VOLTAGE PROFILE IMPROVEMENT AND CONGESTION MANAGEMENT USING CAPACITOR AND FACTS DEVICES

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By

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CERTIFICATE

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This is an authentic work carried by him under supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree.

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The foregoing thesis, entitled as **“VOLTAGE PROFILE IMPROVEMENT AND CONGESTION MANAGEMENT USING CAPACITOR AND FACTS DEVICES”**, is hereby approved by the committee of final examination for evaluation of thesis as a creditable study of an engineering subject carried out and presented by **SANDIP PURNAPATRA** (Registration No. **129427 of 2014-2015** and Roll No. (**M4POW1608**) in a manner satisfactory to warrant its acceptance as a pre-requisite to the degree of **Master of Power Engineering** for which it is submitted. It is understood that by this approval, the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein, but approve the thesis only for the purpose for which it is submitted.

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ABSTRACT

Voltage profile optimization and congestion management is an essential part of power system control. Due to constant load variation in the system the voltage level changes rapidly. In this thesis loads of generator bus in IEEE 30 bus system has been increased and decreased almost 90% of their value respectively to exemplify system load variation. Then load flow equations have been used to solve system load flow problem through Newton-Raphson load flow solution. Newton-Raphson load flow is programmed for any IEEE standard bus system. However IEEE 30 bus system with varied load is used here to achieve load flow solution. At the end of load flow total voltage deviation and loss of the system has been taken as objective function for this work. The main objective of the work is to minimize system voltage deviation and losses to achieve better voltage profile and minimize system congestion. Differential Evolution (DE) and Cultural Algorithm (CA) have been taken as optimization algorithms in the work. FACTS devices like STATCOM, UPFC and Capacitor banks has been used to minimize objective function values. STATCOM and Capacitor both changes reactive powers of the system, where capacitor device can only add reactive power to the system, STATCOM device can inject or if necessary take away reactive power from the line to maintain reliable voltage profile. UPFC device has series or shunt compensation it injects active, reactive power to the bus and changes power angle. Thus UPFC device is suitable for voltage profile improvement as well as to relieve congestion problem of the system. Theory of DE and CA has been discussed to show their working principal, parameters and flowchart for normal operating condition. DE and CA optimization techniques have been implemented into the problem formulation to achieve the optimized outputs. Parameters of both DE and CA have been varied to observe to outcome of results. In the result it is shown that the losses and voltage deviation have been minimized by use of FACTS and capacitor devices. From the results obtained, it can be stated that STATCOM and CAPACITOR devices improve voltage profile of the system where UPFC devices can improve both voltage profile and congestion of the system significantly. Future scope of the thesis has been discussed this thesis work can be implemented on smart grid in near future.

Chapter 1: *Introduction to Grids*

An electrical grid can be described as an interconnected network, whose main purpose is delivering electricity from electricity suppliers to customer end. The components of grid are generating units which produces electrical power and high voltage transmission lines which connect individual consumers. Since the age of industries, the electrical grid has been upgraded from an area based power system component which serviced a particular geographic area to a much wider, expansive network that incorporated multiple areas. Hydro and coal based thermal power plants are still the main power sources of our country. While Hydro power plant has excessive build up cost, running cost of thermal power plants are high and not economical on efficiency point of view. So, in modern times they are inadequate to supply ever growing energy demand.

1.1. INDIAN ENERGY SCENARIO

The position of India in energy consumption is 4th biggest, only after China, USA and Russia. But the energy consumption per capita for India is just 566kwh and is far below most other countries or regions in the world. In India consumers, even if they have access to power, suffer from shortages and quality of power consumers. Our economy bears a large burden due to the poor quality of power supply. To cope with the power cut, variable frequency and low voltage, even industries maintain diesel generator and domestic users have battery powered invertors. The traditional electrical grids are generally used to carry power from a few centrally generators to a large number of users or consumers. Today the electricity disruption such as a blackout can have a series of failures that can affect banking, communications, traffic and security. Ministry of non-conventional energy resources was first set up by India, in early 1980s. The amount of renewable energy supplied to the national grid is 33.8 GW [1]. The renewable energy capacity installed in India is, solar PV 4.59% along with small hydro power and biomass, wind 66% [2]. But the increase in demands of electricity due to ever increasing population has led to several drawbacks of the existing electrical grids.

