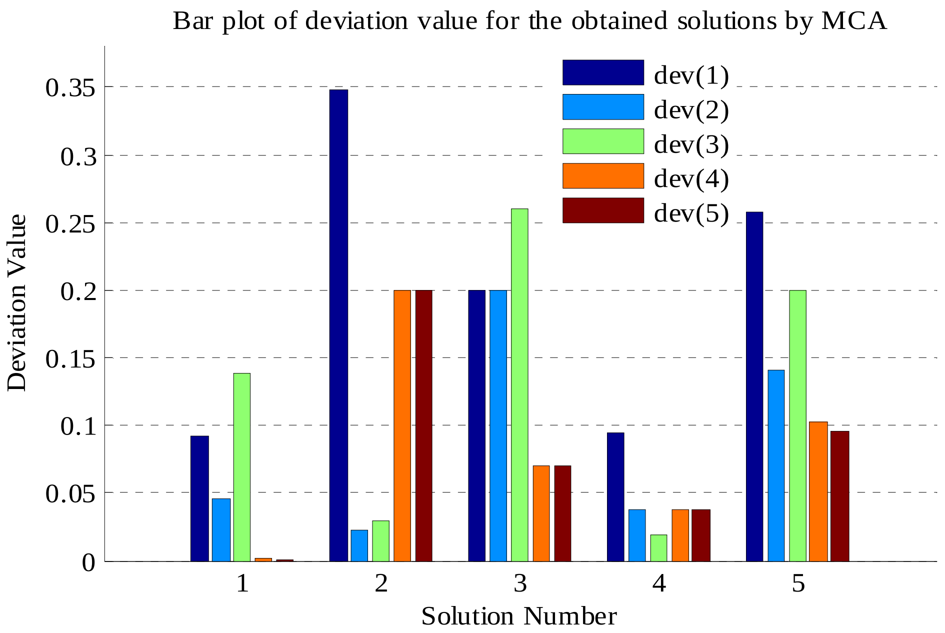

Figure 7.45: Bar plot of the five deviation values for obtained pareto-optimal solutions by MCA

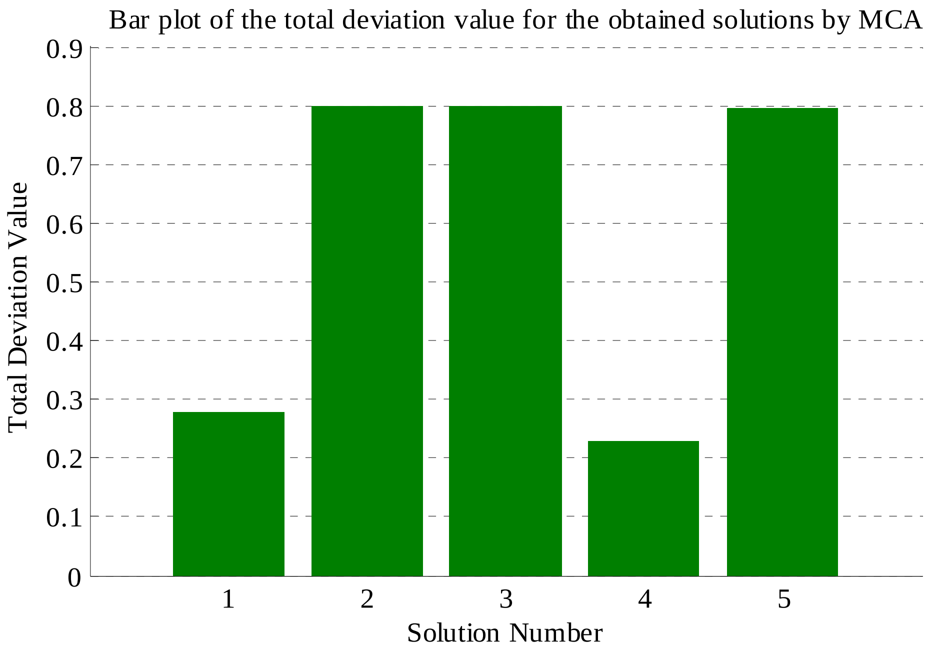

Figure 7.46: Bar plot of total deviation value for the decision making

A straightforward and simple decision making approach has been considered here. This leads to a suitable planning to provide reliable and economic power. However, the above mentioned simulation based study has been performed on thirty four bus microgrid type radial distribution system. This is a small microgrid type distribution system with simple topological structure. A bigger microgrid type radial distribution system with complex topological structure will be interesting to study for single as well as multi objective situations. A sixty nine bus microgrid type radial distribution system has been considered here to observe the reliability improvement as well as cost reduction in various single and multi objective situations.

7.3 Cost based reliability enhancement in 69 bus microgrid type radial distribution system

Sixty nine bus microgrid type radial distribution system has been considered to study various reliability issues. The bus and line data of this distribution system have been shown in Table A4 and Table A6 in Appendix. Single line diagram of this microgrid type distribution system has been shown in Figure A2 in Appendix. Total cost minimization, energy loss reduction, improvement of SAIFI, SAIDI and AENS are the objectives considered in this work. Capacitor placement has been performed optimally in the first attempt to study total cost minimization applying disconnects between buses with lateral protection. In the next attempt, DG integration and capacitor allocation have been performed for both single and multi objective situations considering reinforcement scheme 'applying disconnects with lateral protection'. These stated studies are important to understand different reliability issues.

7.3.1 Reliability linked cost minimization by optimal capacitor placement

Modified cultural algorithm and real coded genetic algorithm have been applied to find the optimal capacitor position to minimize the reliability cost as well as the combined cost. Customer and load oriented reliability indices such as SAIDI, SAIFI, CAIDI, ASUI, ASAI and AENS have also been calculated. The algorithm parameter *tolfac* and *maxiter* for MCA are set for this study at 0.001 and 30, respectively [241]. The dollar conversion constant of energy loss has been considered as 525.6 US$/KWh as annual basis [245]. The dollar conversion constant for capacitor placement has been chosen at US$ 4/kVAR [245]. The smallest and highest unit of installed capacitor value is considered at 200 kVAR and 1200 kVAR, respectively [245]. The life time of this capacitor installation project has been considered as twelve years. The failure rate for maximum impedance and minimum impedance of line data has been considered as 0.5 and 0.1 respectively [77]. The other failure rates have been enumerated between the two mentioned impedance limits linearly with the rest impedance value. The value of failure rate after full compensation has been chosen as 85% of the uncompensated failure rate as denoted earlier [77]. The repair time of main feeder is chosen as 4 hr. The isolation or switching time is chosen as 0.5 hr. The repair time of the lateral feeder is considered as 2 hr. The number of customer at each load point has been calculated on the basis of one customer per kilowatt load value. If the value of load is zero then the number of customer is also zero. The value of economical damage for 4 hr is US$ 15.4752/kW [119]. The same financial damage value for 2hr and 0.5 hr are considered as US$7.6317/kW and US$1.8600/kW respectively [119]. The comparative study amongst the selected soft computing techniques has been performed considering population size and maximum iteration number (*itermax*) as 30 and 5000, respectively [241]. Without placing any capacitor in the microgrid type radial distribution system energy loss has been found to be 225 kWh. The capacitor allocation has been studied for two reinforcement schemes as mentioned earlier. Scheme I has been considered as applying only disconnects between buses. On the other hand, disconnects with lateral protection has been considered as scheme II. Reliability worth and combined cost has been calculated for two schemes (Scheme I & Scheme II). Reliability worth and combined cost concerning to original configuration has been found as US$ 1957632.84 and US$ 3376752.84 respectively for scheme I. The same reliability worth and combined cost has been found without placing any capacitor as US$ 1165354.44 and US$ 2584474.44 respectively for scheme II. On the other hand it has been shown in Table 7.27 that with the implementation of real coded genetic algorithm (rcGA) the energy loss has been found as 170.68 kWh. It has been observed from Table 7.27 that reliability worth and combined cost after applying rcGA have been found as US$ 1872901.08 and US$ 2949413.97 respectively for scheme I. These values have been found by placing twelve capacitors each of 200 kVAR value at bus position 3, 16, 23, 29, 36, 37, 39, 47, 49, 57, 58 and 62 respectively. After shunt capacitor allocation at those bus positions reliability worth and combined cost for scheme II has been found as US$ 1084311.24 and US$ 2160824.13 respectively. The difference between reliability worth and combined cost is the summation of energy loss cost and capacitor installation cost. It has also been observed from Table 7.27 that reliability worth and combined costs of scheme II are less than that for scheme I. It signifies that applying fuse gear protection with disconnects to the radial distribution system the reliability has been enhanced economically. Only disconnects implementation to the radial distribution system do not give the economical benefit in respect of reliability. This reliability enhancement phenomenon has been discussed later with the help of reliability indices. However, the reliability worth and combined cost for both the schemes has been found lesser after implying modified cultural algorithm (MCA) as soft computing technique. It has been observed from Table 7.27 that energy loss after implementation of MCA has been found at 145.18 kWh. The capacitor placement after embedded termination condition has been observed at bus position 2, 4, 15, 18, 37, 50 and 61 with capacitor value of 600 kVAR, 800 kVAR, 200 kVAR, 200 kVAR, 600 kVAR, 800 kVAR and 1200 kVAR respectively. The reliability worth and combined cost for scheme I have been found at US$ 1816876.08 and US$ 2750155.37 respectively. Those values of reliability worth and combined cost for scheme II have been found as US$ 1044509.52 and US$ 1977780.81, respectively. It can be said observing Table 7.27 that the technique MCA has found out lesser value of combined cost and reliability worth for both the schemes in comparison to rcGA. The soft computing technique MCA has also outperformed rcGA in achieving lesser value of energy loss.

Table 7.27: Comparative study after performing optimal capacitor allocation in 69 bus microgrid type radial distribution system

Methods	Reliability worth (US$) (Scheme I)	Reliability worth (US$) (Scheme II)	Combined cost (US$) (Scheme I)	Combined cost (US$) (Scheme II)	Energy loss (kWh)	Capacitor allocated (bus position)	Capacitor value (kVAR)
rcGA	1872901.08	1084311.24	2949413.97	2160824.13	170.68	3,16,23,29,36,37,39,47,49,57,58,62	200, 200,200,200, 200, 200,200,200, 200, 200,200,200
MCA	1816876.08	1044509.52	2750155.37	1977780.81	145.18	2,4,15,18,3, 50,61	600,800, 200,200,600, 800,1200
Without capacitor placement	1957632.84	1165354.44	3376752.84	2584474.44	225.00	-	-

The study of reliability indices has also been done on the standard 69 bus radial distribution system considering only disconnects (Scheme I) and disconnects with lateral protection (Scheme II).The achieved value of reliability indices have been shown in Table 7.28 and Table 7.29 respectively. In those Table 7.28 and Table 7.29, a comparative simulation study has also been shown between modified cultural algorithm (MCA) and real coded genetic algorithm (rcGA). Without reactive power compensation, the enumerated value of SAIDI has been found at 11.6313 hours/customer yr by applying only disconnects as shown in Table 7.28. On the other hand, the value of SAIDI by applying lateral protection with disconnects has been found at 6.8334 hours/customer yr available in Table 7.29. The system average interruption duration index (SAIDI) depends on the annual outage time and number of customer. Annual outage time depends on outage map and failure rate. Outage time matrix is formed by repair time and switching or isolation time. The outage matrix differs in two schemes i.e. applying only disconnects and lateral protection with disconnects. Not only the outage map matrix differs but also the failure rate of individual load point differs for the mentioned two schemes. That's why the value of SAIDI is not same in both the mentioned schemes. However it has been observed from Table 7.28 and Table 7.29 that developed technique MCA is competitive than other soft computing technique rcGA in achieving lesser value of customer oriented reliability index SAIDI. It has been shown in Table 7.28 that rcGA has found SAIDI value at 11.1355 hours/customer yr which is lesser than the value of original configuration. But MCA has found SAIDI value at 10.8032 hours/customer yr as shown in Table 7.28. On the other hand, if we analyze that value of SAIDI in Table 7.29, we observe rcGA has found SAIDI value at 6.360 hours/customer yr. That reliability index SAIDI value has been achieved at 6.126 hours/customer yr after implementation of MCA. The cause of having lesser value of SAIDI than the original configuration is due to the new failure rate after reactive power compensation. Otherwise the outage map matrix is same for independent scheme. On the other hand, the value of system average interruption frequency index (SAIFI) depends on failure rate and number of customer of different load points. As discussed earlier the failure rates of individual load point for the two schemes are not same. That rate is lesser in value for scheme II i.e. disconnects with lateral protection in comparison to scheme I. It has been observed from Table 7.28 and Table 7.29 that the values of SAIFI for original configuration are 12.7554 interruptions/customer yr and 6.3414 interruptions/customer yr respectively. The proposed technique MCA has achieved SAIFI value as 12.2542 interruptions/customer yr whereas rcGA has found the same index value at 12.5572 interruptions/customer yr in Table 7.28. The cause of having less value in case of MCA is due to the development of new failure rate after optimal shunt capacitor installation. On the other hand the value of SAIFI achieved by MCA and rcGA for scheme II are 5.9007 interruptions/customer yr and 6.0912 interruptions/customer yr respectively shown in Table 7.29. The cause of having less value in case of MCA is similar as discussed above. The other customer oriented reliability index in the list is customer average interruption duration index (CAIDI). It is the ratio of SAIDI and SAIFI. The value of CAIDI for the original configuration in scheme I and Scheme II are 0.9119 hours/customer interruption and 1.0775 hours/customer interruption respectively. In this case the value of reliability index is less for scheme I. It is due to the higher value of SAIFI in comparison to SAIDI available in Table 7.28. On the other hand, the value of SAIDI is more than SAIFI as shown in Table 7.28. This anomaly is due to the topological structure of chosen radial distribution system. However the value of CAIDI for rcGA and MCA in scheme I are 0.8868 hours/customer interruption and 0.8816 hours/customer interruption respectively which can be observed from Table 7.28. It has been observed from Table 7.29 that value of CAIDI for rcGA and MCA are 1.0441 hours/customer interruption and 1.0381 hours/customer interruption respectively. The cause of having lesser value of CAIDI is due to the development of new failure rate after optimal reactive power compensation as discussed earlier. The rest two customer oriented reliability indices are average service unavailability index (ASUI) and average service availability index (ASAI). These two indices have no units. The value of ASUI for the original configuration is more in scheme I in comparison to scheme II. It has been observed from Table 7.28 and Table 7.29 that values of ASUI without compensation are 0.001327 and 0.000780 respectively. On the other hand the values of ASUI for rcGA are 0.001271 and 0.000726 shown in Table 7.28 and Table 7.29 respectively. The same value of ASUI after capacitor installation by MCA has been found at 0.001233 and 0.000699 which can be observed from Table 7.28 and Table 7.29 respectively. The value of ASAI without capacitor placement has been enumerated as 0.998672 and 0.999219 shown in Table 7.28 and Table 7.29 respectively. The value of ASAI is the difference between one and ASUI. It can be observed from Table 7.28 and Table 7.29 that applying lateral protection with disconnects average system unavailability decreases and availability increases. However, the competition between rcGA and MCA becomes marginal when it come the case of ASUI or ASAI. It has been observed from Table 7.28 that the value of ASAI for rcGA and MCA are 0.998728 and 0.998766 respectively. Whereas that value of ASAI for rcGA and MCA in scheme II are 0.999273 and 0.999300 respectively shown in Table 7.24. On the other hand, the only load or energy oriented reliability index is average energy not supplied (AENS) available in the Table 7.28 and Table 7.29. The values of AENS for the original configuration of scheme I and scheme II are 11.6314kWh/customeryr and 6.8346kWh/customeryr respectively which are shown in Table 7.28 and Table 7.29. The value of AENS is dependent on kilo Watt hour, number of customer and annual outage time of individual load point. As discussed earlier annual outage time is lesser in scheme II in comparison to scheme I. That's why values of AENS are higher for scheme I (only disconnects) and lower for scheme II (lateral protection with disconnects). However the soft computing technique MCA again wins in achieving lower value of AENS. It has been observed from Table 7.28 that rcGA and MCA has found AENS value as 11.1357kWh/customeryr and 10.8034kWh/customeryr respectively. On the other hand it has been observed from Table 7.29 that MCA and rcGA has found AENS values at 6.1271kWh/customeryr and 6.3611kWh/customeryr respectively. From the above discussion it can be said that applying lateral protection to disconnect not only benefited the system economically but also it has improved the reliability of the radial distribution system. Furthermore capacitor installation at suitable bus position with optimal values has helped in reliability enhancement. It has also improved the utility system technically and economically.

Table 7.28: Reliability indices study by applying only disconnects (Scheme I) after optimal capacitor placement for cost minimization in 69 bus microgrid type radial distribution system

Reliability indices	SAIDI (hours/ customer yr)	SAIFI (interruptions/ customer yr)	CAIDI (hours/customer interruption)	ASUI	ASAI	AENS (kWh/ customer yr)
rcGA	11.1355	12.5572	0.8868	0.001271	0.998728	11.1357
MCA	10.8032	12.2542	0.8816	0.001233	0.998766	10.8034
Without compensation	11.6313	12.7554	0.9119	0.001327	0.998672	11.6314

Table 7.29: Reliability indices study by applying disconnects with lateral protection (Scheme II) after optimal capacitor allocation for cost minimization in 69 bus microgrid type radial distribution system

Reliability indices	SAIDI (hours/ customer yr)	SAIFI (interruptions/ customer yr)	CAIDI (hours/customer interruption)	ASUI	ASAI	AENS (kWh/ customer yr)
rcGA	6.3600	6.0912	1.0441	0.000726	0.999273	6.3611
MCA	6.1260	5.9007	1.0381	0.000699	0.999300	6.1271
Without compensation	6.8334	6.3414	1.0775	0.000780	0.999219	6.8346

As stated earlier the simulation study for cost minimization has been performed considering one customer per one kilowatt load in sixty nine bus microgrid type radial distribution system. In addition, only capacitor allocation has been considered to reduce cost of a microgrid type power system network. Simultaneous DG integration and capacitor allocation can further improve reliability of a microgrid type radial distribution system as discussed earlier. In the next section, reliability enhancement has been studied along with cost minimization considering realistic customer data in time of performing simultaneous DG and capacitor placement.

7.3.2 Special study considering simultaneous DG integration and capacitor allocation with realistic customer data

Distributed generator integration and shunt capacitor allocation have been performed applying four evolutionary computation techniques viz. rcGA, PSO, FEO and MCA on sixty nine bus microgrid type radial distribution system. Practical load data has been considered for considering consumer numbers at the load buses of sixty nine bus microgrid type radial distribution system shown in Table 7.30. This has been considered here to make the system more realistic. Four types of consumers have been considered on the basis of their electrical demand. They are 'high tension bulk', 'low tension bulk', 'low tension' and 'domestic' customers. The demand of 'high tension bulk' customer is greater than 125 kVA. On the other hand, demand of 'low tension bulk' customer is between 50 kVA and 125 kVA. Furthermore, it has been observed from Table 7.30 that demand of 'low tension' customer is less than 50 kVA. Finally the domestic customer's demand is less than equal to 6 kW. Customer description for different ranges of demand has also been shown in Table 7.30. High tension bulk consumers are mostly industrial type. Low tension bulk consumer can be of several types. Multiplex, big shopping mall, hospital, small scale industry etc are included as low tension bulk consumer. The consumers like hospital, nursing home, office/building, commercial establishment, cold storage etc are incorporated as low tension customer. It has been observed from Table 7.30 that the last type consumer is domestic consumer. This type of customers is mostly rural/agricultural and urban residential consumers. The power factor considered for enumeration purpose is 0.85. The data available in Table 7.30 has helped to count the customer number at each load bus of the distribution system at hand. The detail customer description related to specific load for each load bus and customer type is shown in Appendix in Table A7. It can be observed from Table A7 that the total consumer number has also been calculated for each load bus. Finally this has helped to enumerate the reliability indices viz. SAIFI, SAIDI and AENS as customer number has serious impact on reliability indices.

Table 7.30: Data used for counting consumer number

Customer type	High Tension Bulk	Low Tension Bulk	Low Tension	Domestic
Demand	>125 kVA	50 kVA – 125 kVA	<50 kVA	≤6 kW
Customer Description	Industrial	Multiplex, big shopping mall, hospital, small scale industry	Hospital, nursing home, office/building, commercial establishment, cold storage	Rural/agricultural, urban residential

Single objective situations such as total cost minimization, energy loss reduction and improvement of SAIFI, SAIDI and AENS have been performed considering DG penetrations up to 20% and 50% of total real power load. The DG penetration level has been fixed considering the present and futuristic scenario. The stated single objective optimizations have been performed selecting bio mass power plant as DG source. The size of bio mass power plants have been selected as 50 kW and 100 kW considering the load demand of the 69 bus microgrid type radial distribution system. The cost of bio mass power plant has been selected as discussed for 34 bus microgrid system [244]. The capacitor size for simultaneous capacitor and DG allocation has been considered similar as selected for only capacitor placement cases discussed earlier. The cost of the capacitor and bus and line data for 69 bus microgrid type radial distribution system have been considered from elsewhere [245].

7.3.2.1 Total cost minimization

Total cost has been found reduced from the initial value performing capacitor allocation and DG integration using four evolutionary techniques. The reduction of total cost has been shown in Figure 7.47 for DG penetrations made up to 20% and 50% load level. The capacitor allocation and DG integration data concerning to that reduction have been shown in Table 7.31 and Table 7.32 for 20% and 50% DG penetrations, respectively. It has been observed from Figure 7.47 that total cost has been found reduced from US$ 5384155.54 to US$ 4228383.31 and from US$ 5384155.54 to US$ 4233258.75 by the implementation of rcGA considering DG penetration up to 20% and 50%, respectively. The reason behind the increase in total cost value with the increase of maximum DG penetration level from 20% to 50% is entrapment of rcGA technique into the local minima while searching for better total cost value. However, the DG value chosen by rcGA at bus location 3, 15, 22, 33, 47, 60 and 63 is 50 kW for every selected position shown in Table 7.31. Reactive power compensation has been acomplished implementing rcGA by allocating shunt capacitors at bus position 4, 23, 30, 51, 58, 61 and 62 in the 69 bus system.

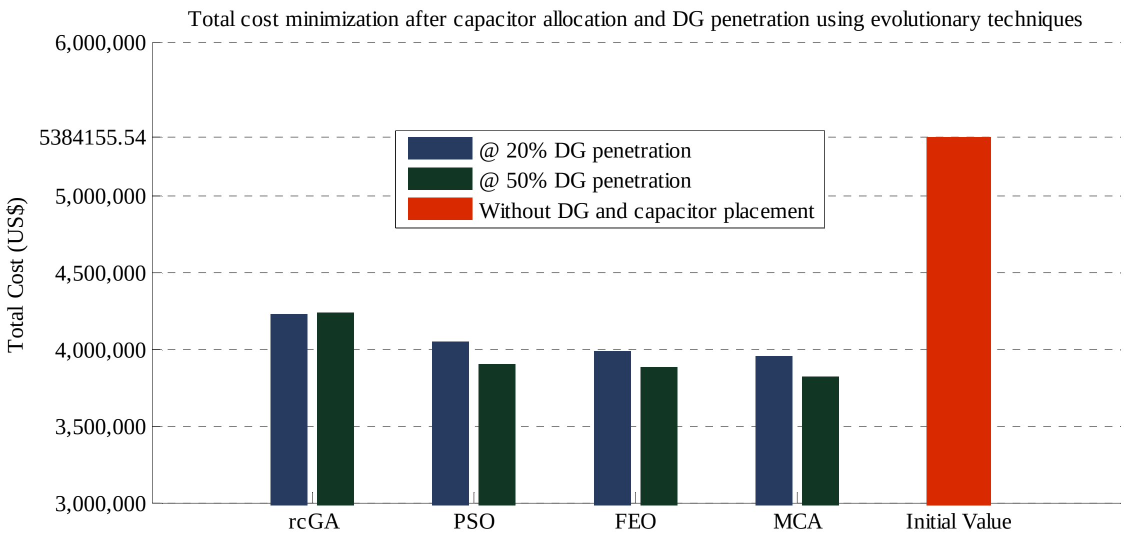

Figure 7.47: Comparative study amongst four evolutionary techniques for total cost minimization in 69 bus microgrid type radial distribution system

The capacitor values selected at those bus locations are 400 kVAR, 400 kVAR, 200 kVAR, 200 kVAR, 400 kVAR, 200 kVAR and 400 kVAR, respectively which can be observed in Table 7.31. Distributed generation integration has been performed applying rcGA at bus location 3, 12, 13, 14, 16, 17, 21, 23, 27, 28, 33, 36, 38, 43, 46, 47, 55, 59, 60, 62, 63, 66 and 67 with DG value of 50 kW at every selected position shown in Table 7.32. Two hundred kilo var of capacitor has been installed by the application of rcGA at bus number 4, 5, 18, 20, 22, 28, 32, 35, 36, 38, 39, 44, 47, 51, 53, 54, 59, 60, 62, 63 and 65. Capacitor value of 400 kVAR has been placed at bus location 64 as shown in Table 7.32. It can be noticed from Figure 7.47 that total cost has been found reduced from US$ 5384155.54 to US$ 4050511.95 and from US$ 5384155.54 to US$ 3897052.35 by the application of PSO considering a maximum of 20% and 50% DG penetration, respectively. The DG integration has been performed implementing PSO at bus number 23, 59 and 63 shown in Table 7.31. The DG value selected for every bus position is 100 kW. Shunt capacitors have been allocated utilizing PSO at bus number 49, 59, 62 and 68 shown in Table 7.31. Capacitor values chosen at those stated locations are 600 kVAR, 1200 kVAR, 200 kVAR and 400 kVAR, respectively. Distributed generation integrations have been performed implementing PSO at bus location 5, 22, 24, 62, 63 and 69 with DG value of 100 kW at every selected location shown in Table 7.32. Capacitors have been placed utilizing PSO algorithm at bus number 10, 15, 49, 50 and 62 with installation of 400 kVAR, 200 kVAR, 400 kVAR, 200 kVAR and 1200 kVAR. Finally it has been observed from Figure 7.47 that total cost has been found reduced from US$ 5384155.54 to US$ 3984777.32 and from US$ 5384155.54 to US$ 3877579.70 by the implementation of FEO considering DG penetration up to 20% and 50%, respectively. Distributed generators have been placed implementing FEO technique at bus location 61, 62 and 63 shown in Table 7.31. The DG value chosen for every mentioned bus position is 100 kW. Furthermore, shunt capacitors have been allocated utilizing FEO at bus number 59 and 67 which can be observed from Table 7.31. Capacitor values selected at those bus positions are 1200 kVAR and 600 kVAR, respectively. Distributed generation integration has been performed applying FEO at bus number 9, 13, 16, 21, 55, 59, 65 and 69 with DG value of 50 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW and 50 kW shown in Table 7.32. Again, shunt capacitors have been placed utilizing FEO technique at bus position 7, 18, 47, 48 and 62 with installation of 400 kVAR, 400 kVAR, 1200 kVAR, 400 kVAR and 1200 kVAR which can be observed from Table 7.32. Lastly it can be noticed from Figure 7.47 that total cost has been decreased from US$ 5384155.54 to US$ 3948094.94 and from US$ 5384155.54 to US$ 3813972.71 with the implementation of MCA considering a maximum of 20% and 50% DG penetrations, respectively. Distributed generators have been placed implementing MCA technique at bus position 27, 52, 54, 58, 59, 61 and 64 shown in Table 7.31. The DG values chosen at those selected locations are 100 kW, 100 kW, 50 kW, 100 kW, 100 kW, 100 kW and 100 kW, respectively. Reactive power compensation has also been performed utilizing MCA technique by allocating shunt capacitors at bus location 7, 17, 23, 32, 36, 47, 58 and 59 which can be observed from Table 7.31. Capacitor values chosen at those selected bus positions are 200 kVAR, 200 kVAR, 200 kVAR, 1000 kVAR, 200 kVAR, 600 kVAR, 400 kVAR and 800 kVAR, respectively. Distributed generation integration has been performed applying MCA technique at bus number 3, 8, 15, 20, 21, 23, 26, 28, 31, 34, 38, 50, 52, 55, 58, 59, 60, 64 and 65 with DG value of 100 kW, 100 kW, 100 kW, 100 kW, 50 kW, 50 kW, 50 kW, 100 kW, 50 kW, 50 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, respectively shown in Table 7.32. Capacitors have been placed utilizing MCA technique at bus location 7, 39, 53, 63 and 66 with installation of 400 kVAR, 800 kVAR, 400 kVAR, 1000 kVAR and 600 kVAR, respectively. It can be said from the above discussion that MCA has outperformed other algorithms in finding the least cost value. Energy loss reduction is another important criteria like total cost minimization for reliability based cost reduction. A comparative study regarding energy loss minimization has been discussed in the next section.

Table 7.31: DG integration and capacitor placement for total cost minimization at a maximum of 20% DG penetration in 69 bus microgrid type radial distribution system

Methods	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	50, 50, 50, 50, 50, 50, 50	3, 15, 22, 33, 47, 60, 63	400, 400, 200, 200, 400, 200, 400	4, 23, 30, 51, 58, 61, 62
PSO	100, 100, 100	23, 59, 63	600, 1200, 200, 400	49, 59, 62, 68
FEO	100, 100, 100	61, 62, 63	1200, 600	59, 67
MCA	100, 100, 50, 100, 100, 100, 100	27, 52, 54, 58, 59, 61, 64	200, 200, 200, 1000, 200, 600, 400, 800	7, 17, 23, 32, 36, 47, 58, 59

Table 7.32: Capacitor allocation and DG integration for total cost minimization at a maximum of 50% DG penetration in 69 bus microgrid type radial distribution system

Methods	DG placement	DG value (kW)	Capacitor placement	Capacitor value (kVAR)
rcGA	3, 12, 13, 14, 16, 17, 21, 23, 27, 28, 33, 36, 38, 43, 46, 47, 55, 59, 60, 62, 63, 66, 67	50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50	4, 5, 18, 20, 22, 28, 32, 35, 36, 38, 39, 44, 47, 51, 53, 54, 59, 60, 62, 63, 64, 65	200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 400, 200
PSO	5, 22, 24, 62, 63, 69	100, 100, 100, 100, 100, 100	10, 15, 49, 50, 62	400, 200, 400, 200, 1200
FEO	9, 13, 16, 21, 55, 59, 65, 69	50, 100, 100, 100, 100, 100, 100, 50	7, 18, 47, 48, 62	400, 400, 1200, 400, 1200
MCA	3, 8, 15, 20, 21, 23, 26, 28, 31, 34, 38, 50, 52, 55, 58, 59, 60, 64, 65	100, 100, 100, 100, 50, 50, 50, 100, 50, 50, 100, 100, 100, 100, 100, 100, 100, 100, 100	7, 39, 53, 63, 66	400, 800, 400, 1000, 600

7.3.2.2 Energy loss minimization for simultaneous capacitor and a maximum of 50% DG integration in 69 bus radial system

Like the previously discussed cost minimization issue, energy loss has also been observed to be reduced after performing DG integration and reactive power compensation by shunt capacitor. The DG and shunt capacitor have been suitably selected and placed in the considered 69 bus microgrid type radial distribution system by the four evolutionary computation techniques. The comparative study has been shown in Figure 7.48.

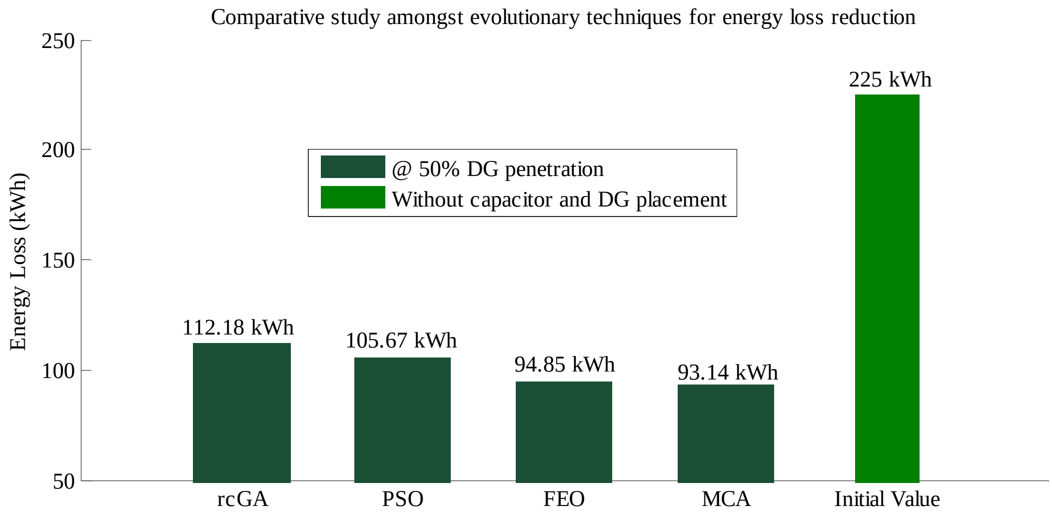

Figure 7.48: Comparative study after capacitor allocation and DG integration for energy loss minimization in 69 bus microgrid type radial distribution system

It has been observed from Figure 7.48 and Table 7.33 that energy loss has been reduced from 225 kWh to 105.67 kWh after placing DG at bus location 7, 19, 26, 33, 47, 48, 58, 60 and 69 by PSO. The DG value chosen is 100 kW for those selected bus positions shown in Table 7.33. Reactive power compensation by shunt capacitor allocation has also been performed by PSO at bus location 4, 6, 25, 63 and 69 which can be observed from Table 7.28. The capacitor values selected at those bus positions are 800 kVAR, 200 kVAR, 200 kVAR, 1200 kVAR and 400 kVAR, respectively shown in Table 7.33. It can be noticed from Figure 7.48 that energy loss has been found decreased from 225 kWh to 112.18 kWh by the implementation of rcGA. Distributed generator integration has been performed implementing rcGA at bus location 7, 9, 10, 12, 17, 18, 20, 22, 23, 24, 32, 33, 34, 38, 39, 49, 55, 58, 60, 62, 63 and 65, respectively shown in Table 7.33. The DG value chosen for every selected location is 50 kW. Shunt capacitors have been placed applying rcGA at bus number 3, 5, 7, 8, 9, 13, 17, 22, 27, 28, 30, 33, 38, 39, 40, 41, 42, 43, 47, 49, 53, 54, 55, 57, 59, 61, 62, 64 and 66 with 200 kVAR for every selected location. Finally it has been observed from Figure 7.48 that energy loss has been found reduced from 225 kWh to 94.85 kWh by the application of FEO algorithm. The distributed generators have been placed applying FEO at bus number 7, 19, 22, 23, 34, 57, 63 and 64 shown in Table 7.33. The DG value chosen at every mentioned bus location is 100 kW. Shunt capacitors have been allocated implementing FEO technique at bus location 4, 9, 26, 30 and 62 with 800 kVAR, 1000 kVAR, 200 kVAR, 600 kVAR and 1000 kVAR values which can be observed from Table 7.33. Lastly it has been observed from Figure 7.48 that energy loss has been found reduced from 225 kWh to 93.14 kWh by the implementation of MCA. The DG values has been selected at bus number 11, 12, 14, 18, 19, 22, 23, 27, 31, 46, 56, 58, 63 and 69 with values 50 kW, 100 kW, 100 kW, 100 kW, 50 kW, 100 kW, 50 kW, 50 kW, 50 kW, 100 kW, 100 kW, 100 kW, 100 kW and 100 kW, respectively by the application of MCA shown in Table 7.28. Capacitors have been placed implementing MCA at bus number 5, 6, 9, 30, 38, 49, 53, 61, 65, 69 with installation of 800 kVAR, 600 kVAR, 400 kVAR, 200 kVAR, 1000 kVAR, 400 kVAR, 200 kVAR, 800 kVAR, 200 kVAR and 400 kVAR values. It can be said from the above discussion that soft computing technique MCA has achieved the least energy loss value amongst all the chosen evolutionary techniques. Reliability enhancement is also important like energy loss reduction. Customer and load oriented distribution system reliability indices have been considered in the following sections for simulation study purpose.

Table 7.33: DG penetration and capacitor placement for energy loss reduction considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

Methods	DG placement	DG value (kW)	Capacitor placement	Capacitor value (kVAR)
PSO	7, 19, 26, 33, 47, 48, 58, 60, 69	100, 100, 100, 100, 100, 100, 100, 100, 100	4, 6, 25, 63, 69	800, 200, 200, 1200, 400
rcGA	7, 9, 10, 12, 17, 18, 20, 22, 23, 24, 32, 33, 34, 38, 39, 49, 55, 58, 60, 62, 63, 65	50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50	3, 5, 7, 8, 9, 13, 17, 22, 27, 28, 30, 33, 38, 39, 40, 41, 42, 43, 47, 49, 53, 54, 55, 57, 59, 61, 62, 64, 66	200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200
FEO	7, 19, 22, 23, 34, 57, 63, 64	100, 100, 100, 100, 100, 100, 100, 100	4, 9, 26, 30, 62	800, 1000, 200, 600, 1000
MCA	11, 12, 14, 18, 19, 22, 23, 27, 31, 46, 56, 58, 63, 69	50, 100, 100, 100, 50, 100, 50, 50, 50, 100, 100, 100, 100, 100	5, 6, 9, 30, 38, 49, 53, 61, 65, 69	800, 600, 400, 200, 1000, 400, 200, 800, 200, 400

7.3.2.3 SAIFI improvement

Customer oriented reliability index SAIFI (system average interruption frequency index) has been found improved from the initial value i.e. without capacitor and DG connectivity after appropriately simultaneous placement of DG and capacitor by the four evolutionary computation techniques. It has been observed from Figure 7.49 that SAIFI value has been found improved from 5.859207 interruptions/customer yr to 5.576522 interruptions/customer yr and from 5.859207 interruptions/customer yr to 5.485340 interruptions/customer yr by the application of rcGA considering DG penetration up to 20% and 50%, respectively. The distributed generators have been placed implementing rcGA at bus number 2, 6, 14, 16, 24, 34 and 40 with DG value of 50 kW at every selected location shown in Table 7.34. Shunt capacitors have been placed utilizing rcGA at bus location 4, 5, 8, 13, 20, 29, 36, 40, 50, 54, 55, 56, 58 and 61 which can be observed from Table 7.34. Capacitor values chosen at those mentioned bus positions are 400 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 400 kVAR, 200 kVAR, 400 kVAR, 200 kVAR and 400 kVAR, respectively. Distributed generation integration has been performed implementing rcGA at bus number 9, 10, 14, 22, 25, 31, 38, 47, 56 and 68 with DG value of 50 kW at every selected position shown in Table 7.35. Capacitors have been allocated applying rcGA at bus location 2, 4, 6, 11, 12, 19, 36, 49, 50, 51, 58, 59, 60 and 61 with installed capacitor value of 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 200 kVAR, 400 kVAR, 200 kVAR, 200 kVAR and 200 kVAR as shown in Table 7.35.

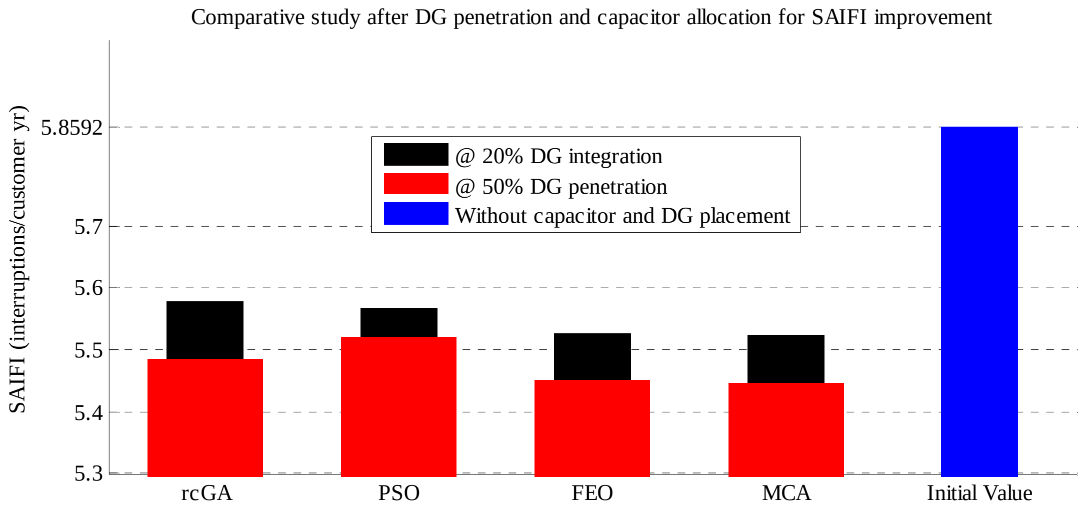

Figure 7.49: Comparative study amongst four evolutionary techniques for SAIFI improvement in 69 bus microgrid type radial distribution system

It can be noticed from Figure 7.49 that SAIFI value has been found reduced from 5.859207 interruptions/customer yr to 5.567214 interruptions/customer yr and from 5.859207 interruptions/customer yr to 5.519951 interruptions/customer yr with the implementation of PSO considering DG penetration up to 20% and 50%, respectively. The distributed generators have been allocated implementing PSO at bus number 20, 25, 42 and 48 shown in Table 7.34. The chosen DG values for those selected bus positions are 100 kW, 50 kW, 100 kW and 100 kW. Reactive power compensation has been performed applying PSO by placing shunt capacitor at bus number 2, 5, 16, 29, 53, 62 and 66 which can be observed from Table 7.34. Capacitor values selected at those stated bus locations are 800 kVAR, 1200 kVAR, 200 kVAR, 600 kVAR, 600 kVAR, 800 kVAR and 200 kVAR, respectively shown in Table 7.34. On the other hand, distributed generation integration has been performed utilizing PSO at bus location 4, 10, 18, 20, 25, 34, 41 and 54 with DG value of 100 kW, 100 kW, 100 kW, 100 kW, 50 kW, 50 kW, 100 kW and 100 kW, respectively shown in Table 7.35. Shunt capacitors have been placed implementing PSO at bus number 14 and 62 with installed capacitor value of 400 kVAR and 1200 kVAR which can be observed from Table 7.35. Finally it has been observed from Figure 7.49 that SAIFI value has been found improved from 5.859207 interruptions/customer yr to 5.525628 interruptions/customer yr and from 5.859207 interruptions/customer yr to 5.452151 interruptions/customer yr by the application of FEO considering DG penetration up to 20% and 50%, respectively. The DG integration has been performed implementing FEO at bus location 17, 22, 50 and 62 shown in Table 7.34. The chosen DG values at those selected locations are 100 kW, 100 kW, 50 kW and 50 kW, respectively. Reactive power compensation has been performed applying FEO placing shunt capacitor at bus location 19, 51, 55 and 64 shown in Table 7.34. Capacitor values have been chosen for those mentioned bus positions are 200 kVAR, 600 kVAR, 400 kVAR and 400 kVAR, respectively. Distributed generation integration has been performed utilizing FEO at bus location 11, 16, 18, 25, 30, 41, 43, 51, 58, 62 and 63 with DG value of 100 kW, 100 kW, 50 kW, 50 kW, 100 kW, 100 kW, 50 kW, 50 kW, 100 kW, 100 kW and 100 kW shown in Table 7.35. Capacitors have been allocated implementing FEO at bus location 8, 18, 28, 36, 54, 56, 62, 64 and 68 with installation of 1000 kVAR, 200 kVAR, 1000 kVAR, 600 kVAR, 600 kVAR, 1000 kVAR, 800 kVAR, 200 kVAR and 200 kVAR values which can be observed from Table 7.35. Lastly it can be noticed from Figure 7.49 that customer oriented reliability index SAIFI value has been found reduced from 5.859207 interruptions/customer yr to 5.524487 interruptions/customer yr and from 5.859207 interruptions/customer yr to 5.446219 interruptions/customer yr with the implementation of MCA considering DG penetration up to 20% and 50%, respectively. Distributed generators have been placed applying MCA at bus location 7, 14, 20 and 48 shown in Table 7.34. The DG values chosen at those selected positions are 50 kW, 100 kW, 100 kW and 100 kW, respectively. Shunt capacitors have been allocated utilizing MCA at bus position 14, 19, 44, 56 and 58 shown in Table 7.34. Capacitor values have been chosen for those stated positions are 200 kVAR, 200 kVAR, 200 kVAR, 1200 kVAR and 600 kVAR, respectively. Distributed generation integration has been performed implementing MCA algorithm at bus number 2, 7, 16, 20, 24, 34, 39, 42, 46, 58 and 66 with DG value of 100 kW, 50 kW, 100 kW, 50 kW, 50 kW, 50 kW, 100 kW, 100 kW, 100 kW, 50 kW and 100 kW shown in Table 7.30. Shunt capacitors have been placed utilizing MCA technique at bus location 22, 37, 53, 61, 62 and 66 with installation of 200 kVAR, 800 kVAR, 400 kVAR, 1200 kVAR, 200 kVAR and 200 kVAR values which can be observed from Table 7.35. It can be said from the above discussion that soft computing technique MCA has outperformed all the selected algorithms in finding the least SAIFI value. Improvement study of another customer oriented reliability index SAIDI is also important to understand from the reliability perspectives.

Table 7.34: Capacitor installation and DG incorporation for SAIFI improvement at a maximum of 20% DG penetration in 69 bus microgrid type radial distribution system

Methods	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	50, 50, 50, 50, 50, 50, 50	2, 6,14,16, 24, 34, 40	400, 200, 200, 200, 200, 200, 200, 200, 200, 400, 200, 400, 200, 400	4, 5, 8, 13, 20, 29, 36, 40, 50, 54, 55, 56, 58, 61
PSO	100, 50, 100, 100	20, 25, 42, 48	800, 1200, 200, 600, 600, 800, 200	2, 5, 16, 29, 53, 62, 66
FEO	100, 100, 50, 50	17, 22, 50, 62	200, 600, 400, 400	19, 51, 55, 64
MCA	50, 100, 100, 100	7, 14, 20, 48	200, 200, 200, 1200, 600	14, 19, 44, 56, 58

Table 7.35: DG integration and capacitor allocation for SAIFI improvement considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

Methods	DG placement	DG value (kW)	Capacitor placement	Capacitor value (kVAR)
rcGA	9, 10, 14, 22, 25, 31, 38, 47, 56, 68	50, 50, 50, 50, 50, 50, 50, 50, 50, 50	2, 4, 6, 11, 12, 19, 36, 49, 50, 51, 58, 59, 60, 61	200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 400, 200, 200, 200
PSO	4, 10, 18, 20, 25, 34, 41, 54	100, 100, 100, 100, 50, 50, 100, 100	14, 62	400, 1200
FEO	11, 16, 18, 25, 30, 41, 43, 51, 58, 62, 63	100, 100, 50, 50, 100, 100, 50, 50, 100, 100, 100	8, 18, 28, 36, 54, 56, 62, 64, 68	1000, 200, 1000, 600, 600, 1000, 800, 200, 200
MCA	2, 7, 16, 20, 24, 34, 39, 42, 46, 58, 66	100, 50, 100, 50, 50, 50, 100, 100, 100, 50, 100	22, 37, 53, 61, 62, 66	200, 800, 400, 1200, 200, 200

7.3.2.4 SAIDI improvement

Customer oriented reliability index SAIDI (system average interruption duration index) has been found improved by opting DG and capacitor placement. Like the said study for SAIFI improvement, four evolutionary algorithms have been considered for SAIDI improvement shown in Figure 7.50. It has been observed from Figure 7.50 that SAIDI value has been found improved from 7.152889 hours/customer yr to 6.758197 hours/customer yr and from 7.152889 hours/customer yr to 6.859626 hours/customer yr by the application of rcGA considering DG penetration up to 20% and 50%, respectively. The SAIDI value has not been found reduced with the increment of DG penetration level from 20% to 50% by the application of rcGA. It is due to the reason that rcGA technique has been trapped into the local minima while searching for better SAIDI value. Distributed generator placing has been performed utilizing rcGA at bus locations 6, 14, 16, 21, 24, 28, 31, 41, 46, 52, 56, 59 and 65 shown in Table 7.36. The DG value chosen for those selected buses are 50 kW, 50 kW, 50 kW, 50 kW, 50 kW, 50 kW, 100 kW, 50 kW, 50 kW, 50 kW, 50 kW, 50 kW and 50 kW. Shunt capacitors have been allocated implementing rcGA at bus locations 5, 23, 36, 59, 60 and 64 which can be observed from Table 7.36. Capacitor values chosen for those selected buses are 200 kVAR, 200 kVAR, 400 kVAR, 200 kVAR, 800 kVAR and 600 kVAR, respectively. Distributed generation integration has been performed at bus location 8, 11, 13, 22, 25, 27, 36, 42, 45 and 48 with DG value of 50 kW connected at every selected position shown in Table 7.32. Capacitors have been placed utilizing rcGA at bus number 3, 4, 9, 11, 12, 13, 19, 46, 47, 50, 53, 55, 56, 57, 58, 61, 64 and 69 with installation of 200 kVAR values at every selected position. It can be noticed from Figure 7.50 that reliability index SAIDI has been found reduced from 7.152889 hours/customer yr to 6.841658 hours/customer yr and from 7.152889 hours/customer yr to 6.876333 hours/customer yr with the implementation of PSO considering a maximum of 20% and 50% DG penetrations, respectively.