1.1.1. DRAWBACKS OF GRID SYSTEM

The power transmission infrastructure suffers aging in all the developing countries even after the modern arrangements. Interconnected grid system has a considerable amount of drawback [3]:

Aging Power equipment: In the power sector the older the instrument, the higher the failure rates, leads to consumer interruption rates and thus affecting the society’s economy. Older equipment and amenities lead to higher maintenance and inspection costs for further repair or restoration.

Obsolete system layout: Large geographical areas which have older infrastructure require additional substation sites area and rights that cannot be obtained in current area and forced to use existing, insufficient facilities.

Outdated Engineering: Conventional apparatus for power delivery planning and engineering are ineffective to address current problems of aged instrument, expired system layouts and deregulated modern loading levels.

Old cultural value: Procedures of planning, engineering, operation system worked in vertically integrated industry to defy the problem under a deregulated industry.

Location of fault: Location of fault is difficult in widespread networks because of the complicacy of the network.

Loss of reliability: The interconnection of grid is made with the high capacity generating station. Small capacity generating stations cannot be connected with them directly. Because it decreases reliability during forced or planned outage time as the whole grid needed to be shut down in case of a failures.

These drawbacks of the existing systems have presented with several challenges of designing a reliable electrical grid for continuous power supply. Hence, the challenges of grid reliability needs a considerable study to find out the reason why smart grids came into the fray.

1.1.2. GRID RELIABILITY CHALLENGES

Reliability analysis has been an important function for power system grid analysis. Maintaining the reliability profile in the power system network is very difficult because of few reasons discussed below [4].

- With the increase of transmission length of transmission line reliability decreases rapidly.
- Grid often operated uneconomically in most of the location, because of
    - Lack of overhauling and ageing infrastructure;
    - Ever growing power demand and energy consumption;
    - Lack of investment at the proper time;
    - Maximum resource utilization by using modern technique of monitoring and control;

Transmission and distribution system can be differentiated by using modern techniques and proper resource utilisation. Smart grid development thus ensures reliable power transmission and distribution in the society.

1.1.3. INTRODUCTION TO FACTS DEVICES

The great example of the power electronics devices capabilities is FACTS devices. FACTS devices have converters to handle high voltage and power levels. FACTS devices are connected at the points of the system which can influences the impedance and reactive power compensation of the system.

‘Dynamic’ and ‘static’, these two terms used to describe different types of FACTS devices. ‘Static’ conveys the device does not contain any moving part and the term ‘Dynamic’ conveys the fast controllable actions of FACTS devices. Most of the facts devices have static and dynamic qualities [5].

Most of the facts devices are built of transformers, inductance, capacitance or resistance and other different switchable mechanical components. With these elements FACTS devices have powerful electronic converters. In the fig 1, the left column shows facts devices consists of thyristors converter because of their decreased switching frequency and low losses.

In Fig 1, the right side column represents facts devices with Insulated Gate Bipolar Transistors (IGBT) or Insulated Gate Commutated Thyristors (IGCT) based advanced voltage source converters. By the pulse width modulation of IGCTs or IGBTs devices, control in voltage magnitude and phase is done by voltage source converters. To compensate network disturbances low harmonics are allowed in the signal output by high modulation frequencies. When the frequency increases, losses also increases. For the compensation purpose voltage source converters are specially designed.

In the fig 1, for each of the column the elements are presented according to their connectional relation to the power system. Primary work of the shunt devices are compensation of reactive power to control system voltage. Static VAR Compensator (SVC) devices compensate reactive power by mechanical switching method, does provide precise voltage control. This helps to improve the stability of the power system and can be implemented instantaneously to the needful scenarios. The STATCOM has more advantages than SVC, it improves the overall power quality even the flickers in voltages.