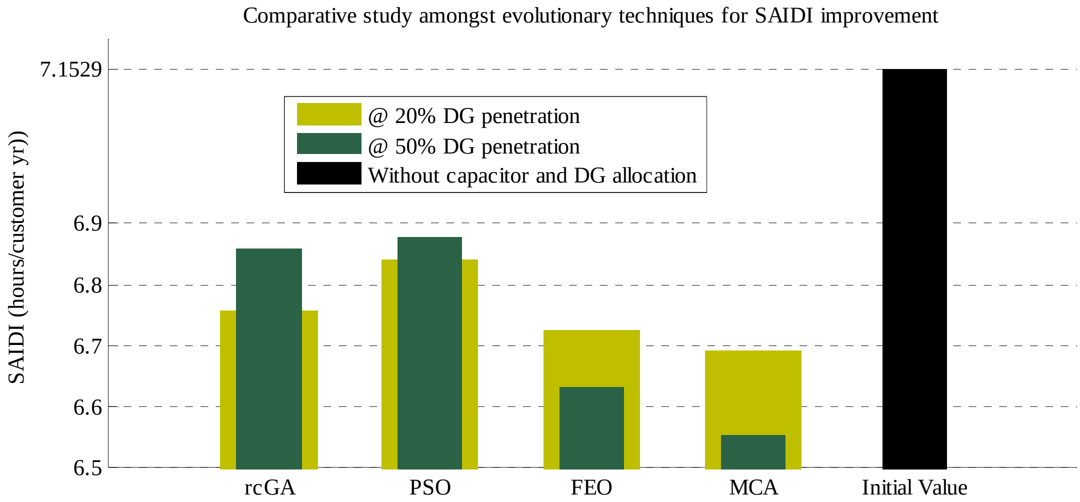

Figure 7.50: Study of SAIDI improvement amongst PSO, rcGA, FEO and MCA after capacitor allocation and DG integration in 69 bus microgrid type radial distribution system

Again the SAIDI value has not been found reduced with the increase in maximum DG penetration level from 20% to 50% in the case of PSO. This is due to the entrapment of PSO algorithm in the local minima while searching for better SAIDI value. The DG placement has been performed utilizing PSO at bus number 15, 25, 33, 62 and 66, respectively shown in Table 7.36. The DG value chosen at those selected bus positions are 100 kW, 100 kW, 50 kW, 100 kW and 100 kW, respectively. Reactive power compensation has been performed implementing PSO by allocating shunt capacitor at bus location 2, 13, 48, 51 and 57 shown in Table 7.36. Capacitor values selected for those buses are 400 kVAR, 400 kVAR, 800 kVAR, 1000 kVAR and 400 kVAR, respectively. Distributed generation integration has been performed applying PSO at bus location 8, 39, 49, 51, 54, 58, 59 and 65 with DG value of 100 kW positioned at every selected position as shown in Table 7.37. Shunt capacitors have been placed implementing PSO at bus number 3, 10, 22, 60 and 62 with installed capacitor value of 1000 kVAR, 400 kVAR, 200 kVAR, 800 kVAR and 400 kVAR, respectively which can be observed from Table 7.37. Finally it has been observed from Figure 7.50 that SAIDI value has been found improved from 7.152889 hours/customer yr to 6.727007 hours/customer yr and from 7.152889 hours/customer yr to 6.630760 hours/customer yr by the application of FEO considering DG penetration up to 20% and 50%, respectively. Distributed generator integration has been performed utilizing FEO at bus location 18, 20, 27, 59, 61, 66 and 68 in shown Table 7.36. The selected DG values for those bus positions are 100 kW, 100 kW, 50 kW, 100 kW, 100 kW, 100 kW and 100 kW. Shunt capacitors have been allocated implementing FEO at bus number 6, 24, 53 and 57 which can be observed from Table 7.36. Chosen capacitor values for those mentioned buses are 1200 kVAR, 200 kVAR, 600 kVAR and 200 kVAR, respectively. Distributed generation integration has been performed utilizing FEO at bus position 3, 5, 17, 24, 46, 47, 55, 62 and 68 with DG value of 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 50 kW, 100 kW and 100 kW, respectively shown in Table 7.37. Capacitors have been placed applying FEO at bus number 11, 20, 53 and 61 with installed capacitor value of 200 kVAR, 200 kVAR, 600 kVAR and 800 kVAR shown in Table 7.37. Lastly it can be noticed from Figure 7.50 that SAIDI value has been found reduced from 7.152889 hours/customer yr to 6.690881 hours/customer yr and from 7.152889 hours/customer yr to 6.553716 hours/customer yr with the implementation of MCA considering

DG penetration up to 20% and 50%, respectively. The DG placement has been performed applying MCA at bus location 6, 12, 14, 26, 40, 45, 65 and 68 shown in Table 7.36. The chosen DG values for those stated buses are 50 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW and 50 kW, respectively. Reactive power compensation has been performed implementing MCA by allocating shunt capacitor at bus number 9, 12, 22, 58 and 69 shown in Table 7.36. Chosen capacitor values at those bus positions are 400 kVAR, 200 kVAR, 200 kVAR, 1200 kVAR and 200 kVAR, respectively. Distributed generation integration has been performed utilizing MCA at bus location 5, 12, 14, 15, 16, 23, 24, 27, 33, 35, 39, 40, 51, 53, 54, 59, 62, 63, 64, 65, 66 and 69 with DG value of 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 50 kW, 50 kW, 50 kW, 50 kW, 50 kW, 50 kW, 100 kW, 50 kW, 50 kW, 50 kW, 100 kW, 100 kW, 100 kW, 100 kW, 50 kW, 100 kW and 50 kW as shown in Table 7.37. Capacitors have been allocated utilizing MCA at bus number 2, 10, 55 and 64 with installed capacitor value of 600 kVAR, 800 kVAR, 1000 kVAR, 400 kVAR which can be observed from Table 7.37. It can be said from the above discussion that the technique MCA has outperformed all the selected soft computing techniques in finding the least SAIDI value. The simulation study concerning to the energy oriented reliability index AENS improvement is also important to understand reliability issues.

Table 7.36: Capacitor placement and DG integration for SAIDI improvement at a maximum of 20% DG penetration in 69 bus microgrid type radial distribution system

Methods	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	50, 50, 50, 50, 50, 50, 100, 50, 50, 50, 50, 50, 50	6, 14, 16, 21, 24, 28, 31, 41, 46, 52, 56, 59, 65	200, 200, 400, 200, 800, 600	5, 23, 36, 59, 60, 64
PSO	100, 100, 50, 100, 100	15, 25, 33, 62, 66	400, 400, 800, 1000, 400	2, 13, 48, 51, 57
FEO	100, 100, 50, 100, 100, 100, 100	18, 20, 27, 59, 61, 66, 68	1200, 200, 600, 200	6, 24, 53, 57
MCA	50, 100, 100, 100, 100, 100, 100, 50	6, 12, 14, 26, 40, 45, 65, 68	400, 200, 200, 1200, 200	9, 12, 22, 58, 69

Table 7.37: DG integration and capacitor allocation for SAIDI improvement at a maximum of 50% DG penetration in 69 bus microgrid type radial distribution system

Methods	DG placement	DG value (kW)	Capacitor placement	Capacitor value (kVAR)
rcGA	8, 11, 13, 22, 25, 27, 36, 42, 45, 48	50, 50, 50, 50, 50, 50, 50, 50, 50, 50	3, 4, 9, 11, 12, 13, 19, 46, 47, 50, 53, 55, 56, 57, 58, 61, 64, 69	200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200
PSO	8, 39, 49, 51, 54, 58, 59, 65	100, 100, 100, 100, 100, 100, 100, 100	3, 10, 22, 60, 62	1000, 400, 200, 800, 400
FEO	3, 5, 17, 24, 46, 47, 55, 62, 68	100, 100, 100, 100, 100, 100, 50, 100, 100	11, 20, 53, 61	200, 200, 600, 800
MCA	5, 12, 14, 15, 16, 23, 24, 27, 33, 35, 39, 40, 51, 53, 54, 59, 62, 63, 64, 65, 66, 69	100, 100, 100, 100, 100, 50, 50, 50, 50, 50, 50, 100, 50, 50, 50, 100, 100, 100, 100, 50, 100, 50	2, 10, 55, 64	600, 800, 1000, 400

7.3.2.5 AENS improvement

Energy and load oriented reliability index AENS (average energy not supplied) has been found improved from the initial value by proper selection and placement of DG and shunt capacitor. The comparative study amongst the four soft computing techniques has been illustrated in Figure 7.51. Distributed generation integration and capacitor allocation data considering 20% and 50% DG penetrations have been shown in Table 7.38 and Table 7.39, respectively. It has been observed from Figure 7.51 that AENS value has been found improved from 38.313253 kWh/customer yr to 36.940309 kWh/customer yr and from 38.313253 kWh/customer yr to 36.422217 kWh/customer yr with the implementation of rcGA considering DG penetration up to 20% and 50%, respectively. The DG integration has been performed utilizing rcGA at bus locations 4, 6, 13, 17, 22 and 46 considering a maximum of 20% DG integration shown in Table 7.33. The chosen DG value is 100 kW at every stated location. On the other hand, shunt capacitors have been placed implementing rcGA at bus number 2, 14, 30, 50, 64 and 66 which can be observed from Table 7.38. Selected capacitor values for those bus positions are 200 kVAR, 200 kVAR, 200 kVAR, 600 kVAR, 1200 kVAR and 600 kVAR, respectively. Distributed generation integration has been performed applying rcGA at bus locations 13, 16, 21, 22, 24, 36, 38, 52, 57, 59, 64 and 66 considering a maximum of 50% DG integration shown in Table 7.39. The selected DG value is 50 kW at every stated location. Capacitor placement has also been performed at bus number 3, 4, 5, 6, 7, 8, 11, 23, 36, 39, 41, 42, 49, 51, 55, 57, 59, 61, 62, 64 and 66 with installed value of 200 kVAR at every selected location. It can be noticed from Figure 7.51 that reliability index AENS value has been found improved from 38.313253 kWh/customer yr to 36.805919 kWh/customer yr and from 38.313253 kWh/customer yr to 35.786702 kWh/customer yr by the application of PSO considering DG penetration up to 20% and 50%, respectively. Distributed generators have been placed utilizing PSO at bus location 16, 26, 48 and 60 shown in Table 7.38. The DG value chosen for every stated location is 100 kW.

On the other hand, reactive power compensation has also been performed by placing shunt capacitor at bus number 10, 12, 38, 49, 60 and 64 which can be observed from Table 7.38. The capacitor values selected implementing PSO for those buses are 200 kVAR, 400 kVAR, 200 kVAR, 600 kVAR, 800 kVAR and 400 kVAR, respectively which is shown in Table 7.38. Distributed generation integration has been performed implementing PSO at 8, 12, 13, 22, 24, 30, 32, 41, 43, 44, 50, 53, 62, 65 and 69 with 100 kW of DG value connected at every selected location shown in Table 7.39.

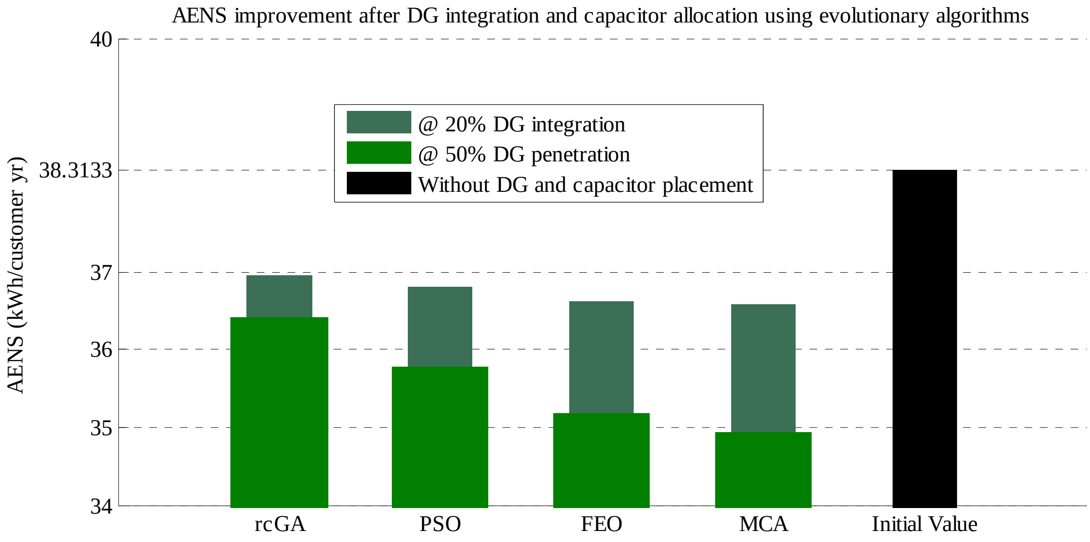

Figure 7.51: Comparative study amongst four evolutionary techniques for AENS improvement in 69 bus microgrid type radial distribution system

Capacitors have been allocated utilizing PSO at bus position 9, 11, 38, 58, 63 and 68 with installed capacitor value of 600 kVAR, 200 kVAR, 200 kVAR, 400 kVAR, 600 kVAR and 200 kVAR, respectively as can be observed from Table 7.39. Finally it has been observed from Figure 7.51 that AENS value has been found improved from 38.313253 kWh/customer yr to 36.616879 kWh/customer yr and from 38.313253 kWh/customer yr to 35.171439 kWh/customer yr with the implementation of FEO for DG penetration up to 20% and 50%, respectively. The DG placement has been performed utilizing FEO at bus number 6, 12, 15, 24, 56, 61 and 69 shown in Table 7.38. The DG value is 100 kW for those mentioned buses. Shunt capacitor has been allocated implementing FEO at bus location 36, 50, 64 and 69 with installed value of 200 kVAR, 600 kVAR, 800 kVAR and 600 kVAR shown in Table 7.38. Distributed generation integration has been exercised utilizing FEO at bus location 10, 12, 13, 18, 30, 48, 52, 56, 58, 62, 65, 67 and 68 with DG value of 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 50 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, 100 kW, respectively shown in Table 7.39. Capacitors have been placed applying FEO at bus number 11, 20, 37, 38, 52, 53 and 63 with installed capacitor value of 400 kVAR, 200 kVAR, 400 kVAR, 600 kVAR, 200 kVAR, 400 kVAR and 400 kVAR, respectively shown in Table 7.39. Lastly it has been observed from Figure 7.51 that AENS value has been found improved from 38.313253 kWh/customer yr to 36.569646 kWh/customer yr and from 38.313253 kWh/customer yr to 34.940375 kWh/customer yr by the application of MCA considering DG penetration up to 20% and 50%, respectively. The DG integration has been performed applying MCA at bus locations 19, 22, 23, 26, 41, 42, 53, 62 and 66 with DG value of 100 kW, 100 kW, 100 kW, 50 kW, 50 kW, 50 kW, 100 kW, 100 kW and 50 kW, respectively shown in Table 7.38. Reactive power compensation has been exercised by allocating shunt capacitors implementing MCA at bus number 3, 8, 47, 57, 61, 62 and 66 with installation of 200 kVAR, 200 kVAR, 400 kVAR, 200 kVAR, 1000 kVAR, 400 kVAR and 400 kVAR, respectively which can be observed from Table 7.38. Distributed generator of 50 kW has been placed at bus number 12, 14, 16, 19, 22, 23, 27, 49, 55, 57 and 62 as shown in Table 7.39. Hundred kilo watt of DG value has been installed at bus position 6, 7, 11, 17, 34, 38, 43, 51, 53, 61, 63 and 65. Capacitor placements have also been performed at bus position 5, 9, 31, 32, 49, 66 with installed capacitor values of 400 kVAR, 800 kVAR, 200 kVAR, 200 kVAR, 600 kVAR and 800 kVAR, respectively which can be observed in Table 7.34.

Table 7.38: Capacitor placement and DG integration for AENS improvement considering DG penetration up to 20% in 69 bus microgrid type radial distribution system

Methods	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	100, 100, 100, 100, 100, 100	4, 6, 13, 17, 22, 46	200, 200, 200, 600, 1200, 600	2, 14, 30, 50, 64, 66
PSO	100, 100, 100, 100	16, 26, 48, 60	200, 400, 200, 600, 800, 400	10, 12, 38, 49, 60, 64
FEO	100,100, 100, 100, 100, 100, 100	6, 12,15, 24, 56, 61, 69	200, 600, 800, 600	36, 50, 64, 69
MCA	100, 100, 100, 50, 50, 50, 100, 100, 50	19, 22, 23, 26, 41, 42, 53, 62, 66	200, 200, 400, 200, 1000, 400, 400	3, 8, 47, 57, 61, 62, 66

Table 7.39: DG incorporation and capacitor allocation for AENS improvement at a maximum of 50% DG penetration in 69 bus microgrid type radial distribution system

Methods	DG placement	DG value (kW)	Capacitor placement	Capacitor value (kVAR)
rcGA	13, 16, 21, 22, 24, 36, 38, 52, 57, 59, 64, 66	50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50	3, 4, 5, 6, 7, 8, 11, 23, 36, 39, 41, 42, 49, 51, 55, 57, 59, 61, 62, 64, 66	200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200, 200
PSO	8, 12, 13, 22, 24, 30, 32, 41, 43, 44, 50, 53, 62, 65, 69	100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100	9, 11, 38, 58, 63, 68	600, 200, 200, 400, 600, 200
FEO	10, 12, 13, 18, 30, 48, 52, 56, 58, 62, 65, 67, 68	100, 100, 100, 100, 100, 100, 50, 100, 100, 100, 100, 100, 100	11, 20, 37, 38, 52, 53, 63	400, 200, 400, 600, 200, 400, 400
MCA	6, 7, 11, 12, 14, 16, 17, 19, 22, 23, 27, 34, 38, 43, 49, 51, 53, 55, 57, 61, 62, 63, 65	100, 100, 100, 50, 50, 50, 100, 50, 50, 50, 50, 100, 100, 100, 50, 100, 100, 50, 50, 100, 50, 100, 100	5, 9, 31, 32, 49, 66	400, 800, 200, 200, 600, 800

It can be said from the above discussion that FEO and MCA techniques have come out as the effective algorithms in the comparative studies performed for total cost minimization, energy loss reduction, SAIFI, SAIDI and AENS improvements. But single objective optimization does not give the clear picture for appropriate planning related to a specific customer such as urban, industrial etc. On the other hand, this can not attain a specific planning when any two criteria amongst power interruption duration, interruption frequency, loss and electricity price are of major concern. That's why multi-objective optimizations considering capacitor allocation and DG integration choosing two conflicting objectives have been performed here to understand the situation in a better way. Two effective techniques viz. MCA and FEO have been opted for these crucial multi-objective optimizations. This has been accomplished considering a maximum of 50% DG integration level.

7.3.3 Multi-objective optimization

Appropriate planning has been conceived in sixty nine bus microgrid type radial distribution system considering two different conflicting objectives. As discussed in earlier sections, modified cultural algorithm and fish electrolocation optimization have come out as effective evolutionary algorithms for single objective situations. That's why these two algorithms have been chosen for multi objective optimizations considering various conflicting objectives. Total cost, energy loss, SAIFI, SAIDI, AENS and CBRI are the selected conflicting objectives. Suitable capacitor allocation and DG integration have been performed utilizing these MCA and FEO techniques considering a maximum of 50% DG penetration of total real power load. The DG penetration level has been fixed considering the futuristic scenario. Nine pairs have been formed for simulation study where each pair is comprised of two conflicting objectives. The reason behind selection of only nine pairs is that cost reduction is an important issue which has been approached here with enerly loss reduction and reliability improvements of SAIFI, SAIDI and AENS. On the other hand, the newly developed reliability index CBRI improvement is also significant to study with improvements of other reliability indices viz. SAIFI, SAIDI and AENS, reduction of energy loss and total cost minimization. These are illustrated one by one in the following sections.

7.3.3.1 Considering total cost and energy loss

Energy loss and total cost have been considered as two conflicting objectives for the first multi objective situation. The objective in this case is to reduce the energy loss and also to minimize the total cost. The scaling factors are considered as 0.6 and 0.4 for total cost and energy loss respectively for the formulation of multi-objective weighted sum value. In the deregulated environment price is an important factor. So higher importance has been provided to the total cost by considering higher scaling factor value. This has been performed considering the requirement of rural/agricultural, commercial and urban types of customers especially for that particular feeder where electricity price and power quality are of major concern. Pareto optimal solutions implementing FEO and MCA techniques considering energy loss and total cost have been has been tabulated in Table 7.40 and Table 7.41, respectively. Two and four non-dominated solutions have been obtained by FEO and MCA techniques shown in Table 7.40 and Table 7.41, respectively. The least total cost value considering both the Table 7.40 and Table 7.41 is US$ 3998202.87. This has been achieved by MCA technique. On the other hand, the least energy loss value considering the above mentioned Tables is 93.26 kWh. It has been obtained by FEO algorithm. It can be said by observing the non-dominated solutions obtained implementing MCA and FEO techniques available in Table 7.40 and Table 7.41 that it is hard to choose one particular solution. The decision maker can select specific solution from the solution sets of Table 7.40 and Table 7.41 considering weightage factor for each conflicting objective.

Table 7.40: Non-dominated solutions achieved after implementation of FEO algorithm for total cost and energy loss reduction in 69 bus microgrid type radial distribution system

Sl No.	Total Cost (US$)	Energy loss (kWh)
1	4113218.31	105.86
2	4211793.16	93.26

Table 7.41: Pareto optimal solutions obtained utilizing MCA technique for total cost and energy loss reduction in 69 bus microgrid type radial distribution system

Sl No.	Total Cost (US$)	Energy loss (kWh)
1	3998202.87	100.22
2	4054605.65	95.32
3	4053719.62	96.65
4	4009112.72	97.60

Like energy loss reduction and total cost minimization, load-oriented reliability index AENS improvement has also been considered with total cost reduction for multi-objective optimization applying FEO and MCA technique. This pair of AENS and total cost has been considered for multi-objective optimization as energy supply and electricity price are important for some feeders.

7.3.3.2 Choosing AENS and Total cost

In the second attempt, total cost and load-oriented distribution system reliability index AENS have been chosen as two conflicting objectives for multi-objective situation. The objective in this case is to minimize the total cost and also to improve the AENS by reducing its value from original configuration i.e. without capacitor and DG connectivity. The planning approach opted here is suitable for that particular feeder where electricity price and energy supply are significant factors. The scaling factors considered for total cost and AENS are 0.6 and 0.4, respectively. More importance has been given to the total cost factor by providing higher scaling factor value in comparison to AENS. The simulation results after performing multi-objective DG penetration and capacitor allocation applying FEO and MCA techniques have been shown in Table 7.42 and Table 7.43. Five and three non-dominated solutions have been achieved by FEO and MCA techniques which can be observed from Table 7.42 and Table 7.43, respectively. The least total cost value shown in Table 7.24 is US$ 3998099.17. The corresponding AENS value to the least total cost is the highest as shown in Table 7.42. On the other hand, the least AENS value in Table 7.42 is 36.117234 kWh/customer yr. The total cost value related to the least AENS is the highest. So, a compromise has to be done in choosing a particular solution from the solution set of Table 7.42 considering the two conflicting objectives viz. total cost and AENS. Like the case of FEO algorithm, the solution set obtained by MCA technique after performing multi-objective optimization reflects the same scenario. The solution achieving least AENS value obtains highest total cost and vice versa as shown in Table 7.43. Decision maker has to consider weightage factor to select a particular solution from the pareto-optimal solutions of Table 7.43. This is due to the reason that decision making method such as TOPSIS discussed earlier in Chapter 4 assigns a few weight values to reach a suitable solution.

Table 7.42: Non-dominated solutions achieved after applying FEO algorithm for total cost reduction and AENS improvement in 69 bus microgrid type radial distribution system

Sl No.	Total Cost (US$)	AENS kWh/customer yr
1	3998099.17	36.763628
2	4004750.34	36.745312
3	4106839.22	36.133167
4	4343583.30	36.124110
5	4619909.04	36.117234

Table 7.43: Pareto optimal solutions obtained implementing MCA technique for total cost reduction and AENS improvement in 69 bus microgrid type radial distribution system

Sl No.	Total Cost (US$)	AENS kWh/customer yr
1	4215021.17	36.605098
2	4747422.87	36.537952
3	4200474.58	37.338514

Customer oriented distribution system reliability index SAIDI has been considered with total cost for performing multi-objective optimization. This has been done to accomplish SAIDI improvement vis. a vis. cost reduction implementing FEO and MCA techniques.

7.3.3.3 Total cost and SAIDI as conflicting objectives

Customer oriented distribution system reliability index SAIDI and total cost have been chosen for multi-objective optimization. The final solution approached here is appropriate for that particular type of customer who is concerned about electricity price and power interruption duration. Like the previous sections, capacitor allocation and DG integration have been performed considering the stated two conflicting objectives at a maximum of 50% DG penetration. Scaling factor values for performing multi-objective optimization have been considered as 0.6 and 0.4 for total cost and SAIDI, respectively. More importance has been given to total cost in comparison to SAIDI by providing extra scaling factor value. Three non-dominated solutions have been achieved implementing FEO algorithm shown in Table 7.44.

Table 7.44: Pareto optimal solutions achieved utilizing FEO algorithm for total cost reduction and SAIDI improvement in 69 bus microgrid type radial distribution system

Sl No.	Total Cost (US$)	SAIDI
1	3885660.58	6.874034
2	3929524.74	6.751510
3	3968247.03	6.697302

On the other hand, MCA technique has found three pareto-optimal solutions performing multi-objective optimization shown in Table 7.45. The lesser total cost and SAIDI values are better for system improvement.

Table 7.45: Non-dominated solutions obtained implementing MCA technique for total cost reduction and SAIDI improvement in 69 bus microgrid type radial distribution system

Sl No.	Total Cost (US$)	SAIDI
1	4089147.25	6.704575
2	4043435.04	6.765307
3	3985421.68	6.830675

It can be said by observing the non-dominated solutions obtained by FEO and MCA techniques available in Table 7.44 and Table 7.45 that both solutions are competitive to each other. So the decision maker has to select the suitable solution by providing some weightage factors to these conflicting objectives. However, reliability index SAIFI dealing with interruption frequency and total cost signifying electricity price can be considered for reliability purpose.

7.3.3.4 SAIFI and the Total cost

In this case, total cost reduction and customer oriented distribution system reliability index SAIFI have been selected for performing multi-objective optimization. This planning scheme is suitable for that particular feeder where electricity price and power interruption frequency are of major concern. The scatter plot of the non-dominated solutions obtained by MCA and FEO techniques has been shown in Figure 7.52.