Series FACTS devices compensate reactive power. Thus they influence stability and power flow of the by changing line impedance. Most of the FACTS devices are installed in series to the line. Series compensation in the system is used as fixed FACTS device configuration. Often series compensation system protection is needed for that a Thyristor-bridge is used. TCSC device is used for stability improvement for damping of inter-area oscillation.

SSSC device provide series compensation but its implementation in the system is not cost efficient so TCSC device is used in the place of SSSC. Voltage source converters devices is used in the industries to improve supply power quality by deducting voltage flickers and certain voltage dips. Among the industries these type of voltage source converters are called Static Voltage Restorer (SVR) or Dynamic Voltage Restorer (DVR).

According to the demands of the consumer and the system further research on FACTS lead it to classify as shunt and series devices to control line power flow. Due to the varying load activity impacts on power flow, implementation of flexible use of transmission capacity is necessary. Phase shifters used in system shift power to the less congested lines from congested lines.

HVDC devices provide dynamic control like that of FACTS device if installed in the system. HVDC devices decouple frequency from the connected with it thus provide back-to-back control of line power flow. HVDC, if combined with a thyristor device only controls active power of the network connected, but if it is combined with voltage source converters, they provide reactive power flow control on the both sides of the network. These combination of device also improve system stability and provide better system control by dynamic control of power flow.