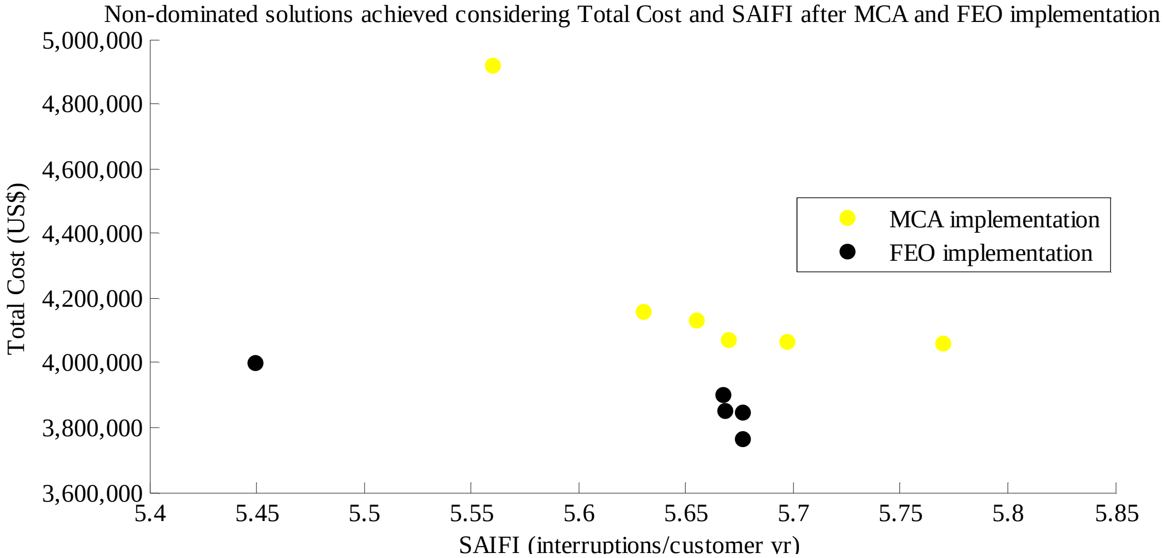

Figure 7.52:Scatter plot of pareto optimal solutions for total cost reduction and SAIFI improvement in 69 bus microgrid type radial distribution system

Six and five pareto-optimal solutions have been achieved implementing MCA and FEO techniques which can be observed from Table 7.46 and Table 7.47, respectively. The lesser total cost and SAIFI values are better for cost based reliability enhancement. In this regard, the non-dominated solutions achieved by FEO and MCA techniques are comparative to each other as shown in Figure 7.52.

Table 7.46: Non-dominated solutions achieved implementing MCA technique for total cost reduction and SAIFI improvement in 69 bus microgrid type radial distribution system

Sl No.	Total Cost (US$)	SAIFI
1	4158650.15	5.629965
2	4130968.05	5.654806
3	4068029.35	5.696760
4	4074188.11	5.669800
5	4919780.90	5.559359
6	4060784.19	5.769173

Table 7.47: Pareto optimal solutions obtained by applying FEO algorithm for total cost reduction and SAIFI improvement in 69 bus microgrid type radial distribution system

Sl No.	Total Cost (US$)	SAIFI
1	3764423.57	5.676244
2	3846986.41	5.675912
3	3852732.21	5.667714
4	4003024.56	5.449310
5	3904438.20	5.667233

Novel reliability index CBRI dealing with reliability worth and total cost representing reliability cost can be considered to assess reliability benefit and investment cost to achieve certain level of reliability.

7.3.3.5 Considering Total cost and CBRI

Multi objective capacitor allocation and DG integration have been performed considering CBRI improvement and total cost reduction in sixty nine bus microgrid type radial distribution system. This planning approach is appropriate for that feeder where electricity price and power interruption cost is of major concern. The scaling factors for multi objective optimization have been considered as 0.4 and 0.6 for CBRI and total cost, respectively. More importance has been given to total cost in comparison to CBRI in this attempt by providing extra scaling factor value. The evolutionary techniques MCA and FEO have obtained 4 and 2 non-dominated solutions in connection to CBRI improvement and total cost reduction in Table 7.48 and Table 7.49, respectively. The lesser total cost value is better for the system. On the other hand, the higher CBRI value means improvement. It can be seen from the Table 7.43 that least total cost value achieved by MCA technique is US$ 4034181.25. On the other hand, the best CBRI value shown in Table 7.48 is 0.231614. But the connected CBRI value to the least cost and connected total cost value to the best CBRI are the worst which can be observed from Table 7.48. On the other hand, the least cost value obtained by FEO algorithm as observable in Table 7.49 is US$ 3875002.98. The best CBRI value achieved by FEO technique is 0.195972 as shown in Table 7.49. It can be said from the above discussion that the least total cost value achieved by FEO algorithm is better than that value obtained by MCA technique. But the highest CBRI value achieved by MCA technique is better than that value obtained by FEO algorithm. Both the pareto-optimal solution sets shown in Table 7.48 and Table 7.49 are comparative to each other. The decision maker has to do compromise while selecting the appropriate solution from these solution sets.

Table 7.48: Non-dominated solutions achieved after MCA application considering total cost reduction and CBRI improvement in 69 bus microgrid type radial distribution system

Sl No.	Total cost (US$)	CBRI
1	4330673.50	0.231614
2	4034181.25	0.101539
3	4040081.90	0.103626
4	4043967.36	0.110114

Table 7.49: Pareto optimal solutions obtained after FEO implementation considering total cost minimization and CBRI improvement in 69 bus microgrid type distribution system

Sl No.	Total cost (US$)	CBRI
1	3875002.98	0.180415
2	4015211.80	0.195972

Power quality and power interruption costs are major factors for sustainable business purpose. This business sustainability can be achieved by considering developed reliability index CBRI and energy loss.

7.3.3.6 Opting CBRI and energy loss

Multi objective capacitor allocation and DG integration have been performed considering CBRI improvement and energy loss reduction in sixty nine bus microgrid type radial distribution system. This planning scheme is suitable for that feeder where power interruption cost and power quality are of major concern. The scaling factors for multi objective optimization have been considered as 0.5 and 0.5 for CBRI and energy loss, respectively. Eqaul importance has been given to energy loss reduction and CBRI improvement in this attempt. The pareo-optimal solutions achieved by the application of MCA and FEO techniques are shown in Table 7.50 and Table 7.51, respectively. The lesser energy loss value is better for the system. On the other hand, the higher CBRI value means reliability improvement. It can be observed from Table 7.51 that least energy loss value obtained by MCA technique is 79.07 kWh. On the other hand, the highest CBRI value achieved by MCA technique is 0.441528 shown in Table 7.50. But the connected energy loss value to the best CBRI and connected CBRI value to the best energy loss are not the best. It can be noticed from Table 7.51 that three non-dominated solutions have been achieved by FEO algorithm. The least energy loss value achieved by FEO technique is 88.56 kWh. The highest CBRI value obtained by FEO algorithm is 0.296196. It can be noticed from Table 7.50 and Table 7.51 that the pareto-optimal solution set achieved by MCA technique shown in Table 7.50 is comparatively better than the non-dominated solutions obtained by FEO algorithm shown in Table 7.51. The decision maker can finally select the appropriate solution from the pareto-optimal solutions achieved by MCA technique as shown in Table 7.50.

Table 7.50: Non-dominated solutions achieved after MCA application considering energy loss reduction and CBRI improvement in 69 bus microgrid type distribution system

Sl No.	Energy loss (kWh)	CBRI
1	79.07	0.372759
2	79.49	0.402020
3	78.08	0.345672
4	80.15	0.441528

Table 7.51: Pareto optimal solutions achieved after FEO application considering energy loss reduction and CBRI improvement in 69 bus microgrid type radial distribution system

Sl No.	Energy loss (kWh)	CBRI
1	88.80	0.296196
2	88.73	0.290455
3	88.56	0.282092

Reliability index AENS dealing with energy supply issue and CBRI signifying reliability worth should be considered for economic reasons.

7.3.3.7 Selecting AENS and CBRI

Multi objective capacitor allocation and DG integration have been performed considering improvements of AENS and CBRI in sixty nine bus microgrid type radial distribution system. The final solution approached here is appropriate for that particular feeder where energy supply and power interruption costs are major issues. The scaling factors for multi objective optimization have been considered as 0.4 and 0.6 for CBRI and AENS, respectively. More importance has been given to AENS in comparison to CBRI in this attempt by providing extra scaling factor value. Three and two pareto-optimal solutions have been achieved by MCA and FEO techniques which can be observed from Table 7.52 and Table 7.53. The lesser AENS value is better and assures reliability improvement. On the other hand, the higher CBRI value means betterment of power interruption cost. It can be noticed from Table 7.52 that best AENS value obtained by MCA technique is 34.794827 kWh/customer yr as shown in Table 7.52. On the other hand, the highest CBRI value achieved by MCA technique is 0.689536. But the connected CBRI value to the least AENS and connected AENS value to the highest CBRI are not the best. It has been observed from Table 7.53 that the best AENS and CBRI values obtained by FEO algorithm are 35.096761 kWh/customer yr and 0.477429. But these values are not connected to each other.

This means both the values have been achieved by performing different DG integrations and capacitor allocations in 69 bus microgrid type radial distribution system. It can be said by analyzing the non-dominated solutions of Table 7.52 and Table 7.53 that the pareto-optimal solutions achieved by MCA technique shown in Table 7.52 are comparatively better than the solutions obtained by FEO algorithm which can be observed from Table 7.53. So the decision maker will finally select the appropriate solution from the pareto-optimal solutions achieved by MCA technique shown in Table 7.52.

Table 7.52: Non-dominated solutions achieved after MCA application considering AENS and CBRI improvement in 69 bus microgrid type radial distribution system

Sl No.	AENS kWh/customer yr	CBRI
1	35.085028	0.689536
2	34.794827	0.619777
3	34.878856	0.661183

Table 7.53: Pareto optimal solutions achieved after FEO application considering AENS and CBRI improvement in 69 bus microgrid type distribution system

Sl No.	AENS kWh/customer yr	CBRI
1	35.297621	0.477429
2	35.096761	0.468538

Power interruption duration and reliability worth have major impact on customer. This can be taken care of by considering SAIDI and CBRI simultaneously.

7.3.3.8 Involving SAIDI and CBRI

Multi objective capacitor allocation and DG integration have been performed considering improvements of CBRI and SAIDI in sixty nine bus microgrid type radial distribution system. The planning scheme attained here is suitable for that feeder where power interruption duration and cost due to power interruption are of major concern. The scaling factors for multi objective optimization have been considered as 0.4 and 0.6 for CBRI and SAIDI, respectively. More importance has been given to SAIDI in comparison to CBRI in this attempt by providing extra scaling factor value. Six and three pareto-optimal solutions have been obtained by MCA and FEO techniques after performing simultaneous capacitor allocations and DG integrations as shown in Table 7.54 and Table 7.55. The decrease in SAIDI value means improvement. On the other hand, the increase in CBRI value means betterment. It has been observed from Table 7.54 that the best SAIDI value achieved by MCA technique is 6.800543 hours/customer yr. The highest CBRI value obtained by MCA technique is 0.146780. But the least SAIDI value and highest CBRI value are not connected to each other. This signifies that these values correspond to different solutions. On the other hand, it can be noticed from Table 7.55 that the least SAIDI value achieved by FEO algorithm is 6.483182 hours/customer yr. The best CBRI value obtained by FEO algorithm is 0.647697. It can be said by studying the non-dominated solutions of Table 7.54 and Table 7.55 that the pareto-optimal solutions achieved by FEO algorithm are comparatively better than the solutions obtained by MCA technique. Finally the decision maker will choose the suitable solution from the pareto-optimal solutions achieved by FEO technique as observable in Table 7.55.

Table 7.54: Non-dominated optimal solutions obtained after MCA implementation considering SAIDI and CBRI improvement in 69 bus microgrid type radial distribution system

Sl No.	SAIDI hours/customer yr	CBRI
1	6.819240	0.104297
2	6.817454	0.091441
3	6.962203	0.146780
4	6.800543	0.086512
5	6.956268	0.111782
6	6.837226	0.105956

Table 7.55: Pareto optimal solutions obtained after FEO implementation considering SAIDI and CBRI improvement in 69 bus microgrid type distribution system

Sl No.	SAIDI hours/customer yr	CBRI
1	6.492506	0.639718
2	6.536401	0.647697
3	6.483182	0.599489

Like reliability index SAIDI, another customer oriented distribution system reliability index SAIFI can be considered with novel reliability index CBRI to assess interruption frequency and power interruption cost.

7.3.3.9 Effect of CBRI and SAIFI

Multi objective capacitor allocation and DG integration have been performed considering improvements of CBRI and SAIFI in sixty nine bus microgrid type radial distribution system. The planning scheme attained here is appropriate for that particular feeder where power interruption cost and interruption frequency are of major concern. The scaling factors for multi objective optimization have been considered as 0.6 and 0.4 for CBRI and SAIFI, respectively. More importance has been given to CBRI in comparison to SAIFI in this attempt by providing extra scaling factor value. Three and five non-dominated solutions considering SAIFI and CBRI have been obtained by MCA and FEO techniques as shown in Table 7.56 and Table 7.57, respectively. The lesser SAIFI value signifies improvement in power interruption frequency. On the other hand the higher CBRI value means reliability enhancement in terms of reduction in power interruption cost. It can be noticed from Table 7.56 that the best SAIFI value obtained by MCA technique is 5.497321 interruptions/customer yr. The highest CBRI value achieved by MCA technique is 0.517837 as observable in Table 7.56. These said SAIFI and CBRI values are not connected to each other. These values correspond to different solutions. It has been observed from Table 7.57 that the best SAIFI value obtained by FEO technique is 5.499879 interruptions/customer yr. On the other hand, the highest CBRI value achieved by FEO algorithm is 0.371539 as observable in Table 7.57. It can be said by analyzing the pareto-optimal solutions of Table 7.56 and Table 7.57 that CBRI and SAIFI values achieved by MCA technique are comparatively better than those values obtained by FEO algorithm. So the decision maker can finally select the proper solution from the non-dominated solutions achieved by MCA technique as observable in Table 7.56.

Table 7.56: Pareto optimal solutions achieved after MCA application considering SAIFI and CBRI improvement in 69 bus microgrid type radial distribution system

Sl No.	SAIFI interruptions/customer yr	CBRI
1	5.508704	0.483801
2	6.073456	0.517837
3	5.497321	0.465691

Table 7.57: Non-dominated optimal solutions achieved after FEO application considering SAIFI and CBRI improvement in 69 bus microgrid type distribution system

Sl No.	SAIFI interruptions/customer yr	CBRI
1	5.517121	0.247162
2	5.862846	0.371539
3	5.520529	0.250889
4	5.513341	0.239776
5	5.499879	0.176554

Multi-objective capacitor allocation and DG integration have been performed considering two conflicting objectives so far. But consideration of energy loss, total cost, SAIFI, SAIDI and AENS simultaneously will give the real scenario for more specific customer based planning purpose. In the next section, the stated five conflicting objectives have been considered simultaneously for performing multi-objective DG and capacitor placement for various types of customers such as rural, urban, commercial, hospital, office and industrial. This planning has been accomplished considering a maximum of 50% DG penetration.

7.3.4 Customer based DG integration and capacitor allocation in 69 bus microgrid type radial distribution system

Cost incorporated customer specific simultaneous capacitor allocation and at a maximum of 50% DG integration have been performed considering cost, loss, SAIFI, SAIDI and AENS. Multi-objective optimization has been exercised with the objective of cost reduction; loss minimization and improvement of reliability indices viz. SAIFI, SAIDI and AENS in 69 bus microgrid type system. Effective evolutionary techniques i.e. modified cultural algorithm (MCA) and fish electrolocation optimization (FEO) have been considered for this multi-objective situation. Modified cultural algorithm and fish electrolocation optimization have obtained twenty one and fifteen pareto optimal solutions as shown in Table 7.58 and Table 7.59 respectively. The best and worst solutions concerning to each conflicting objective have been notified in bold and italics format respectively which can be observed from Table 7.58 and Table 7.59.

Table 7.58: Pareto optimal solutions found by MCA technique considering five conflicting objectives at a maximum of 50% DG penetration in 69 bus microgrid type radial distribution system

Sl no.	Cost (US$)	Energy loss (kWh)	SAIFI interruptions/customer yr	SAIDI hours/customer yr	AENS kWh/customer yr
1	4076572.64	99.30	5.871508	7.162449	37.077801
2	4434182.35	121.64	5.869317	7.076868	36.868824
3	**4007649.41**	**96.40**	*5.950844*	7.212201	*37.596272*
4	4406590.19	113.22	5.899648	*7.259620*	36.804675
5	4623398.29	149.54	5.624780	6.937963	37.028414
6	4049051.89	106.69	5.854470	7.046482	36.913132
7	4102298.24	98.91	5.918328	7.175757	37.590177
8	4381367.74	124.50	5.601637	6.915938	37.049655
9	4283644.57	123.23	5.670479	6.888438	36.866352
10	4025271.12	101.10	5.879920	7.126850	37.285386
11	4507866.42	125.05	5.698076	6.877434	**36.736941**
12	4078046.28	107.57	5.800625	7.026831	36.870735
13	4104253.30	123.23	5.800641	6.998877	37.122474
14	4101317.76	125.17	5.712755	6.931400	37.028412
15	4505386.15	138.19	5.719114	6.883751	37.022053
16	4403599.30	132.57	5.626836	6.848133	37.206139
17	4766658.00	158.22	5.597774	6.874460	36.969883
18	4443139.57	128.45	5.733750	6.866574	37.374358
19	4594884.86	144.17	5.681629	6.875919	36.815653
20	*4778076.20*	*159.39*	**5.537634**	**6.799405**	36.895780
21	4516074.56	136.96	5.706885	6.862361	37.039869

It has been observed from Table 7.58 that least energy loss found is 96.40 kWh. The worst solution related to energy loss achieved by MCA is 159.39 kWh. Other solutions lie inside the upper and lower range of energy loss. It can be said that energy loss has been reduced after DG integration and capacitor placement from initial value of 225.00 kWh. On the other hand, total cost has been decreased from initial value of US$ 5384155.54 after suitable DG and capacitor allocation using MCA technique. The least cost obtained in Table 7.58 is US$ 4007649.41. The worst cost value achieved by MCA algorithm is US$ 4778076.20. The reliability index SAIFI has been improved from the initial value of 5.859207 interruptions/customer yr. The least SAIFI value obtained in Table 7.58 is 5.537634 interruptions/customer yr. It has been observed from Table 7.58 that worst SAIFI value obtained is 5.950844 interruptions/customer yr. It has also been observed from Table 7.58 that SAIDI value has been reduced from 7.152889 hours/customer yr for seventeen cases out of twenty one solutions after appropriate DG integration and capacitor sitting. The least SAIDI value obtained by MCA algorithm available in Table 7.58 is 6.799405 hours/customer yr. The worst SAIDI value achieved by MCA technique shown in Table 7.58 is 7.259620 hours/customer yr. Finally it can be noticed from Table 7.58 that after implementation of MCA algorithm load-oriented reliability index AENS has been improved from the initial value of 38.313253 kWh/customer yr. The best AENS value found out in Table 7.58 is 36.736941 kWh/customer yr. The worst solution regarding the reliability index AENS shown in Table 7.58 is 37.596272 kWh/customer yr.

Like the non-dominated solutions obtained by MCA, pareto optimal solutions have also been achieved by FEO but in lesser number than the former one. It has been observed from Table 7.59 that best energy loss value obtained by FEO algorithm is 84.99 kWh. The worst solution related to energy loss shown in Table 7.59 is 113.33 kWh. The least energy loss value found by FEO algorithm is better than that value achieved by MCA technique available in Table 7.58. It can be noticed from Table 7.59 that total cost has been reduced from the initial value after appropriate DG integration and capacitor placement. The least cost value found by FEO algorithm is US$ 4028611.88 shown in Table 7.59. On the other hand, the worst solution available in Table 7.59 regarding total cost is US$ 4246939.85. The best found solution concerning to the total cost by FEO technique is higher than the value obtained by MCA algorithm shown in Table 7.58. Furthermore, it can be noticed from Table 7.59 that best SAIFI value achieved by FEO algorithm is 5.401679 interruptions/customer yr. The worst solution regarding SAIFI is 5.784265 interruptions/customer yr. The best SAIFI value obtained by FEO algorithm is lower than that value achieved by MCA technique available in Table 7.58. On the other hand, the least SAIDI value found by FEO technique is 6.641809 hours/customer yr whereas the worst solution related to SAIDI is 6.838496 hours/customer yr shown in Table 7.59. Again the best value concerning to SAIDI as observable in Table 7.59 is lower than that value achieved by MCA technique shown in Table 7.53. Finally it can be noticed from Table 7.59 that least AENS value achieved by FEO technique is 35.611360 kWh/customer yr. The worst AENS value obtained by FEO algorithm is 36.277693 kWh/customer yr shown in Table 7.59. The best AENS value available in Table 7.59 is better than that value found by MCA technique as observable in Table 7.58.

Table 7.59: Pareto optimal solutions obtained by FEO algorithm for five conflicting objectives considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

Sl. No.	Cost (US$)	Energy loss (kWh)	SAIFI interruptions/customer yr	SAIDI hours/customer yr	AENS kWh/customer yr
1	**4028611.88**	98.07	*5.784265*	*6.838496*	36.451405
2	4038519.25	112.65	5.404957	6.658174	36.197292
3	*4246939.85*	106.68	5.608689	6.816690	36.443610
4	4047276.72	111.31	5.590130	6.739670	36.298205
5	4050950.55	110.76	**5.401679**	6.648410	36.137228
6	4052072.61	110.03	5.589105	6.737127	36.283992
7	4059813.77	**84.99**	5.707972	6.797090	**35.611360**
8	4045598.83	110.97	5.591159	6.742858	36.316942
9	4125235.37	*113.33*	5.401911	6.648353	36.128824
10	4087669.48	109.55	5.588810	6.736175	36.272176
11	4106332.82	109.35	5.589140	6.734466	*36.277693*
12	4153777.74	112.01	5.399709	**6.641809**	36.128246
13	4097124.27	110.27	5.587978	6.735165	36.272222
14	4122119.02	111.26	5.401937	6.646297	36.141047
15	4107957.42	107.94	5.587084	6.730075	36.252739

It can’t be said from the above discussion that the solution of one technique is strictly better than the other method. On the other hand, different customers want different type of service conditions. Justification regarding selection of different weight value is necessary to reach that perspective via TOPSIS method discussed in Chapter 4. This has been briefly discussed in the next section.

7.3.4.1 Justification of choosing different weight value

Six types of customers have been considered here. They are rural, urban, hospital, office/building, industrial and commercial consumer. Multi-objective optimization has been performed considering five conflicting objectives. In the essence of customer based decision making, different weight values have been selected for those five conflicting objectives related to various customers. The weight values have been chosen to reach to the final solution in TOPSIS method. This has been shown in Table 7.55. It can be noticed from Table 7.60 that weight values chosen as 0, 0.85, 0.05, 0.05 and 0.05 for energy loss, cost, SAIFI, SAIDI and AENS respectively are connected to rural customer. The higher importance has been given to the cost issue for rural customer. This has been considered as they can't afford to pay the electricity bill if it's expensive. That's why weight value of 0.85 is assured to the cost issue. On the other hand, power quality is not a very big issue to the rural customer. If the voltage fluctuates within range then it's acceptable for them. In this regard the voltage has been maintained for every load bus between 0.9 p.u and 1.1 p.u in this research work. No importance has been given to the energy loss issue for that reason. But 'uninterruptible power supply' and 'energy not supplied' are those issues which seek more importance than the 'power quality' issue to the rural customer. That's why weight value of 0.05 has been given to each reliability index SAIFI, SAIDI and AENS. Furthermore, it has been observed from Table 7.60 that weight value of 0.2 has been given to each conflicting objective for urban customer. Equal importance has been given to all the chosen objectives for urban customer. This has been done as urban customer simultaneously wants economic good quality power for twenty four hours uninterruptedly. In many cases they use computers, refrigerator, cooking system, heating system, air conditioning, lighting system, fan etc to make their life comfortable. In this regard, 'energy not provided' issue is also significant for them. Additionally, it has been noticed from Table 7.60 that weight values for hospital customer have been chosen as 0.1, 0, 0.55, 0.35 and 0 related to energy loss, cost, SAIFI, SAIDI and AENS respectively. Standard voltage and power factor are necessary as there are sensible electrical appliances in operation theatre and laboratory. That's why weight value of 0.05 has been given to the 'energy loss' objective. But the most coveted issue is the uninterruptible power supply as operation and emergency situation can occur any time in a day inside a hospital. Furthermore nobody can assure about the duration of that critical situation when life is at stake. Cost has been given zero weightage here. This has been done as Government hospital or private nursing home can afford the cost of electricity bill. Energy supply issue is also important as there is freezing system, air condition etc in the hospital. A weight value of 0.05 has been assured to AENS.