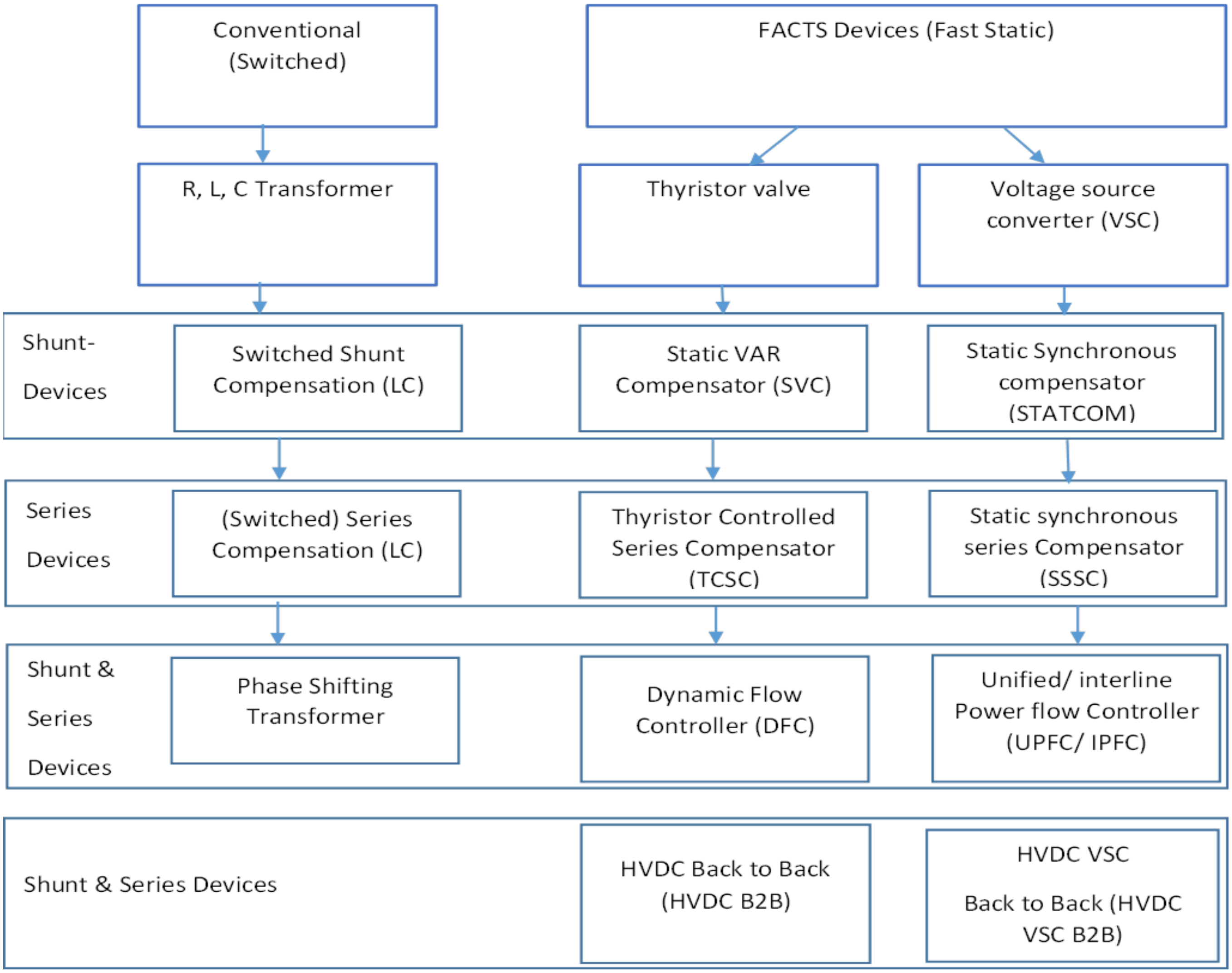


Figure 1: Overview of major FACTS devices [5]

1.1.4. FACTS DEVICES FIELD OF APPLICATION

Various type of power electronics devices, offers high controllability of power system devices. Amongst them Flexible AC Transmission system (FACTS) is a very well-known term. For the last two decades various types of FACTS devices has been developed across the laboratory of many countries. Research work on several new FACTS devices are on the way. The configuration and concepts of various FACTS devices has been discussed in the following section.

In modern days expansion of the power system is quite impossible due to the high installation cost, land requirement and other geo-graphic or economic barriers. For these several reasons up gradation or addition of new power lines and substation are not considerable, so the controllability application is becoming popular day by day. FACTS devices provide better controllability, adopts easily to varying operational requirements and improve the operation of other existing system devices. Fundamental application of FACTS-devices can be stated as follows:

- Compensation of reactive power
- Transmission system capability enhancement
- Control of system voltage
- Improvement of supplying power quality
- Control of line power flow
- Improvement of overall system stability
- Mitigation of system flickers
- Distributed and renewable generation interconnection
- Better conditioning of System power

For the justification of implementation of new facts device it is mandatory to check if it benefits practical requirements, economic value or the purpose. In the Fig. , the basic idea of a transmission system connected to FACTS device is shown. During the time of active power transmission the thermal limits of the conductors should be kept in mind. Use of several FACTS devices directly influences stability and voltage limits of the system. It can be stated that the importance of facts devices grows with the radius of power system operation.

Switch or shunt compensation control, phase shift and series compensation control defines the working principal of the FACTS devices. As power electronic devices have a low response time, less than 1 second, FACTS devices works as a fast voltage, current or impedance controller.

1.1.5. FACTS DEVICES

For the reliability enhancement in terms of voltage profile and congestion management of smart grid network few measures are taken and further research work is being done on this advances grid system. However this paper completely focuses on how to improve voltage profile and answer congestion management problem by using FACTS devices in series and parallel to the bus bar in grid network to give proper response to the reactive power demand of the network along with capacitors in parallel for significant improvement in voltage stability.