Table 7.60: Selected weight value for different type of customer

Customer type	Weight chosen by decision maker in TOPSIS method				
	energy loss	Cost	SAIFI	SAIDI	AENS
rural	0	0.85	0.05	0.05	0.05
urban	0.2	0.2	0.2	0.2	0.2
hospital	0.05	0	0.55	0.35	0.05
Office/building	0.2	0	0.6	0.15	0.05
Industrial	0.05	0	0	0.05	0.9
Commercial	0.05	0.15	0.15	0.6	0.05

It has also been observed from Table 7.60 that to reach practical solution weight values selected for office/building customer are 0.2, 0, 0.6, 0.15 and 0.05 for energy loss, cost, SAIFI, SAIDI and AENS respectively. Good quality power is necessary for office/building customer as computers, printers, fax, xerox machine, air conditioner etc are there. Computer is very much sensitive to voltage fluctuation and sag issues. Frequent interruption also gives detrimental effect to the computing system. That's why weight value of 0.6 has been given to the SAIFI index. Interruption duration is also important as the office's work is to serve customer uninterruptedly. A weight of 0.15 has been given to SAIDI index. Energy not supplied issue is not so much important like SAIFI, energy loss and SAIDI for office/building customer. On the other hand electricity bill is affordable for this type of consumer. Finally it has been noticed from Table 7.60 that weight values of 0.05, 0, 0, 0.05 and 0.9 have been given to energy loss, cost, SAIFI, SAIDI and AENS respectively for industrial customer. The amount of energy supply issue is very significant for industrial customer apart from all other aspects. This is due the fact that various motors of various capacities are operational in small scale or large scale industry. Interruption duration and good quality power are also important to run those motors effectively. Frequent interruption will cause break in industrial process but will not cause any damage if that does not sustain longer. On the other hand, industrial company can pay electricity bill. So, cost has least significance to them. Lastly it has been observed from Table 7.60 that weight values of 0.05, 0.15, 0.15, 0.6 and 0.05 have been chosen for energy loss, cost, SAIFI, SAIDI and AENS respectively concerning to commercial customer. Commercial customer can be of any category from small shop owner to multiplex or big shopping mall. Good quality of power provided uninterruptedly is essential for their operation. At the same time they want to make maximum profit. Cost is therefore an important issue to them. On the other hand, sustained interruption is detrimental for their business. That’s why higher weight has been given to the SAIDI index.

Justification for choosing different weight values for various customers has been briefly elaborated in the above paragraph. It will be an interesting study to observe the decision making for the stated six types of customers. The multi-criteria decision making method called TOPSIS has been utilized here to reach the specific appropriate solution. The specific solution is fetched by observing the rank of pareto optimal solutions achieved by MCA and FEO algorithm.

7.3.4.2 Selecting feasible and appropriate solution for rural customer

In this section appropriate solution regarding the satisfaction of rural customer is chosen and discussed. It has been observed from Figure 7.53 that solution number 3 has been selected for rural customer amongst the twenty one pareto optimal solutions obtained using MCA technique. A few solutions amongst the achieved non-dominated solutions implementing MCA have been shown in Figure 7.53. This has been done as the rank values of other solutions are lower than 0.85. The conflicting objectives of energy loss, total cost, SAIFI, SAIDI and AENS values related to solution number 3 are 96.40 kWh, US$ 4007649.41, 5.950844 interruptions/customer yr, 7.212201 hours/customer yr and 37.596272 kWh/customer yr respectively. The total cost value of solution number 3 is the least value amongst the twenty one solutions obtained by MCA technique. The cost issue is very much important to the rural customer apart from all other chosen conflicting objectives. That’s why this above stated solution is feasible for rural customer but it can’t be said conclusively to be the ultimate one without the prior information concerning the solutions achieved by FEO algorithm.

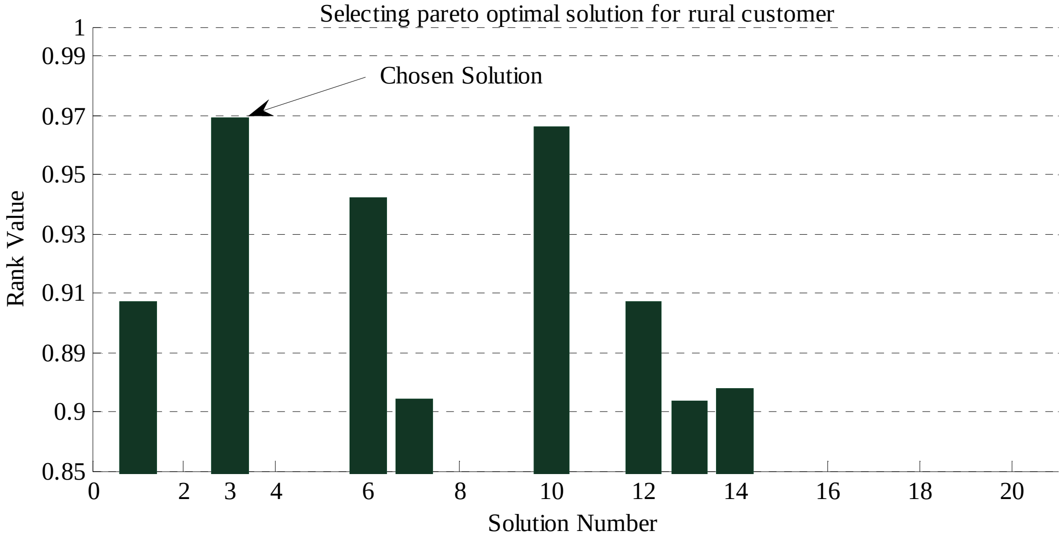

Figure 7.53: Non-dominated solutions obtained by MCA technique utilized via TOPSIS method for finding appropriate solution for rural customer considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

Likewise the solution obtained via TOPSIS method for the rural customer by MCA, Figure 7.54 represents the rank order amongst the solutions found by FEO algorithm. It has been shown in Figure 7.54 that solution number 1 has been selected for rural customer amongst the fifteen solutions obtained by FEO algorithm. The energy loss, total cost, SAIFI, SAIDI and AENS values of solution number 1 are 98.07 kWh, US$ 4028611.88, 5.784265 interruptions/customer yr, 6.838496 hours/customer yr and 36.451405 kWh/customer yr respectively as observable in Table 7.59. Significantly the total cost value of solution number 3 available in Table 7.58 is lesser than that value of solution number 1 as shown in Table 7.59. This is vital. There is no doubt that the solution number 3 achieved by MCA technique as observable in Table 7.58 is appropriate for rural customer. To achieve solution number 3 as shown in Table 7.58 simultaneous shunt capacitor placement and DG integration have been performed. Shunt capacitors have been placed at bus number 17, 18, 29, 31, 38, 47, 48, 56, 60, 65 and 69 in sixty nine bus microgrid type radial distribution system. Capacitor values selected for those chosen bus positions are 200 kVAR, 200 kVAR, 1000 kVAR, 800 kVAR, 400 kVAR, 1000 kVAR, 1200 kVAR, 200 kVAR, 400 kVAR, 600 kVAR and 200 kVAR respectively. Distributed generator integration has been performed at bus locations 10, 14, 29, 34, 38, 55, 57, 59, 63, 64 and 65. The DG value chosen at those bus locations are 50 kW, 50 kW, 100 kW, 50 kW, 50 kW, 100 kW, 50 kW, 100 kW, 50 kW, 100 kW and 100 kW, respectively.

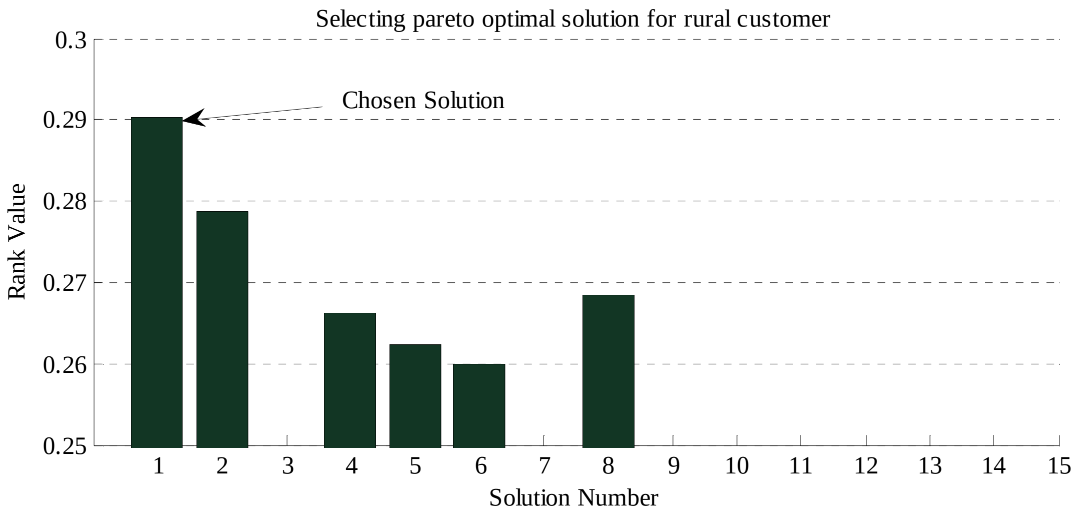

Figure 7.54: Pareto optimal solutions achieved by FEO algorithm used through TOPSIS method for obtaining feasible solution for rural customer at a maximum of 50% DG penetration in 69 bus microgrid type radial distribution system

On the contrary urban customer need is not similar to rural customer. Selection of pareto optimal solution related to urban customer is also important to understand.

7.3.4.3 Choosing pareto optimal solution for urban customer

Urban residential customers desire to have good quality of supply uninterruptedly. They also want to have economic power. Feasible solution for urban customer has been found out by TOPSIS method satisfying all the criteria.

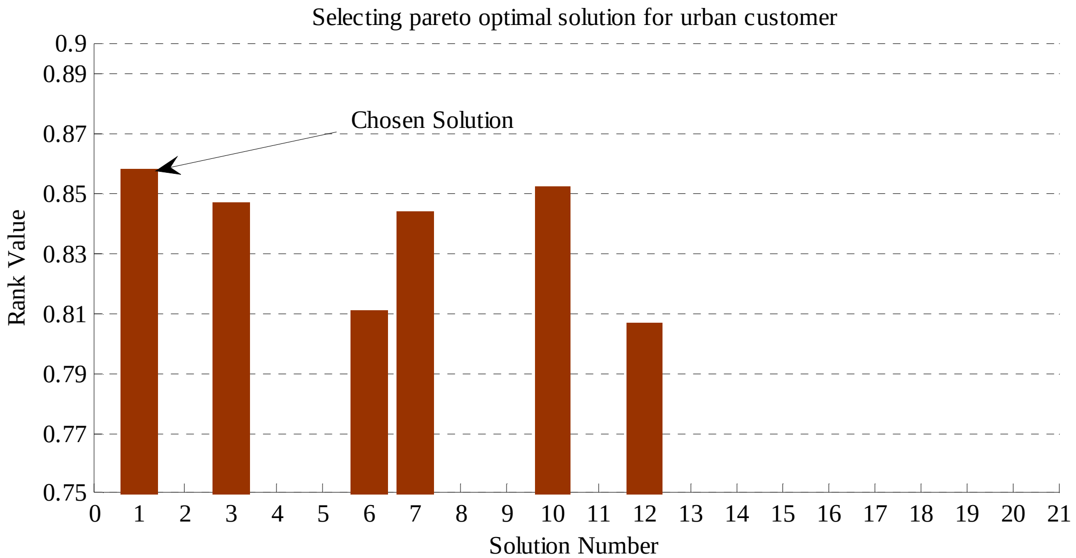

Figure 7.55: Selecting specific solution by TOPSIS method for urban customer from the achieved non-dominated solutions using MCA algorithm considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

It can be noticed from Figure 7.55 that solution number 1 has been chosen by TOPSIS method amongst the obtained twenty one solutions using MCA technique. This solution has been selected considering the weight value for urban customer shown in Table 7.58. The energy loss, total cost, SAIFI, SAIDI and AENS values concerning to solution number 1 are 99.30 kWh, US$ 4076572.64, 5.871508 interruptions/customer yr, 7.162449 hours/customer yr and 37.077801 kWh/customer yr respectively. On the other hand, Figure 7.56 represents the rank order for the eleven solutions obtained by FEO algorithm. It has been observed from Figure 7.56 that solution number 7 has been selected by TOPSIS method amongst fifteen solutions achieved by FEO method. The energy loss, total cost, SAIFI, SAIDI and AENS values related to the chosen solution number 7 are 84.99 kWh, US$ 4059813.77, 5.707972 interruptions/customer yr, 6.797090 hours/customer yr and 35.611360 kWh/customer yr respectively as shown in Table 7.59. All the conflicting objectives' values concerning to solution number 7 availble in Figure 7.56 are lesser than those values related to solution number 1 shown in Figure 7.55. It can be said by doing comparative study that the solution number 7 as observable in Figure 7.56 and Table 7.59 is better than solution number 1 shown in Figure 7.55 and Table 7.58. Finally that solution number 7 as shown in Table 7.59 and Figure 7.56 is selected for urban customer. Solution number 7 has been achieved using FEO algorithm after performing DG integration and shunt capacitor allocation. Capacitors have been placed at bus number 5, 12, 39, 42, 44, 47, 48, 57, 59, 63 and 64 with 400 kVAR installed capacity at every selected location. Distributed generators have been allocated at bus positions 3, 5, 4, 10, 15, 17, 30, 31, 34, 48, 58, 59, 60, 63, 66, 67 and 69. The DG value chosen by FEO algorithm for each selected location is 100 kW.

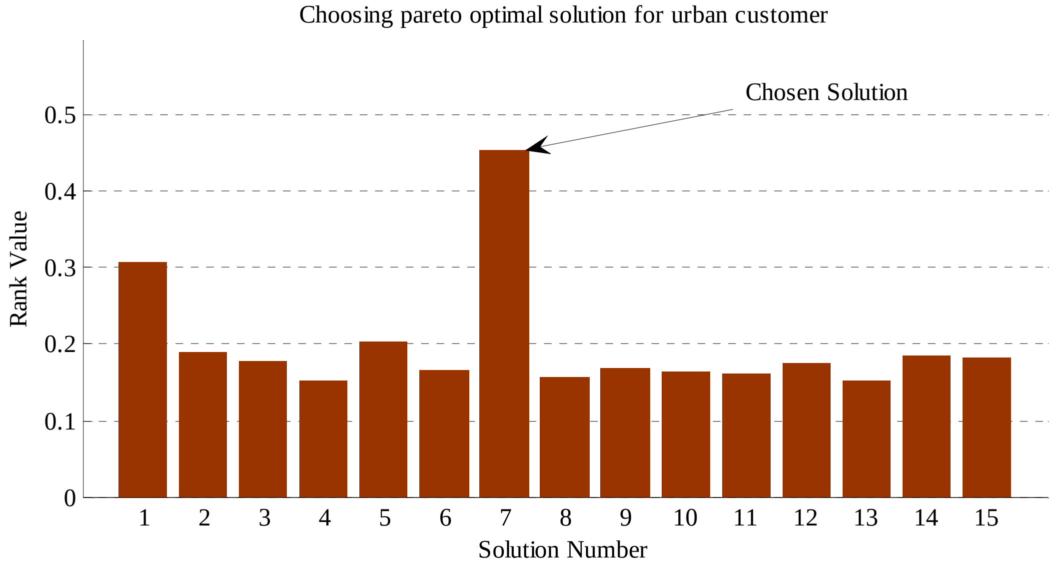

Figure 7.56: Choosing feasible solution for urban customer by TOPSIS method from the obtained pareto optimal solutions using FEO algorithm at a maximum of 50% DG penetration in 69 bus microgrid type radial distribution system

Urban customer and hospital customer sometimes have common interest issues. But the necessity of hospital customer regarding power quality issues such as voltage, outage etc are different in comparison to urban customer. The determination of appropriate solution for hospital customer is therefore important.

7.3.4.4 Selection of proper solution for hospital customer

Hospital customer is a significant end user of utility system. Here non-dominated solutions obtained by MCA and FEO algorithms have also been utilized to find out the feasible solution by TOPSIS method. It has been observed from Figure 7.57 that the rank value of solution number 8 is higher than other solutions obtained by MCA technique. This solution is selected for hospital customer as shown in Figure 7.57. The energy loss, total cost, SAIFI, SAIDI and AENS values concerning to that chosen solution are 124.50 kWh, US$ 4381367.74, 5.601637 interruptions/customer yr, 6.915938 hours/customer yr and 37.049655 kWh/customer yr respectively.

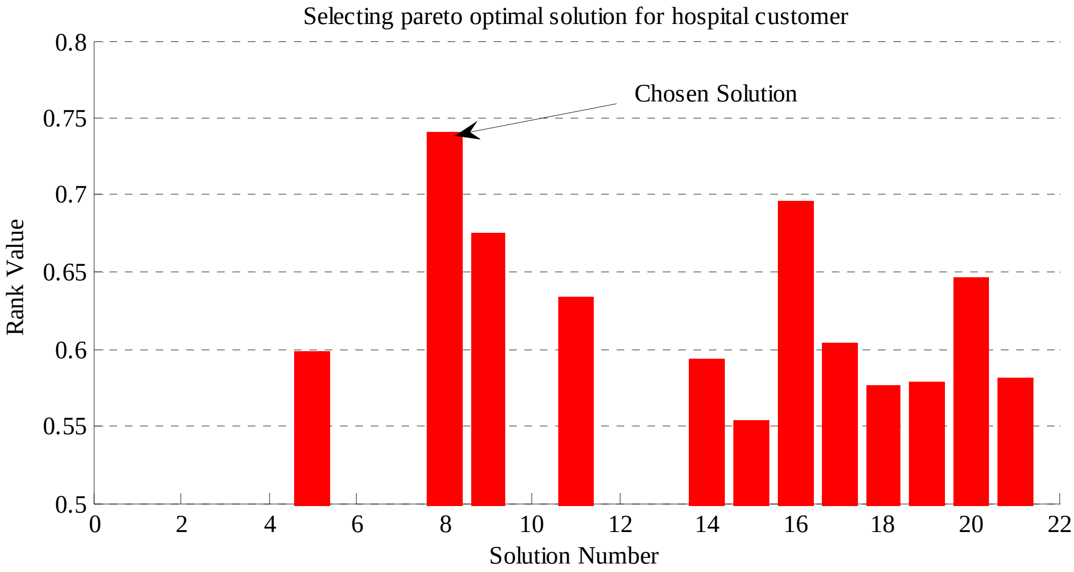

Figure 7.57: Selection of specific solution by TOPSIS method for hospital customer from the obtained non-dominated solutions using MCA technique considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

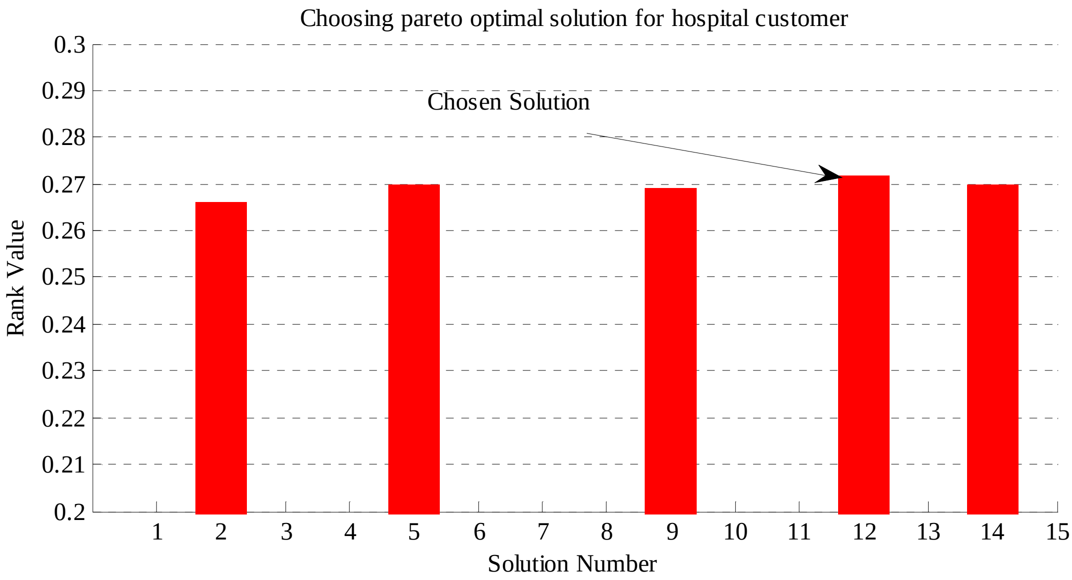

Figure 7.58: Choosing feasible solution for hospital customer by TOPSIS method from the achieved pareto optimal solutions using FEO algorithm at a maximum of 50% DG penetration in 69 bus microgrid type radial distribution system

On the other hand, Figure 7.58 represents the bar chart of rank values related to the fifteen solutions found by FEO algorithm. It can be noticed from Figure 7.58 that solution number 12 has been selected for hospital customer. The energy loss, total cost, SAIFI, SAIDI and AENS values related to that chosen solution are 112.01 kWh, US$ 4153777.74, 5.399709 interruptions/customer yr, 6.641809 hours/customer yr and 36.128246 kWh/customer yr respectively. It can be said from the above values that all the conflicting objectives values concerning to the solution number 12 as shown in Figure 7.58 is lower in magnitude than the solution number 8 available in Figure 7.57. So, the solution number 12 depicted in Figure 7.58 is better in comparison to the solution number 8 available in Figure 7.57. This specific solution has been finally selected for hospital customer. The final solution for hospital consumer has been obtained by FEO algorithm after performing simultaneous DG integration and capacitor placement. Capacitors have been installed at bus locations 4, 21, 50, 57 and 59. Capacitor values chosen for those selected bus positions are 1000 kVAR, 200 kVAR, 1000 kVAR, 600 kVAR and 1200 kVAR respectively. Distributed generation integration has been performed at bus number 8, 9, 11, 17, 21, 50, 57, 63 and 69 with DG value of 100 kW only. Office / building customer is another significant consumer who has variety loads such as AC, computers etc. The selection of particular solution for office/building consumer is also important as regards business is concerned.

7.3.4.5 Suitable solution for office/building customer

The suitable solution for office/building customer has been chosen on the basis of highest rank value as observable in Figure 7.59. Selected rank values of non-dominated solutions achieved by MCA technique has been shown in Figure 7.59. The rank values have been achieved by TOPSIS method considering the weight values of office/building customer. Solution number 1 has been selected as the significant solution for office/building customer as available in Figure 7.59. The energy loss, total cost, SAIFI, SAIDI and AENS values related to that chosen solution are 99.30

kWh, US$ 4076572.64, 5.871508 interruptions/customer yr, 7.162449 hours/customer yr and 37.077801 kWh/customer yr respectively.

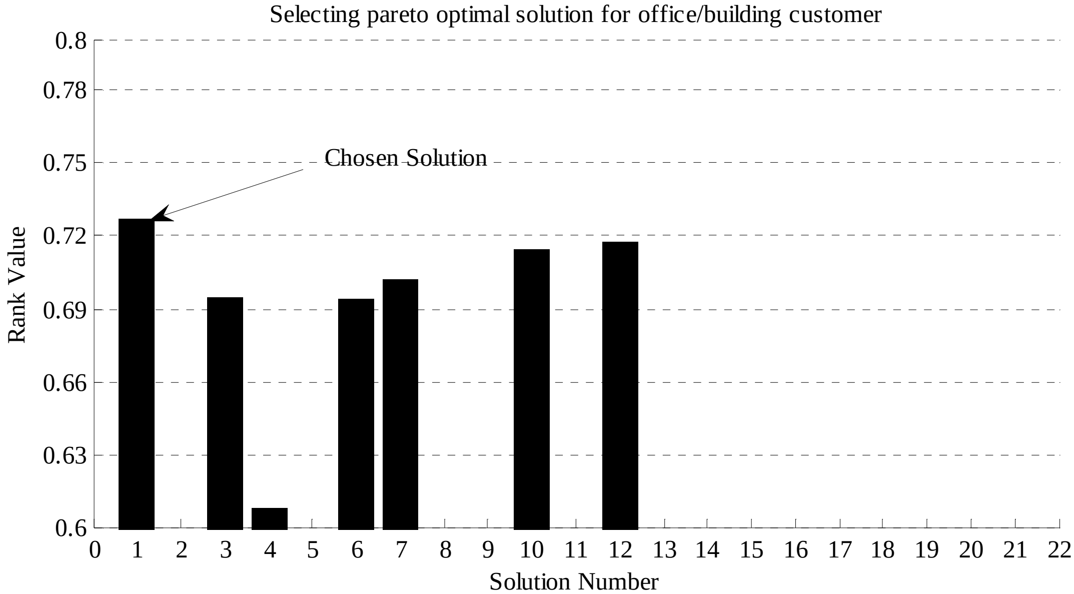

Figure 7.59: Selection of appropriate solution for office/building customer by TOPSIS method from the obtained non-dominated solutions after implementation of MCA technique considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

On the other hand, Figure 7.60 represents the rank values of achieved solutions using FEO algorithm. The rank values are calculated by previously stated TOPSIS method considering the weight values of office/building consumer. It can be noticed from Figure 7.60 that solution number 7 has been chosen for office/building consumer. The energy loss, total cost, SAIFI, SAIDI and AENS values related to the chosen solution number 7 are 84.99 kWh, US$ 4059813.77, 5.707972 interruptions/customer yr, 6.797090 hours/customer yr and 35.611360 kWh/customer yr respectively as observable in Table 7.59. All the conflicting objectives' values of solution number 7 of Figure 7.60 are better than solution number 1 of Figure 7.59. Finally the solution number 7 of Figure 7.60 has been chosen for office/building consumer in this work.

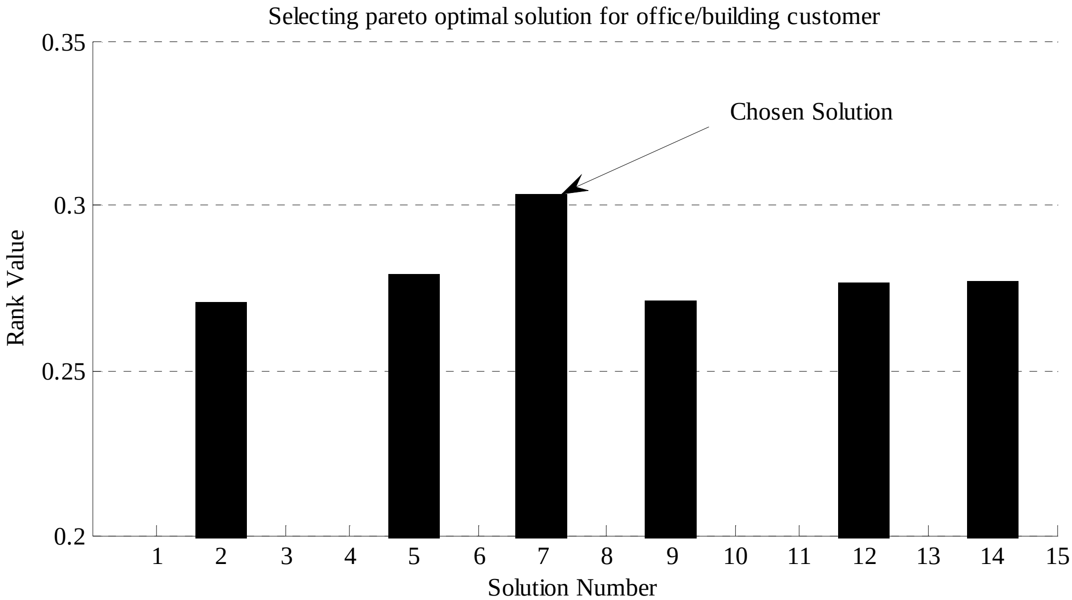

Figure 7.60: Selection of suitable solution for office/building customer by TOPSIS method from the obtained non-dominated solutions after application of FEO algorithm considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

The final solution selected for office/building consumer is same as the final solution for urban customer. That's why the DG integration and the capacitor allocation details related to this final solution have not been illustrated here. The information can easily be obtained for DG integration and capacitor placement from the earlier sub-section discussed for urban customer. Furthermore, industrial customer is another type of consumer who prefers uninterrupted power supply of certain amount of power for a company. The determination of that specific solution is therefore important in this regard.

7.3.4.6 Decision regarding industrial customer

The industrial customers are considered as high tension bulk and low tension bulk consumers of electricity. They consumes bulk amount of power to feed the various motors electrically for doing industrial processes. The rank values considering the weights for industrial consumer have been enumerated by TOPSIS method. Figure 7.61 represents the rank values of pareto optimal solutions achieved by MCA technique. It has been observed from Figure 7.61 that solution number 12 possesses the highest rank value amongst all the solutions. This specific solution has been chosen for industrial customer. The energy loss, total cost, SAIFI, SAIDI and AENS values concerning to that selected solution are 107.57 kWh, US$ 4078046.28, 5.800625 interruptions/customer yr, 7.026831 hours/customer yr and 36.870735 kWh/customer yr respectively. On the other hand, Figure 7.62 represents the rank values (calculated by TOPSIS method) of fifteen non-dominated solutions obtained by FEO algorithm. Like the rank values shown in Figure 7.61, rank values observable in Figure 7.62 have also been enumerated considering the weights for industrial consumer. It can be noticed from Figure 7.62 that solution number 7 has been selected for industrial customer as the rank value of that solution is highest. The energy loss, total cost, SAIFI, SAIDI and AENS values concerning to that solution number 7 shown in Figure 7.62 are 84.99 kWh, US$ 4059813.77, 5.707972 interruptions/customer yr, 6.797090 hours/customer yr and 35.611360 kWh/customer yr respectively.

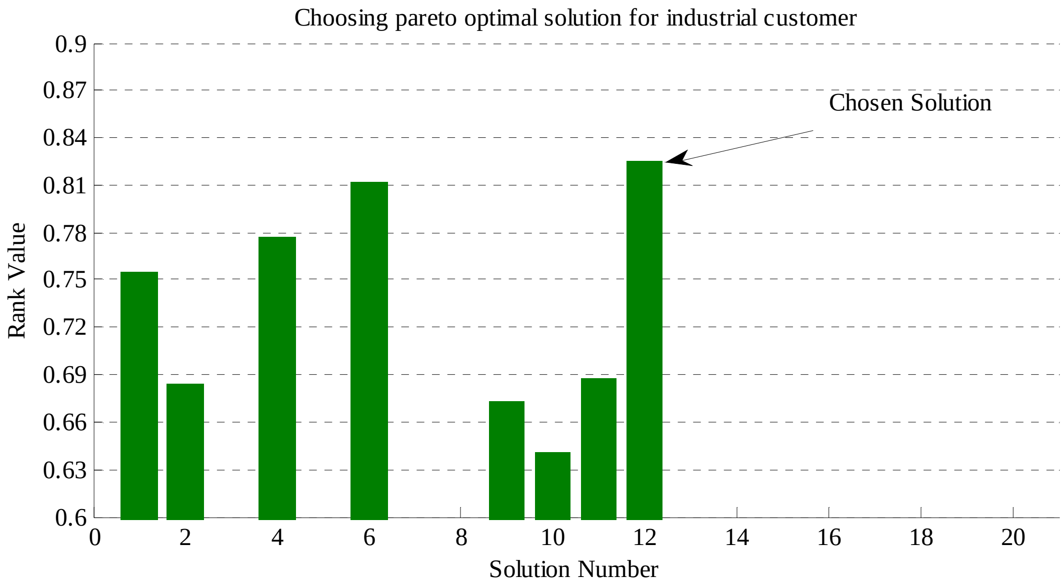

Figure 7.61: Choosing feasible solution for industrial customer by TOPSIS method from the obtained non-dominated solutions using MCA algorithm considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

It can be said from the above discussion that all the conflicting objectives' values related to solution number 7 available in Figure 7.62 are lesser in magnitude than those values of solution number 12 observable in Figure 7.66.

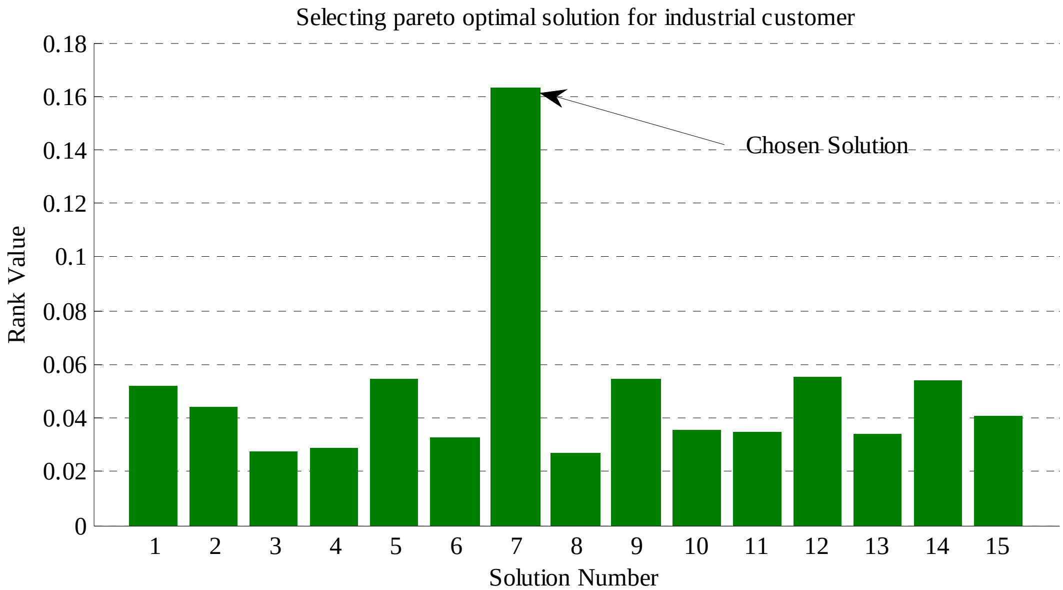

Figure 7.62: Selection of appropriate solution for industrial customer by TOPSIS method from the pareto optimal solutions obtained using FEO technique considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

Again the final solution selected for industrial consumer is same as the final solution for urban customer. That's why the DG integration and the capacitor allocation details related to this final solution have not been illustrated here.
The last consumer of electricity supply considered in this work is commercial customer. The decision related to suitable DG integration and capacitor placement for commercial customer has been briefly stated in the next section.

7.3.4.7 Opting appropriate solution concerning to commercial customer

Commercial customer can be of several types. It can be a multiplex, big shopping mall etc. On the other hand, it can be a small shop. Uninterrupted power supply with lower cost of electricity is the coveted thing for all types of commercial customers. The decision regarding selection of suitable solution has been taken choosing highest rank value amongst the twenty one pareto optimal solutions achieved by MCA technique as observable in Figure 7.63. Rank values have been enumerated by TOPSIS method considering the weight values of commercial customer. It has been observed from Figure 7.63 that the solution number 9 possesses the highest rank value amongst all the solutions. The energy loss, total cost, SAIFI, SAIDI and AENS values concerning to that chosen solution are 123.23 kWh, US$ 4283644.57, 5.670479 interruptions/customer yr, 6.888438 hours/customer yr and 36.866352 kWh/customer yr respectively.

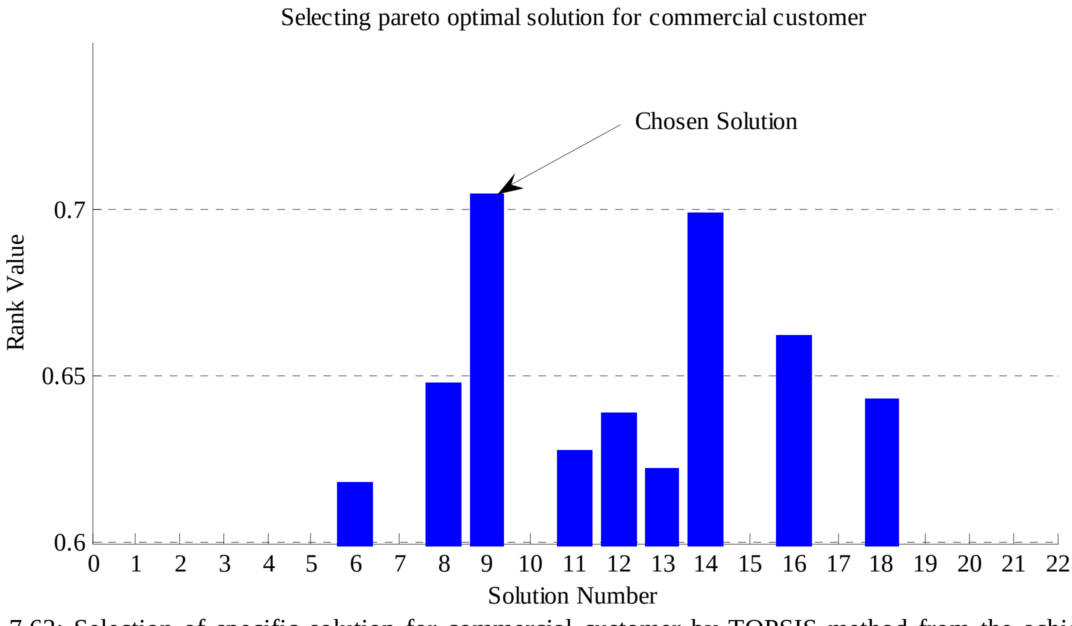

Figure 7.63: Selection of specific solution for commercial customer by TOPSIS method from the achieved non-dominated solutions using MCA algorithm considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

On the other hand, fifteen non-dominated solutions' rank values considering the weights for commercial customer have been shown in Figure 7.64. The fifteen pareto optimal solutions have been achieved by FEO method. Solution number 5 has been selected for commercial customer as its rank value is the highest amongst all the solutions. This feasible solution achieved by FEO technique has energy loss, total cost, SAIFI, SAIDI and AENS values given as 110.76 kWh, US$

4050950.55, 5.401679 interruptions/customer yr, 6.648410 hours/customer yr and 36.137228 kWh/customer yr respectively. It can be said from the above discussion that all the conflicting objectives' values concerning to solution number 5 shown in Figure 7.64 are better than solution number 9 available in Figure 7.63. That's why the solution number 5 observable in Figure 7.64 has been finally chosen as the appropriate solution for commercial customer.

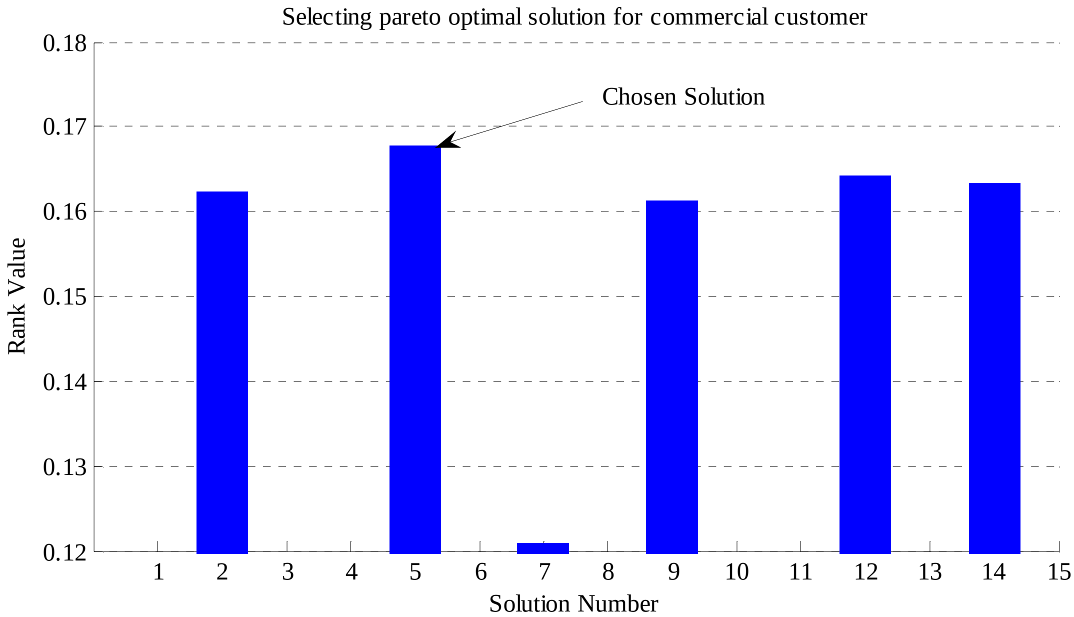

Figure 7.64: Choosing appropriate solution for commercial customer by TOPSIS method from the obtained pareto optimal solutions using FEO algorithm considering DG penetration up to 50% in 69 bus microgrid type radial distribution system

Final solution for commercial consumer has been achieved after appropriate simultaneous DG integration and capacitor placement using FEO algorithm. Shunt capacitors have been suitably placed at bus location 4, 21, 50 and 59 with installed values of 1200 kVAR, 200 kVAR, 600 kVAR and 1200 kVAR, respectively. Distributed generator integration has been performed at bus number 9, 11, 17, 21, 57, 63 and 69 with DG value of 100 kW at each selected position.

Cost incorporated customer based capacitor allocations and DG integrations have been studied in the earlier sections. These studies have been performed on a 69 bus microgrid type radial distribution system having real power load of 3.669 MW. Simulation studies performed in this microgrid type radial distribution system with near about four mega watt total load are important in business perspective as deregulation is prevailing in the distribution system. The larger size distribution system is one kind of reflection of this considered small scale microgrid type distribution system. So appropriate planning evaluated for this microgrid type system can be very useful for conventional large scale distribution system. In this regard a study related to suitable capacitor and DG placement considering enhanced load for futuristic demand in this microgrid type network would be important for deregulated business purpose.

7.3.5 Capacitor allocation and DG integration considering enhanced futuristic demand

Simultaneous capacitor allocations and DG integrations have been performed in enhanced load sixty nine bus microgrid type radial distribution system to improve reliability as well as to reduce total cost. The life time of the components of this project has been considered for twenty five years. Load enhancement has been exercised in sixty nine bus microgrid type system keeping line data same as before. This load enhancement has been performed considering futuristic demand. The bus data of this microgrid type distribution system has been shown in Appendix in Table A5. The total real power load of this newly developed microgrid type distribution system is 40.6 MW. Customer data for this enhanced load model has been shown in Table A8 in Appendix section. Solar photovoltaic plants as DG source of 500 kW and 1000 kW have been considered as distributed generation source. The size of DG source has been selected considering the load of the microgrid type radial distribution system at hand. The cost of those DG units has been considered from elsewhere [246]. Maximum limit of distributed generation penetration level has been restricted to 20% of total active power load. This limit has been fixed in view of cost reduction as well as reliability improvement and also considering the DG penetration level in different scenarios. Capacitor values have been considered as 1000 kVAR, 5000 kVAR and 10,000 kVAR here. The capacitor size has also been selected considering the load values in the microgrid type system. Failure rate and outage time have been enumerated considering the same principle discussed earlier [77, 119]. Four evolutionary techniques viz. rcGA, PSO, FEO and MCA have been considered here to study energy loss reduction, minimization of total cost and improvement of SAIFI, SAIDI and AENS.

7.3.5.1 Reduction of energy loss

Energy loss has been found reduced from its initial value i.e. without capacitor and DG connectivity by appropriate simultaneous capacitor allocation and DG integration in sixty nine bus microgrid type system available in Table 7.61. It has been observed from Table 7.61 that energy loss has been found decreased from 2284.69 kWh to 981.88 kWh by the application of rcGA. Distributed generation integration has been performed by implementing rcGA at bus position 5, 13, 16, 20, 23, 24, 25, 38, 42, 44, 50, 59, 61, 62, 64 and 69 with 500 kW of solar PV at every bus as shown in Table 7.61. Reactive power compensation has been performed installing shunt capacitor at bus location 3, 4, 5, 7, 9, 10, 15, 20, 23, 24, 25, 26, 27, 28, 32, 35, 38, 39, 44, 46, 47, 50, 51, 55, 58, 59, 60, 61, 62, 63, 64, 65, 66, 68 and 69 by employing rcGA available in Table 7.56. Capacitor value of 5000 kVAR has been installed in bus number 5, 44 and 60. Other selected bus positions apart from the mentioned three buses are selected for deployment of 1000 kVAR of capacitor value as observable in Table 7.61. On the other hand, energy loss has been observed to be decreased from 2284.69 kWh to 971.40 kWh by the implementation of PSO shown in Table 7.61. Distributed generators have been placed at bus number 2, 10, 15, 48, 58, 60 and 63 with DG value of 1000 kW at each bus. Capacitors have been allocated by applying PSO at bus number 10, 19, 26, 36, 39, 50, 52, 58, 60 and 61 with installed capacitor values of 5000 kVAR, 1000 kVAR, 1000 kVAR, 5000 kVAR, 1000 kVAR, 10000 kVAR, 10000 kVAR, 5000 kVAR, 1000 kVAR and 5000 kVAR, respectively. Finally it can be noticed that energy loss has been found reduced from 2284.69 kWh to 952.11 kWh by the application of FEO as observable in Table 7.61.

Table 7.61: Energy loss minimization in enhanced load 69 bus microgrid type radial distribution system considering a maximum of 20% DG penetration

Methods	Energy loss kWh	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	981.88	500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500	5, 13, 16, 20, 23, 24, 25, 38, 42, 44, 50, 59, 61, 62, 64, 69	1000, 1000, 5000, 1000, 1000, 1000,1000, 1000, 1000, 1000,1000, 1000, 1000, 1000,1000, 1000, 1000, 1000,5000, 1000, 1000, 1000,1000, 1000, 1000, 1000,5000, 1000, 1000, 1000,1000, 1000, 1000, 1000,1000	3, 4, 5, 7, 9, 10, 15, 20, 23, 24, 25, 26, 27, 28, 32, 35, 38, 39, 44, 46, 47, 50, 51, 55, 58, 59, 60, 61, 62, 63, 64, 65, 66, 68, 69
PSO	971.40	1000, 1000, 1000, 1000, 1000, 1000, 1000	2, 10, 15, 48, 58, 60, 63	5000, 1000, 1000, 5000, 1000, 10000, 10000, 5000, 1000, 5000	10, 19, 26, 36, 39, 50, 52, 58, 60, 61
FEO	952.11	500, 500, 500, 1000, 1000, 1000, 1000, 1000	9, 20, 46, 57, 60, 63, 64, 66	5000, 1000, 10000, 1000, 1000, 5000, 5000, 10000, 5000	6, 9, 36, 44, 51, 59, 63, 66, 68
MCA	788.68	500, 1000, 1000, 1000, 500, 500, 1000, 1000, 1000, 500	5, 13, 23, 24, 35, 58, 61, 64, 65, 68	1000, 5000, 5000, 10000, 1000, 1000, 10000	5, 6, 22, 39, 54,58, 61
Without DG and capacitor placement	2284.69	-	-	-	-

Bus positions 9, 20, 46, 57, 60, 63, 64 and 66 have been selected for DG allocation by FEO. Distributed generator value of 500 kW has been placed at bus number 9, 20 and 46. Thousand kilo watt of DG value has been placed at other selected locations for DG integrations as observable in Table 7.56. On the other hand, capacitor placement has been performed at bus locations 6, 9, 36, 44, 51, 59, 63, 66 and 68 with installed capacitor values of 5000 kVAR, 1000 kVAR, 10000 kVAR, 1000 kVAR, 1000 kVAR, 5000 kVAR, 5000 kVAR, 10000 kVAR and 5000 kVAR, respectively. Lastly it has been observed from Table 7.61 that energy loss value has been decreased from 2284.69 kWh to 788.68 kWh by the implementation of MCA. Shunt capacitor values have been selected by MCA as 1000 kVAR, 5000 kVAR, 5000 kVAR, 10000 kVAR, 1000 kVAR, 1000 kVAR and 10000 kVAR for bus locations 5, 6, 22, 39, 54, 58 and 61, respectively. On the other hand, solar PV (DG source) has been integrated at bus positions 5, 13, 23, 24, 35, 58, 61, 64, 65 and 68. The DG values as have been selected for those chosen bus locations are 500 kW, 1000 kW, 1000 kW, 1000 kW, 500 kW, 500 kW, 1000 kW, 1000 kW, 1000 kW and 500 kW. It can be said from the above discussion that MCA technique has found the least energy loss value amongst all the chosen soft computing tools.

Energy loss price has an influence in total cost. Total cost has also other parts like power interruption cost and installation cost of capacitor and capital cost of DG. This total cost can be reduced by appropriate simultaneous capacitor allocation and DG integration. The study of total cost minimization is also important to understand futuristic business activities.

7.3.5.2 Minimization of total cost

Total cost has been found reduced from the initial value of US$ 56778222.95 with suitable simultaneous DG integration and capacitor placement as observable in Figure 7.70 and Table

7.62. It has been observed from Figure 7.70 that total cost value has been found decreased from initial value by applying rcGA, PSO, FEO and MCA. It can be noticed from Figure 7.65 that FEO algorithm has found the least total cost value of US$ 44040143.29 amongst four considered algorithms. Distributed generator integration has been performed by FEO at bus location 63 and 64 with DG value of 1000 kW at every selected location as shown in Table 7.62.

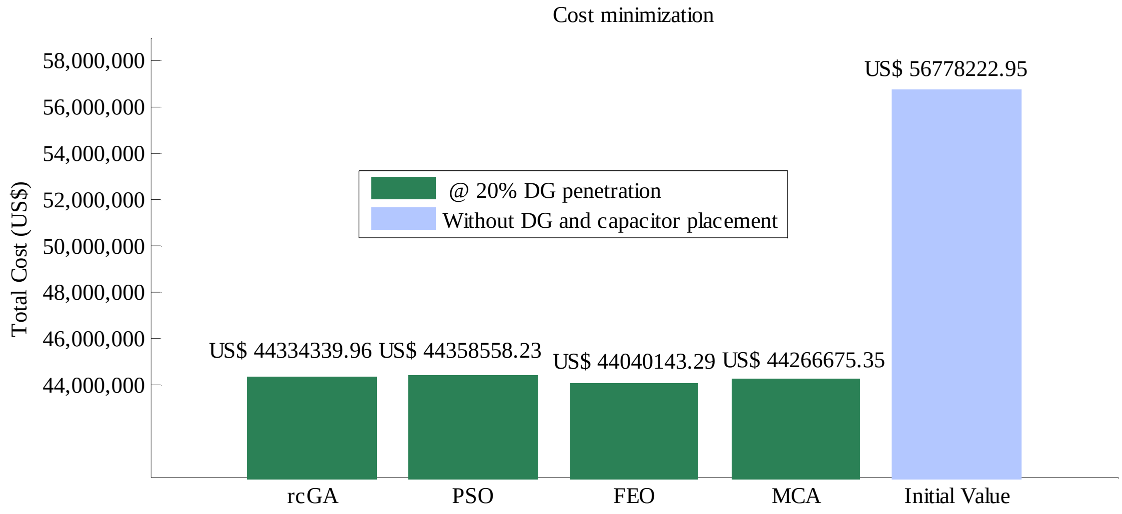

Figure 7.65: Minimization of total cost by the implementation of rcGA, PSO, FEO and MCA considering DG penetration up to 20% in 69 bus enhanced load microgrid type radial distribution system

On the other hand, bus locations 4, 43, 62 and 67 have been chosen by FEO for installing capacitor values of 1000 kVAR, 5000 kVAR, 10000 kVAR and 10000 kVAR, respectively. The next better position has been achieved by MCA technique in finding the better total cost value available in Figure 7.65. It has been observed from Figure 7.65 and Table 7.62 that total cost value has been found reduced from US$ 56778222.95 to US$ 44266675.35 with the simultaneous placement of DG and capacitor at bus locations 8, 26, 63 and 69; and 6, 12, 20, 40, 44, 53, 54, 62, 66 and 69 by applying MCA. The DG and capacitor values chosen for those selected locations are 500 kW, 1000 kW, 500 kW and 1000 kW and 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 5000 kVAR, 1000 kVAR, 10000 kVAR, 1000 kVAR and 5000 kVAR. The third position has been secured by rcGA amongst considered four techniques in finding the lesser total cost value as shown in Figure 7.65. Capacitor allocation has been performed by rcGA at bus positions 4, 17, 26, 27, 31, 32, 38, 55, 56, 60, 62, 67 and 68 with installed values of 5000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 5000 kVAR, 5000 kVAR, 5000 kVAR and 5000 kVAR. Solar PV as DG of 500 kW has been selected by rcGA at bus number 65. Finally it has been observed from Figure 7.65 that total cost has been found decreased from US$ 56778222.95 to US$ 44358558.23 by applying PSO. This cost reduction has been achieved by PSO due to DG integration at bus location 14 with DG value of 1000 kW. Capacitor allocation has been performed by PSO at bus positions 7, 17, 39, 56 and 62 with installed capacitor values of 5000 kVAR, 5000 kVAR, 5000 kVAR, 5000 kVAR and 10000 kVAR, respectively.

Table 7.62: Capacitor allocations and DG integrations for total cost minimization considering a maximum of 20% DG penetration in enhanced load 69 bus microgrid type radial distribution system

Methods	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	500	65	5000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 5000, 5000, 5000, 5000	4, 17, 26, 27, 31, 32, 38, 55, 56, 60, 62, 67, 68
PSO	1000	14	5000, 5000, 5000, 5000, 10000	7, 17, 39, 56, 62
FEO	1000, 1000	63, 64	1000, 5000, 10000, 10000	4, 43, 62, 67
MCA	500, 1000, 500, 1000	8, 26, 63, 69	1000, 1000, 1000, 1000, 1000, 5000, 1000, 10000, 1000, 5000	6, 12, 20, 40, 44, 53, 54, 62, 66, 69

Reliability worth or power interruption cost is an integral part of total cost as discussed earlier. Failure rate is connected with reliability worth. This failure rate is also linked with the customer oriented reliability index SAIFI. Improvement of SAIFI can be done by suitable DG integration and capacitor allocation. This has been studied in the next section.

7.3.5.3 Improvement of SAIFI

System average interruption frequency index (SAIFI) has been found improved by performing minimization considering simultaneous capacitor allocation and DG integration in sixty nine bus microgrid type radial distribution system. It has been observed from Table 7.63 that SAIFI value has been found improved from 5.884177 interruptions/customer yr to 5.492566 interruptions/customer yr due to simultaneous capacitor and DG placement by the application of rcGA as shown in Table 7.63. Capacitors have been allocated by rcGA at bus locations 2, 5, 10, 14, 15, 25, 31, 36, 38, 39, 40, 43, 51, 54, 57, 60, 68 and 69. Capacitor value of 5000 kVAR has been chosen for bus number 5. Thousand kilo VAR of capacitor has been installed at other selected locations. On the other hand, DG value of 500 kW has been placed at bus locations 8, 12, 16, 22, 24, 30, 31, 34, 42, 45, 58 and 59 by rcGA. It can be noticed from Table 7.58 that SAIFI value has been found improved from 5.884177 interruptions/customer yr to 5.730330 interruptions/customer yr by the implementation of PSO. Distributed generation integration has been performed at bus location 16 and 49 with DG value of 1000 kW at every selected location. On the other hand, reactive power compensation has also been performed by PSO placing shunt capacitor at bus number 7, 10, 24, 28, 40 and 55 with installed capacitor value of 5000 kVAR, 10000 kVAR, 1000 kVAR, 5000 kVAR, 1000 kVAR and 5000 kVAR. Finally it has been observed from Table 7.58 that SAIFI value has been found improved from 5.884177 interruptions/customer yr to 5.458275 interruptions/customer yr by performing minimization using FEO technique. Solar PVs have been placed by FEO at bus locations 11, 12, 18, 19, 22, 45 and 48 with 1000 kW of installed DG value at every selected location. On the other hand, shunt capacitors have been installed using FEO at bus numbers 12, 26, 28, 39 and 67. Capacitor values chosen for those selected locations are 1000 kVAR, 1000 kVAR, 5000 kVAR, 1000 kVAR and 5000 kVAR. Lastly it can be noticed from Table 7.63 that SAIFI value has been found improved from 5.884177 interruptions/customer yr to 5.442109 interruptions/customer yr by the usage of MCA technique. Distributed generation integrations have been performed by MCA at bus numbers 9, 16, 17, 24, 33, 34, 56, 58 and 68 with DG value of 1000 kW, 1000 kW, 500 kW, 1000 kW, 500 kW, 500 kW, 500 kW, 1000 kW and 1000 kW, respectively. On the other hand, shunt capacitors have been allocated by using MCA technique at bus positions 11, 14, 18, 19, 26, 58, 66 and 68 with installed capacitor values of 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR and 5000 kVAR, respectively. It can be said from the above discussion that MCA technique has found the least and the most improved SAIFI value amongst all the considered algorithms as observable in Table 7.63.

Table 7.63: Comparative study of SAIFI improvement amongst rcGA, PSO, FEO and MCA at a maximum of 20% DG penetration in enhanced load 69 bus microgrid type radial distribution system

Methods	SAIFI interruptions/ customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	5.492566	500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500	8, 12, 16, 22, 24, 30, 31, 34, 42, 45, 58, 59	1000, 5000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000	2, 5, 10, 14, 15, 25, 31, 36, 38, 39, 40, 43, 51, 54, 57, 60, 68, 69
PSO	5.730330	1000, 1000	16, 49	5000, 10000, 1000, 5000, 1000, 5000	7, 10, 24, 28, 40, 55
FEO	5.458275	1000, 1000, 1000, 1000, 1000, 1000, 1000	11, 12, 18, 19, 22, 45, 48	1000, 1000, 5000, 1000, 5000	12, 26, 28, 39, 67
MCA	5.442109	1000, 1000, 500, 1000, 500, 500, 500, 1000, 1000	9, 16, 17, 24, 33, 34, 56, 58, 68	1000, 1000, 1000, 1000, 1000, 1000, 1000, 5000	11, 14, 18, 19, 26, 58, 66, 68
Without DG and capacitor placement	5.884177	-	-	-	-

Failure rate is also connected with another customer oriented distribution system reliability index SAIDI. The improvement of SAIDI is important to understand like the above studied customer based reliability enhancement.

7.3.5.4 Upgrading reliability index SAIDI

System average interruption duration index has been found improved from the initial value after suitable DG integration and capacitor placement as shown in Figure 7.66 and Table 7.64. It has been observed from Figure 7.71 that SAIDI value has been found improved from initial value of 6.551647 hours/customer yr by applying rcGA, PSO, FEO and MCA. It can be noticed from Figure 7.66 that FEO technique has found the least SAIDI value of 6.168688 hours/customer yr amongst four considered algorithms. Distributed generator integrations have been performed by using FEO technique at bus location 9, 18, 21, 22, 25, 32, 40 and 58 with DG values of 1000 kW, 1000 kW, 1000 kW, 1000 kW, 500 kW, 500 kW, 1000 kW and 1000 kW as shown in Table 7.59. On the other hand, bus locations 4, 15, 43, 55 and 57 have been chosen by FEO for installing capacitor values of 10000 kVAR, 5000 kVAR, 1000 kVAR, 10000 kVAR and 10000 kVAR, respectively. The second position has been achieved by MCA technique in finding the better SAIDI value as available in Figure 7.66. It has been observed from Figure 7.66 and Table 7.64 that SAIDI value has been found improved from 6.551647 hours/customer yr to 6.220986 hours/customer yr with simultaneous placement of DG and capacitor. Distributed generator of 1000 kW has been selected for bus number 18, 22, 25, 30, 39 and 58. Five hundred kilo watt of DG value has been allocated at bus position 23, 41, 57 and 62. Capacitor values of 1000 kVAR, 5000 kVAR, 1000 kVAR, 1000 kVAR, 5000 kVAR, 1000 kVAR, 5000 kVAR, 1000 kVAR, 1000 kVAR, 10000 kVAR, 1000 kVAR, 5000 kVAR have been placed at bus number 8, 10, 15, 16, 30, 37, 51, 53, 59, 60, 62 and 68 by applying MCA technique. The third position has been secured by rcGA amongst considered four techniques in finding the lesser SAIDI value at 6.227614 hours/customer yr as shown in Figure 7.66. Capacitor allocation has been performed by rcGA at bus number 4, 6, 7, 8, 12, 15, 16, 27, 28, 32, 33, 36, 38, 43, 45, 55, 57, 61, 62 and 63 with installed value of 1000 kVAR. Five thousand kilo var of capacitor has been installed at bus position 2, 9 and 61 by the implementation of rcGA. Solar PV as DG of 500 kW has been selected by rcGA at bus locations 13, 17, 19, 26, 28, 31, 44, 45, 49, 50, 55, 57, 63 and 65. Finally it has been observed from Figure 7.66 that SAIDI has been found improved from 6.551647 hours/customer yr to 6.324262 hours/customer yr by applying PSO. This SAIDI improvement has been achieved by PSO due to DG integration at bus locations 3, 25, 30, 32, 40 and 58 with DG value of 1000 kW, 1000 kW, 500 kW, 500 kW, 1000 kW, 1000 kW. Capacitor allocation has been performed by PSO at bus positions 2, 7, 15, 42, 48 and 68 with installed capacitor values of 10000 kVAR, 10000 kVAR, 5000 kVAR, 1000 kVAR, 10000 kVAR, 5000 kVAR, respectively.

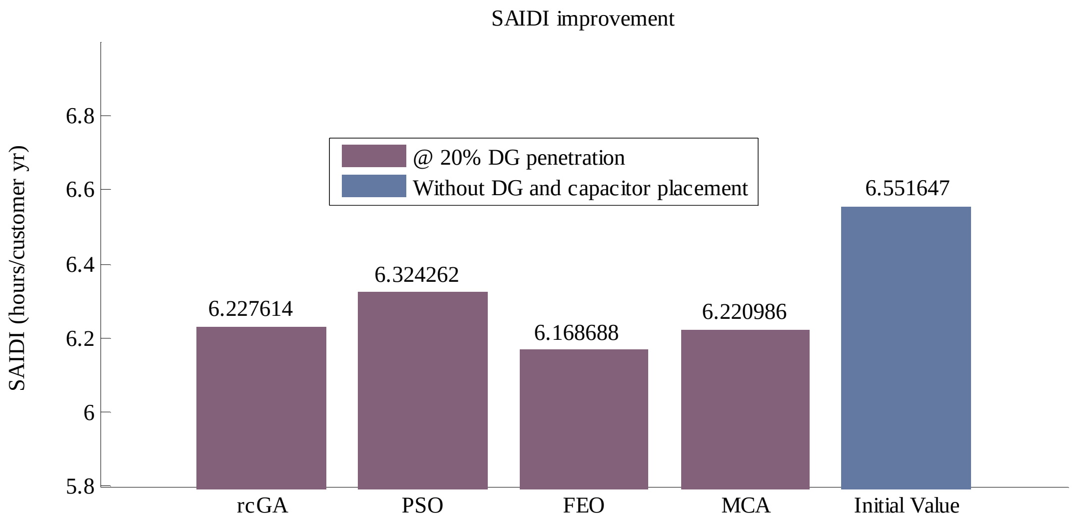

Figure 7.66: Comparative study related to improvement of SAIDI amongst rcGA, PSO, FEO and MCA considering DG penetration up to 20% in enhanced load 69 bus microgrid type radial distribution system

Table 7.64: Capacitor allocation and DG integration for SAIDI improvement in enhanced load 69 bus microgrid type radial distribution system at a maximum of 20% DG penetration

Methods	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500	13, 17, 19, 26, 28, 31, 44, 45, 49, 50, 55, 57, 63, 65	5000, 1000, 1000, 1000, 1000, 5000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 1000, 5000, 1000, 1000, 1000	2, 4, 6, 7, 8, 9, 12, 15, 16, 27, 28, 32, 33, 36, 38, 43, 45, 47, 55, 57, 58, 61, 62, 63, 66
PSO	1000, 1000, 500, 500, 1000, 1000	3, 25, 30, 32, 40, 58	10000, 10000, 5000, 1000, 10000, 5000	2, 7, 15, 42, 48, 68
FEO	1000, 1000, 1000, 1000, 500, 500, 1000, 1000	9, 18, 21, 22, 25, 32, 40, 58	10000, 5000, 1000, 10000, 10000	4, 15, 43, 55, 57
MCA	1000, 1000, 500, 1000, 1000, 1000, 500, 500, 1000, 500	18, 22, 23, 25, 30, 39, 41, 57, 58, 62	1000, 5000, 1000, 1000, 5000, 1000, 5000, 1000, 1000, 10000, 1000, 5000	8, 10, 15, 16, 30, 37, 51, 53, 59, 60, 62, 68

Load oriented distribution system reliability index is also important as customer oriented reliability index. Annual outage time is linked with the load oriented reliability index AENS like the above studied reliability index SAIDI. The improvement of this AENS can be exercised by performing minimization.

7.3.5.5 Improvement of AENS

Average energy not supplied (AENS) has been found improved by performing minimization after simultaneous capacitor allocation and DG integration in sixty nine bus microgrid type radial distribution system. It has been observed from Table 7.65 that AENS value has been found improved from 96.751641 kWh/customer yr to 91.874053 kWh/customer yr due to simultaneous capacitor and DG placement by the application of rcGA as shown in Table 7.65. Capacitor value of 1000 kVAR has been placed at bus position 2, 6, 9, 14, 16, 23, 25, 29, 36, 37, 38, 42, 44, 56 and 62 by using rcGA. Five thousand kilo var of capacitor has been allocated by the implementation of rcGA at bus number 28, 55, 57 and 66. On the other hand, DG value of 500 kW has been placed at bus locations 7, 8, 12, 17, 20, 21, 27, 47, 51, 68 and 69 by rcGA. It can be noticed from Table 7.65 that AENS value has been found improved from 96.751641 kWh/customer yr to 93.500735 kWh/customer yr by the implementation of PSO. Distributed generation integration has been performed at bus location 4, 16 and 23 with DG values of 1000 kW, 1000 kW and 500 kW, respectively. On the other hand, reactive power compensation has also been performed by PSO placing shunt capacitors at bus numbers 3, 6, 11, 21, 49, 56, 57 and 67 with installed capacitor values of 5000 kVAR, 5000 kVAR, 5000 kVAR, 1000 kVAR, 5000 kVAR, 5000 kVAR, 1000 kVAR, 5000 kVAR, respectively. Finally it has been observed from Table 7.65 that AENS value has been found improved from 96.751641 kWh/customer yr to 91.563161 kWh/customer yr by performing minimization using FEO technique. Solar PVs have been placed using FEO at bus locations 2, 8, 13, 14, 15, 17, 21, 27, 48, 53, 56 and 67 with installed DG values of 500 kW, 500 kW, 500 kW, 1000 kW, 500 kW, 500 kW, 1000 kW, 500 kW, 500 kW, 500 kW, 1000 kW, 1000 kW, respectively. On the other hand, shunt capacitors have been installed using FEO at bus numbers 10, 15, 19, 27, 37, 47, 51 and 55. Capacitor values chosen for those selected locations are 10000 kVAR, 1000 kVAR, 1000 kVAR, 1000 kVAR, 5000 kVAR, 1000 kVAR, 5000 kVAR and 5000 kVAR. Lastly it can be noticed from Table 7.65 that AENS value has been found improved from 96.751641 kWh/customer yr to 91.779689 kWh/customer yr by the usage of MCA technique. Distributed generation integrations have been performed by MCA at bus numbers 3, 18, 19, 20, 27, 37 and 61 with DG values of 1000 kW, 1000 kW, 1000 kW, 500 kW, 500 kW, 1000 kW and 1000 kW, respectively. On the other hand, shunt capacitor values of 1000 kVAR has been placed at bus location 2, 7, 20, 32, 37, 40, 41, 54 and 57. Five thousand kilovar of capacitor has been allocated at bus number 36 and 53. MCA technique has also selected 10000 kVAR of capacitor for allocating it into bus position 60. It can be said from the above discussion that FEO technique has found the most improved AENS value amongst all the considered algorithms observable in Table 7.65.

Table 7.65: Comparative study of AENS improvement in enhanced load 69 bus microgrid type radial distribution system at a maximum of 20% DG penetration

Methods	AENS kWh/customer yr	DG value (kW)	DG placement	Capacitor value (kVAR)	Capacitor placement
rcGA	91.874053	500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500	7, 8, 12, 17, 20, 21, 27, 47, 51, 68, 69	1000, 1000, 1000, 1000, 1000, 1000, 1000, 5000, 1000, 1000, 1000, 1000, 5000, 1000, 1000, 5000, 5000, 1000, 5000, 1000, 5000	2, 6, 9, 14, 16, 23, 25, 28, 29, 36, 37, 38, 39, 42, 44, 49, 55, 56, 57, 62, 66
PSO	93.500735	1000, 1000, 500	4, 16, 23	5000, 5000, 5000, 1000, 5000, 5000, 1000, 5000	3, 6, 11, 21, 49, 56, 57, 67
FEO	91.563161	500, 500, 500, 1000, 500, 500, 1000, 500, 500, 500, 1000, 1000	2, 8, 13, 14, 15, 17, 21, 27, 48, 53, 56, 67	10000, 1000, 1000, 1000, 5000, 1000, 5000, 5000	10, 15, 19, 27, 37, 47, 51, 55
MCA	91.779689	1000, 1000, 1000, 500, 500, 1000, 1000	3, 18, 19, 20, 27, 37, 61	1000, 1000, 1000, 1000, 5000, 1000, 1000, 1000, 5000, 1000, 1000, 10000	2, 7, 20, 32, 36, 37, 40, 41, 53, 54, 57, 60
Without DG and capacitor placement	96.751641	-	-	-	-

Capacitor allocations and DG integrations have been exercised so far to observe cost based reliability enhancement in both 34 bus and 69 bus microgrid type radial distribution systems. Comparative studies have been performed considering single objective situations. On the other hand, multi-objective optimizations have also been executed by the application of most effective MCA and FEO techniques. The overall objective of these simulation studies is to reduce the cost as well as to improve the reliability. This aim has been attained by appropriate planning discussed in this chapter. But there is always a scope of further improvement. With this view conclusion has been drawn and future scope has also been illustrated in the next chapter.

Chapter 8

Conclusion and future scope

8.1 Conclusion

Simultaneous distributed generation integrations and shunt capacitor allocations have been successfully performed for single and multi objective optimization situations in thirty four and sixty nine bus microgrid type radial distribution systems. Loss reduction, total cost minimization; improvements of SAIFI, SAIDI and AENS have been exercised as single objective optimization cases. Total cost minimization has been performed considering two reinforcement schemes at different DG penetration levels in 34 bus microgrid based radial distribution system. One is the scheme of disconnect/isolators with additional fuse gear and the other is only disconnects between buses. The improvements of distribution system reliability indices viz. SAIFI, SAIDI and AENS have been studied considering the reinforcement scheme i.e. 'applying disconnects between buses with lateral protection' in thirty four bus microgrid radial distribution system. Changes or modifications in other parameters apart from the considered objectives have been analyzed for 10%, 15% and 20% DG penetration levels in thirty four bus microgrid type radial distribution system. Capacitor placement has been executed optimally to minimize the total cost comprising power interruption cost, loss cost and capacitor installation cost in 69 bus microgrid type radial distribution system. Studies related to the change of reliability indices have also been performed. Capacitor allocation in sixty nine bus microgrid based radial distribution system has been exercised considering disconnects/isolators with additional fuse gear. The capacitor sitting and sizing data concerning to the above stated scheme have been employed for the other reinforcement scheme of applying only disconnects between buses. On the other hand, capacitor allocations and DG integrations have been performed to observe cost reduction, loss minimization, improvements of SAIFI, SAIDI and AENS considering 20% and 50% DG penetrations in 69 bus microgrid type radial distribution system. This study has been done on the basis of common and futuristic scenario in different situations selecting realistic customer data. Comparative studies for cost reduction, loss minimization, improvements of SAIFI, SAIDI and AENS have been performed amongst real coded genetic algorithm, particle swarm optimization, modified cultural algorithm and fish electrolocation optimization. Real coded genetic algorithm and particle swarm optimization are available standard techniques which have been implemented here for DG integration and capacitor allocation. But modified cultural algorithm (MCA) and fish electrolocation optimization (FEO) are novel techniques which have been developed on the basis of nature inspired phenomena. Modified cultural algorithm has been developed on the basis of original cultural algorithm. Two knowledge sources viz. situation knowledge and history knowledge have been engineered and developed further for application in this work. Four mathematical operators viz. addition, multiplication, replacement and unchanged have been newly thought out to perform the influence work of situation knowledge. Influence of the history knowledge on population space has been studied on the context of a plan related to the combinatorial optimization which is optimal DG and capacitor placement or only optimal capacitor allocation. On the other hand, fish electrolocation optimization has been mathematically developed for both continuous and combinatorial optimization problems. The concept of active and passive electrolocation phenomena of elephant nose fish and shark has been considered to develop the optimization tool named fish electrolocation optimization. The technique searches the feasible solution from a solution pool by performing randomization and localization like the conceptual electro fish's food searching procedure. The conceptual electro fish has both the active and passive electrolocation property. It switches between the two types of electrolocation depending on the situation that arises through iterations for a particular type of optimization problem. The population in this newly developed stochastic algorithm evolves by generating electric wave providing importance to electrical capacitance value. Both the developed techniques have been successfully implemented here for combinatorial optimization problems in various situations.

Modified cultural algorithm and fish electrolocation optimization have come out as effective evolutionary computation techniques as they have outperformed real coded genetic algorithm and particle swarm optimization. Sometimes fish electrolocation optimization has secured the first position in competition and for the other cases modified cultural algorithm has obtained the best results. Multi-objective optimization has been performed by the application of MCA and FEO techniques considering 50% DG penetration in 34 bus microgrid type radial distribution system. Modified cultural algorithm has been selected as the optimization tool for decision making in the case of multi-objective optimization situation in thirty four bus microgrid type system. This decision making has been exercised by giving equal importance to real power loss reduction, cost minimization and improvement of reliability indices. Pareto-optimal solutions have been formulated inspired by weighted sum method. Modified cultural algorithm has obtained eight non-dominated solutions whereas fish electrolocation optimization has found seven pareto-optimal solutions in the multi-objective environment. The lowest deviation value based non-dominated solution implementing MCA has been selected as the final solution. On the other hand, multi-objective optimizations have been exercised implementing the efficient modified cultural algorithm and fish electrolocation optimization in 69 bus microgrid type radial distribution system considering realistic customer data. Various multi-objective situations have been assessed considering two different conflicting objectives. Customer based decision making has also been performed. Rural, urban, hospital, office, commercial and industrial customers have been considered for study purpose. Cost, loss, SAIFI, SAIDI and AENS have been considered as conflicting objectives for performing multi-objective optimization. Finally appropriate distributed generation integrations and capacitor allocations have been found out evaluating TOPSIS method for each type of considered customer. The ultimate decision making has been executed analyzing the conflicting objectives values found out by FEO and MCA. Load enhancement of 69 bus microgrid type radial distribution system has been executed in view of futuristic load growth. Comparative studies amongst rcGA, PSO, MCA and FEO have been executed for cost reduction, loss minimization and improvements of SAIFI, SAIDI and AENS. These studies have been performed in the load enhanced 69 bus microgrid system exercising DG integration and capacitor allocation at 20% DG penetration.

Reliability indices viz. SAIFI, SAIDI and AENS have been found improved from their initial values. On the other hand, cost and loss have also been observed to be reduced from their original configuration values. It has been observed after performing capacitor and DG placements selecting reinforcement scheme 'applying disconnects with lateral protection' that FEO technique has found the least total cost values at a maximum of 10% and 20% DG penetrations amongst all the considered algorithms in 34 bus microgrid system. The MCA technique has found the least total cost at US$ 5756486.90 considering DG penetration up to 15%. The most improved SAIFI values have been achieved by MCA technique at a maximum of 15% and 20% DG penetrations in 34 bus microgrid type system. The least SAIFI value has been obtained by FEO algorithm at a maximum of 10% DG penetration. The best SAIDI values have been obtained by MCA technique at a maximum of 10% and 15% DG penetrations in 34 bus microgrid type radial distribution system. On the other hand, the most improved SAIDI value has been found by FEO algorithm at a maximum of 20% DG penetration as 8.624611 hours/customer yr. The effects of cost minimization have been observed on reliability and loss parameters. The consequences of improvements of a particular reliability index on other reliability indices, loss and cost parameters have also been observed. Most of the reliability indices, cost and loss values have been found improved from initial values after performing capacitor allocations and DG integrations. The best energy loss value has been found out as 788.68 kWh by the application of MCA technique for the enhanced load at 69 bus microgrid system. On the other hand, the FEO algorithm has obtained the least total cost value considering DG penetration up to 20%. Furthermore, the least load oriented reliability index AENS has been obtained by FEO technique at 91.563161 kWh/customer yr amongst all the considered algorithms.

8.2 Future scope of research

There is always a scope of further study in any research work. The untouched issues and the assumptions considered here may lead to the future extended scope of this research work. In this regard, standardization of 'alpha' value regarding the ratio of two currents can be a good option for new failure rate enumeration. On the other hand, reliability of power quality considering voltage improvement issue has not been considered here. Development of a new reliability index evaluating the power quality and voltage issue will also be a good move. The consumer number at each load bus has been considered realistically which defines the chosen radial distribution system as a mixture of several types of customers. But selection of pareto optimal solution for a specific type of customer has been performed considering the radial distribution system as a mixture of two types of consumers or simply as single type consumer. This will be a challenging task to fetch the appropriate solution for the entire radial distribution system as a mix of several types of customers. Hybridization of the newly developed techniques with the available standard techniques can generate another better evolutionary technique. Evolutionary techniques developed here can be further tuned by performing manipulations with the inherent parameters. Future scope of research lies also on the appropriate planning scheme. Network reconfiguration and optimal switch allocation are the two schemes which can be considered as engineering option apart from computational processes. Combination of network reconfiguration, DG integration and capacitor allocation could be a good research attempt in this regard.

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Appendix

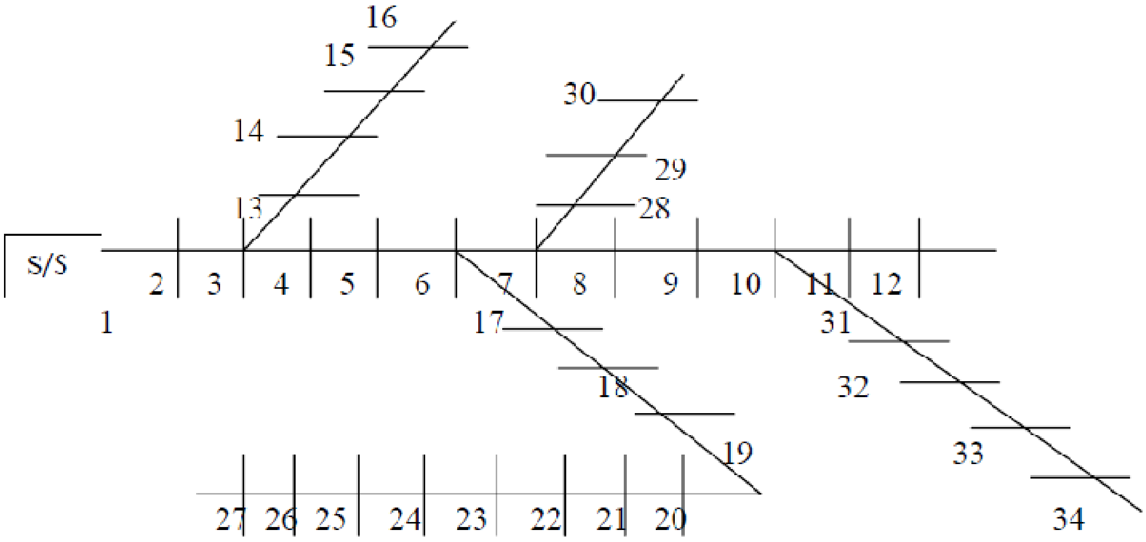

Figure A1: Microgrid type 34 bus radial distribution system

Table A1: Bus data of 34 bus microgrid type radial distribution system

Substation voltage = 11 kV			
Bus No	P (kW)	Q (kVAR)	Number of customer
1	0	0	0
2	230	142.5	1000
3	0	0	0
4	230	142.5	1000
5	230	142.5	1000
6	0	0	0
7	0	0	0
8	230	142.5	1000
9	230	142.5	1000
10	0	0	0
11	230	142.5	1000
12	137	84	613
13	72	45	343
14	72	45	343
15	72	45	343
16	13.5	7.5	100
17	230	142.5	1000
18	230	142.5	1000
19	230	142.5	1000
20	230	142.5	1000
21	230	142.5	1000
22	230	142.5	1000
23	230	142.5	1000
24	230	142.5	1000
25	230	142.5	1000
26	230	142.5	1000
27	137	85	613
28	75	48	356
29	75	48	356
30	75	48	356
31	57	34.5	281
32	57	34.5	281
33	57	34.5	281
34	57	34.5	281

Table A2: Line data of 34 bus microgrid type radial distribution system

From bus	To bus	R (p.u/km)	X (p.u/km)	Length (km)	Failure rate (f/yr)
1	2	0.195	0.08	0.6	0.2100
2	3	0.195	0.08	0.55	0.1942
3	4	0.299	0.083	0.55	0.2766
4	5	0.299	0.083	0.5	0.2532
5	6	0.299	0.083	0.5	0.2532
6	7	0.524	0.09	0.6	0.5000
7	8	0.524	0.09	0.4	0.3399
8	9	0.524	0.09	0.6	0.5000
9	10	0.524	0.09	0.4	0.3399
10	11	0.524	0.09	0.25	0.2198
11	12	0.524	0.09	0.2	0.1797
13	3	0.524	0.09	0.3	0.2598
14	13	0.524	0.09	0.4	0.3399
15	14	0.524	0.09	0.2	0.1797
16	15	0.524	0.09	0.1	0.1000
17	6	0.299	0.083	0.6	0.3000
18	17	0.299	0.083	0.55	0.2766
19	18	0.278	0.086	0.55	0.2606
20	19	0.378	0.086	0.5	0.3115
21	20	0.378	0.086	0.5	0.3115
22	21	0.524	0.09	0.5	0.4199
23	22	0.524	0.09	0.5	0.4199
24	23	0.524	0.09	0.6	0.5000
25	24	0.524	0.09	0.4	0.3399
26	25	0.524	0.09	0.25	0.2198
27	26	0.524	0.09	0.2	0.1797
28	7	0.524	0.09	0.3	0.2598
29	28	0.524	0.09	0.3	0.2598
30	29	0.524	0.09	0.3	0.2598
31	10	0.524	0.09	0.3	0.2598
32	31	0.524	0.09	0.4	0.3399
33	32	0.524	0.09	0.3	0.2598
34	33	0.524	0.09	0.2	0.1797

Table A3: Available capacitor size and cost for 34 bus microgrid type radial distribution system

Sl No.	Capacitor size (kVAR)	Cost (US$/kVAR)
1	150	0.5
2	300	0.35
3	450	0.253
4	600	0.220
5	750	0.276
6	900	0.183
7	1050	0.228
8	1200	0.170
9	1350	0.207
10	1500	0.201
11	1650	0.193
12	1800	0.187
13	1950	0.211
14	2100	0.176
15	2250	0.197
16	2400	0.170
17	2550	0.189
18	2700	0.187
19	2850	0.183

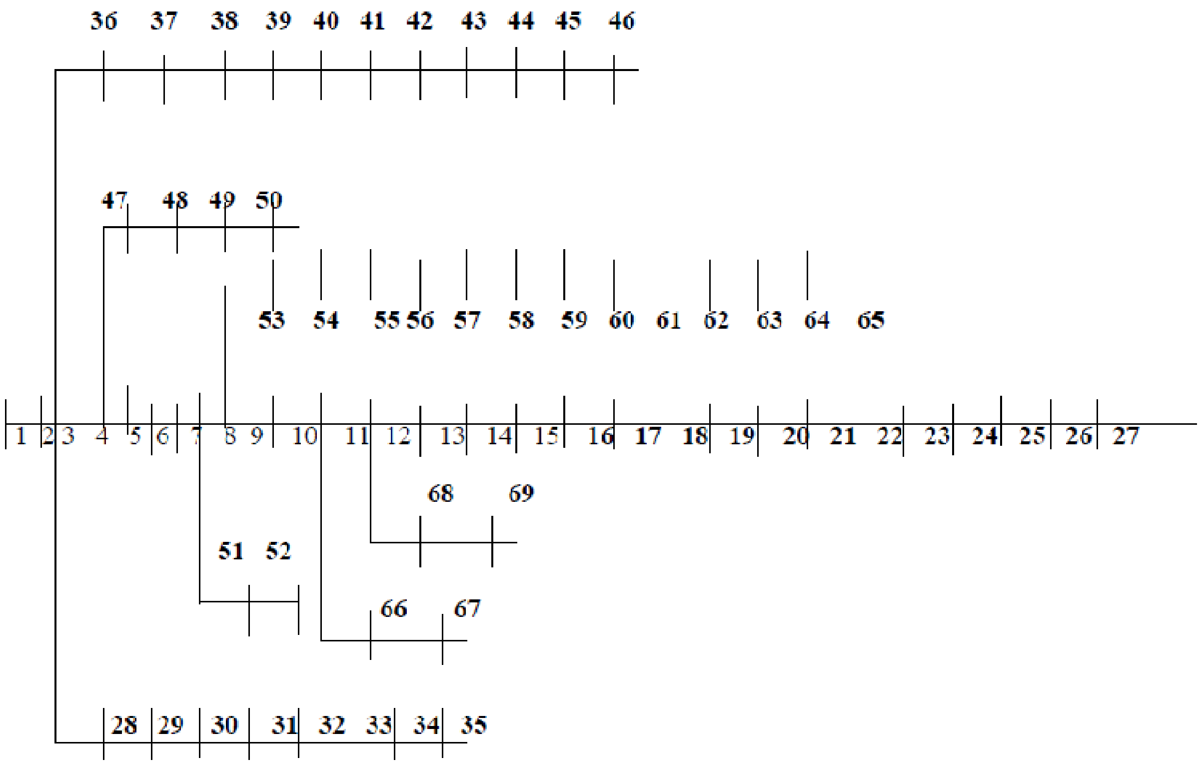

Figure A2: Microgrid type 69 bus radial distribution system

Table A4: Bus data of 69 bus microgrid type radial distribution system

Substation voltage = 12.66 kV		
Bus No	P (kW)	Q (kVAR)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	2.6	2.2
7	40.4	30
8	75	54
9	30	22
10	28	19
11	145	104
12	145	104
13	8	5.5
14	8	5.5
15	0	0
16	45.5	30
17	60	35
18	60	35
19	0	0
20	1	0.6
21	11.4	81
22	5.3	3.5
23	0	0
24	28	20
25	0	0
26	14	10
27	14	10
28	26	18.6
29	26	18.6
30	0	0
31	0	0
32	0	0
33	14	10
34	19.5	14
35	6	4
36	26	18.55
37	26	18.55
38	0	0
39	24	17
40	24	17
41	1.2	1
42	0	0
43	6	4.3
44	0	0
45	39.22	26.3
46	39.22	26.3
47	0	0
48	79	56.4
49	384.7	274.5
50	384.7	274.5
51	40.5	28.3

52	3.6	2.7
53	4.35	3.5
54	26.4	19
55	24	17.2
56	0	0
57	0	0
58	0	0
59	100	72
60	0	0
61	1244	888
62	32	23
63	0	0
64	227	162
65	59	42
66	18	13
67	18	13
68	28	20
69	28	20

Table A5: Bus data of enhanced load 69 bus microgrid type radial distribution system

Substation voltage = 12.66 kV		
Bus No	P (kW)	Q (kVAR)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	35	29
7	400	350
8	1000	920
9	500	450
10	400	220
11	3000	2100
12	4000	3300
13	96	82
14	100	90
15	0	0
16	600	510
17	800	750
18	900	810
19	0	0
20	15	11
21	200	160
22	100	91
23	0	0
24	400	360
25	0	0
26	300	240
27	200	170
28	400	320
29	500	410
30	0	0
31	0	0
32	0	0
33	200	160
34	250	210
35	70	50
36	270	230
37	250	210
38	0	0
39	230	180
40	260	210
41	15	10
42	0	0
43	70	50
44	0	0
45	400	320
46	410	340
47	0	0
48	800	750
49	4000	3400
50	4300	3800
51	500	450

52	50	40
53	60	52
54	300	220
55	250	180
56	0	0
57	0	0
58	0	0
59	1100	910
60	0	0
61	12000	10000
62	400	330
63	0	0
64	300	250
65	60	50
66	20	15
67	20	16
68	30	21
69	40	28

Table A6: Line data of 69 bus microgrid type radial distribution system

From bus	To bus	R (p.u)	X (p.u)	Failure rate (f/yr)
1	2	0.005	0.0012	0.1008
2	3	0.005	0.0012	0.1008
3	4	0.0015	0.0036	0.1005
4	5	0.0251	0.0294	0.1082
5	6	0.366	0.1864	0.1910
6	7	0.3811	0.1941	0.1948
7	8	0.0922	0.047	0.1227
8	9	0.0493	0.0251	0.1119
9	10	0.819	0.2707	0.2916
10	11	0.1872	0.0691	0.1440
11	12	0.7114	0.2351	0.2664
12	13	1.03	0.34	0.3410
13	14	1.044	0.345	0.3443
14	15	1.058	0.3496	0.3476
15	16	0.1966	0.065	0.1457
16	17	0.3744	0.1238	0.1874
17	18	0.0047	0.0016	0.1007
18	19	0.3276	0.1083	0.1764
19	20	0.2106	0.0696	0.1490
20	21	0.3416	0.1129	0.1797
21	22	0.014	0.0046	0.1029
22	23	0.1591	0.0526	0.1369
23	24	0.3463	0.1145	0.1808
24	25	0.7488	0.2475	0.2751
25	26	0.3089	0.1021	0.1720
26	27	0.1732	0.0572	0.1402
3	28	0.0044	0.0108	0.1022
28	29	0.064	0.1565	0.1372
29	30	0.3978	0.1315	0.1929
30	31	0.0702	0.0232	0.1161
31	32	0.351	0.116	0.1819
32	33	0.839	0.2816	0.2966
33	34	1.708	0.5646	0.5
34	35	1.474	0.4873	0.4451
3	36	0.0044	0.0108	0.1022
36	37	0.064	0.1565	0.1372
37	38	0.1053	0.123	0.1357
38	39	0.0304	0.0355	0.1100
39	40	0.0018	0.0021	0.1002
40	41	0.7283	0.8509	0.3489
41	42	0.31	0.3623	0.2057
42	43	0.041	0.0478	0.1136
43	44	0.0092	0.0116	0.1029
44	45	0.1089	0.1373	0.1386
45	46	0.0009	0.0012	0.1
4	47	0.0034	0.0084	0.1016
47	48	0.0851	0.2083	0.1497
48	49	0.2898	0.7091	0.2701
49	50	0.0822	0.2011	0.1480
8	51	0.0928	0.0473	0.1228
51	52	0.3319	0.1114	0.1775
9	53	0.174	0.0886	0.1431

53	54	0.203	0.1034	0.1503
54	55	0.2842	0.1447	0.1706
55	56	0.2813	0.1433	0.1699
56	57	1.59	0.5337	0.4729
57	58	0.7837	0.263	0.2836
58	59	0.3044	0.1006	0.1709
59	60	0.3861	0.1172	0.1894
60	61	0.5075	0.2585	0.2264
61	62	0.0974	0.0496	0.1239
62	63	0.145	0.0738	0.1358
63	64	0.7105	0.3619	0.2771
64	65	1.041	0.5302	0.3596
11	66	0.2012	0.0611	0.1464
66	67	0.0047	0.0014	0.1007
12	68	0.7394	0.2444	0.2729
68	69	0.0047	0.0016	0.1007

Table A7: Customer chart for 69 bus radial distribution system resembling microgrid

Bus No.	Active Power load (kW)	HT bulk consumer	LT bulk consumer	LT consumer	Domestic consumer	Total consumer	Customer description
1	0	0	0	0	0	0	-
2	0	0	0	0	0	0	-
3	0	0	0	0	0	0	-
4	0	0	0	0	0	0	-
5	0	0	0	0	0	0	-
6	2.6	0	0	0	4	4	Rural/agricultural; 0.65 kW each
7	40.4	0	0	3	8	11	Shop @10 kW, urban residential @1.3 kW
8	75	0	1	0	25	26	hospital@50kW, urban residential @ 1kW
9	30	0	0	3	0	3	Commercial @ 10kW
10	28	0	0	2	8	10	Commercial @ 10kW, urban residential @ 1 kW
11	145	1	0	0	7	8	Industrial @140 kW, rural @0.72 kW
12	145	1	0	0	50	51	Industrial @110 kW, rural @0.7 kW
13	8	0	0	0	8	8	Urban residential @1 kW
14	8	0	0	0	8	8	Urban residential @ 1 kW
15	0	0	0	0	0	0	-
16	45.5	0	1	0	2	3	Hospital @ 43 kW, urban residential @ 1.25 kW
17	60	0	1	0	10	11	Multiplex @ 50 kW, urban residential @ 1kW
18	60	0	0	2	20	22	Shop @ 20 kW, urban residential @ 1kW
19	0	0	0	0	0	0	-
20	1	0	0	0	1	1	Urban residential @ 1kW
21	11.4	0	0	1	0	1	Shop @11.4 kW
22	5.3	0	0	0	8	8	Rural @ 0.6625 kW
23	0	0	0	0	0	0	-
24	28	0	0	0	35	35	Rural @ 0.8 kW
25	0	0	0	0	0	0	-
26	14	0	0	0	14	14	Urban residential

							@ 1 kW
27	14	0	0	0	20	20	Rural @ 0.7 kW
28	26	0	0	1	16	17	Commercial @ 10kW, urban residential @ 1kW
29	26	0	0	2	6	8	Office @ 10kW, urban residential @ 1kW
30	0	0	0	0	0	0	-
31	0	0	0	0	0	0	-
32	0	0	0	0	0	0	-
33	14	0	0	0	20	20	Rural/agricultural @ 0.7 kW
34	19.5	0	0	1	14	15	Institution @ 10 kW, rural @ 0.6785 kW
35	6	0	0	0	6	6	Urban residential @ 1kW
36	26	0	0	1	18	19	Office @ 8kW, urban residential @ 1kW
37	26	0	0	3	2	5	Office/buildings @ 8kW, urban residential @1kW
38	0	0	0	0	0	0	-
39	24	0	0	1	14	15	Commercial @ 10kW, urban residential @1kW
40	24	0	0	1	16	17	Office @ 12kW, rural @ 0.75 kW
41	1.2	0	0	0	1	1	Urban residential @ 1.2kW
42	0	0	0	0	0	0	-
43	6	0	0	0	6	6	Urban residential @ 1kW
44	0	0	0	0	0	0	-
45	39.22	0	0	3	11	14	Small nursing home @ 8kW, commercial @10kW, office/building @10kW, urban residential @1.02 kW
46	39.22	0	0	2	25	27	Commercial @10kW, office @9.22 kW, rural @0.67 kW, urban residential @ 1kW
47	0	0	0	0	0	0	-
48	79	0	1	3	0	4	Hospital @50 kW, school

							institution @ 10kW, office@9 kW
49	384.7	3	0	0	35	38	Industrial @ 120kW, rural @0.7057 kW
50	384.7	2	0	1	0	3	Industrial @180kW, small scale industry @24.7 kW
51	40.5	0	0	3	10	13	Commercial @10kW, urban residential @1.05 kW
52	3.6	0	0	0	3	3	Urban residential @1.2kW
53	4.35	0	0	0	6	6	Rural @0.725kW
54	26.4	0	0	2	6	8	Commercial @10kW, urban residential @ 1.066 kW
55	24	0	0	1	18	19	Office/building @ 12 kW, rural/agricultural @ 0.67 kW
56	0	0	0	0	0	0	-
57	0	0	0	0	0	0	-
58	0	0	0	0	0	0	-
59	100	0	1	1	10	12	Hospital @50kW, office/buildings @ 40kW, urban @ 1kW
60	0	0	0	0	0	0	-
61	1244	10	0	0	65	75	Industrial @120kW, rural @0.676 kW
62	32	0	0	4	0	4	Commercial @10 kW, office @12kW, institution @8kW, residential complex @2kW
63	0	0	0	0	0	0	-
64	227	2	0	0	10	12	Industrial @110kW, rural @0.7kW
65	59	0	1	0	13	14	hospital@ 46kW, urban residential @1kW
66	18	0	0	1	8	9	Commercial @10kW, urban residential @1kW
67	18	0	0	1	13	14	office@ 9kW, rural @0.692 kW

68	28	0	0	2	10	12	Commercial @9kW, urban residential @1kW
69	28	0	0	1	8	9	Auditorium @20kW, urban residential @ 1kW

Table A8: Realistic customer chart considering enhanced load in 69 bus microgrid type radial distribution system

Bus No.	Active Power load (kW)	HT bulk consumer	LT bulk consumer	LT consumer	Domestic consumer	Total consumer	Customer description
1	0	0	0	0	0	0	-
2	0	0	0	0	0	0	-
3	0	0	0	0	0	0	-
4	0	0	0	0	0	0	-
5	0	0	0	0	0	0	-
6	35	0	0	0	21	21	Urban residential @ 3 kW, rural @ 0.67 kW
7	400	0	0	12	20	32	Shop @ 30 kW, urban residential @ 2 kW
8	1000	0	17	0	15	32	Hospital @ 90 kW, Commercial @ 50 kW, urban residential @ 2 kW
9	500	0	6	0	10	16	Office @ 80 kW, urban residential @ 2 kW
10	400	0	6	0	20	26	Commercial @ 60 kW, urban residential @ 2 kW
11	3000	7	0	0	250	257	Industrial @ 400 kW, rural @ 0.8 kW
12	4000	8	0	15	120	143	Industrial @ 450 kW, Shop @ 20 kW, rural @ 0.84 kW
13	96	0	0	1	28	29	Shop @ 12 kW, urban residential @ 3 kW
14	100	0	0	1	22	23	Shop @ 12 kW, urban residential @ 4 kW
15	0	0	0	0	0	0	-
16	600	0	2	15	0	17	Nurshing home @ 75 kW, shop @ 30 kW
17	800	0	8	0	40	48	Commercial complex @ 90 kW, urban residential @ 2 kW
18	900	0	10	0	25	35	Office @ 85 kW, urban residential @ 2 kW
19	0	0	0	0	0	0	-
20	15	0	0	0	7	7	Urban residential @ 2 kW and @ 3 kW
21	200	0	3	0	10	13	Institution @ 60 kW, urban residential @ 2 kW

22	100	0	0	1	30	31	Shop @ 10 kW, urban residential @ 3 kW
23	0	0	0	0	0	0	-
24	400	0	5	0	25	30	Office @ 70 kW, urban residential @ 2 kW
25	0	0	0	0	0	0	-
26	300	0	3	0	75	78	Hospital @ 60 kW, urban residential @ 2 kW, rural @ 0.8 kW
27	200	1	0	0	75	76	Industrial @ 140 kW, rural @ 0.8 kW
28	400	2	0	0	100	102	Industrial @ 150 kW, rural @ 1 kW
29	500	0	6	0	10	16	Office @ 80 kW, urban residential @ 2 kW
30	0	0	0	0	0	0	-
31	0	0	0	0	0	0	-
32	0	0	0	0	0	0	-
33	200	0	0	5	0	5	Commercial @ 40 kW
34	250	0	0	1	80	81	Shop @ 10 kW, urban residential @ 3 kW
35	70	0	1	0	10	11	Nursing home @ 50 kW, urban residential @ 2 kW
36	270	0	0	0	90	90	Urban residential @ 3 kW
37	250	0	0	10	80	90	Commercial @ 9 kW, urban @ 2 kW
38	0	0	0	0	0	0	-
39	230	0	4	0	0	4	Commercial @ 60 kW, Office @ 50 kW
40	260	0	2	0	30	32	Office @ 70 kW, urban residential @ 4 kW
41	15	0	0	0	20	20	Rural @ 0.75 kW
42	0	0	0	0	0	0	-
43	70	0	0	0	81	81	Shop @ 6 kW, rural @ 0.8 kW
44	0	0	0	0	0	0	-
45	400	0	0	5	100	105	Commercial @ 40 kW, urban @ 2 kW
46	410	0	0	10	0	10	Commercial @ 41 kW
47	0	0	0	0	0	0	-
48	800	0	10	0	0	10	Office @ 80 kW
49	4000	10	0	0	200	210	Industrial @ 380

							kW, rural @ 1 kW
50	4300	10	0	0	300	310	Industrial @ 400 kW, rural @ 1 kW
51	500	0	5	0	100	105	Institution @ 60 kW, urban @ 2 kW
52	50	0	0	5	0	5	Shop @ 10 kW
53	60	0	0	3	0	3	Commercial @ 20 kW
54	300	0	3	0	50	53	Institution @ 50 kW, urban @ 3 kW
55	250	0	0	10	0	10	Commercial @ 25 kW
56	0	0	0	0	0	0	-
57	0	0	0	0	0	0	-
58	0	0	0	0	0	0	-
59	1100	0	10	0	200	210	Commercial @ 50 kW, urban @ 3 kW
60	0	0	0	0	0	0	-
61	12000	20	35	0	250	305	Industrial @ 500 kW, Office @ 50 kW, rural @ 1 kW
62	400	3	0	0	40	43	Industrial @ 120 kW, rural @ 1 kW
63	0	0	0	0	0	0	0
64	300	0	0	10	0	10	Commercial @ 30 kW
65	60	0	0	0	20	20	Urban @ 3 kW
66	20	0	0	0	10	10	Urban @ 2 kW
67	20	0	0	1	4	5	Shop @ 12 kW, urban @ 2 kW
68	30	0	0	0	10	10	Urban @ 3 kW
69	40	0	0	1	10	11	Commercial @ 20 kW, urban @ 2 kW