1.1.5.1. OPERATION OF FACTS DEVICES

There are several FACTS devices to supply reactive power, overcome sub-synchronous resonance problem, and provide electro-mechanical damping. But according to the size, response time and relevance this paper focuses on a few devices. The name and short working principle of these devices are listed below:

- **STATIC VAR COMPENSATOR (SVC):**

This device can continuously supply reactive power demand to control voltage oscillation of the under strenuous operating conditions to improve power system stability. Installation of a SVC device at any particular point or several points increase power transfer capability and reduce system losses while maintaining steady voltage profile. To provide better controllability, series connected anti-parallel thyristors are used inside SVC. The main disadvantages of this device are it requires large spaces to install and its responsive time and effectiveness is low in terms of a few modern FACTS devices.

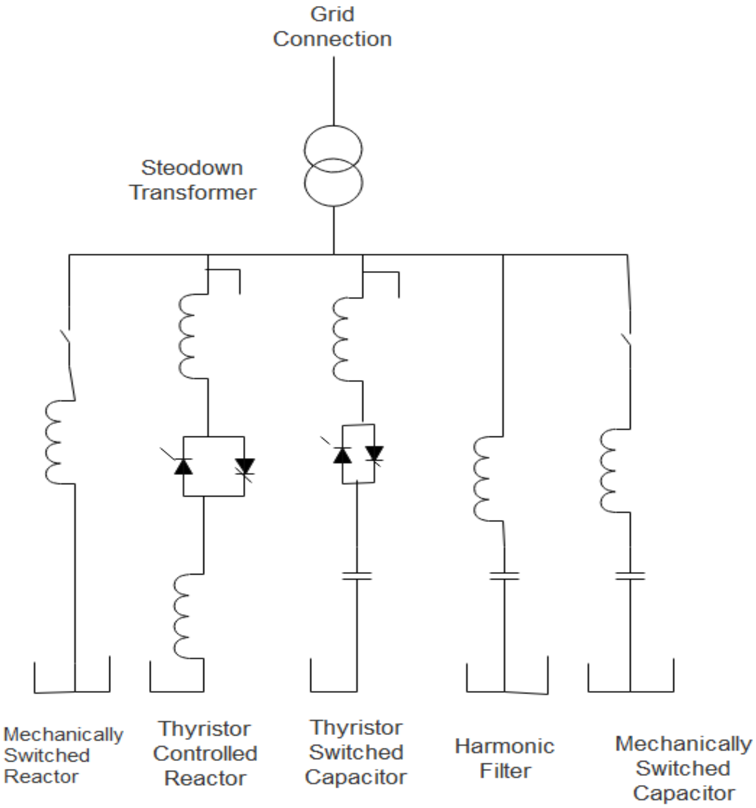


Figure 2: Circuit diagram of SVC device

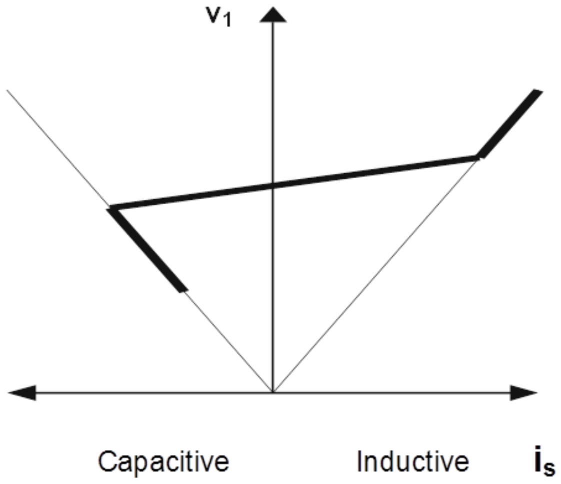


Figure 3: Voltage improvement graph of SVC device

STATIC COMPENSATOR (STATCOM):

This device has characteristics similar as a synchronous condenser but has several advantages over it like it has better dynamics, a lower investment and installation, operating and maintenance costs. This device has no inertia. This device has turn-off capability like GTO (Gate Turn off) or modern day electronics devices like IGBT (Insulated gate bipolar transistor) or IGCT (Insulated gated commutated transistor). This device's reactive power provision is not dependent on the actual voltage on connection point. This device is mainly used for grid interconnection.

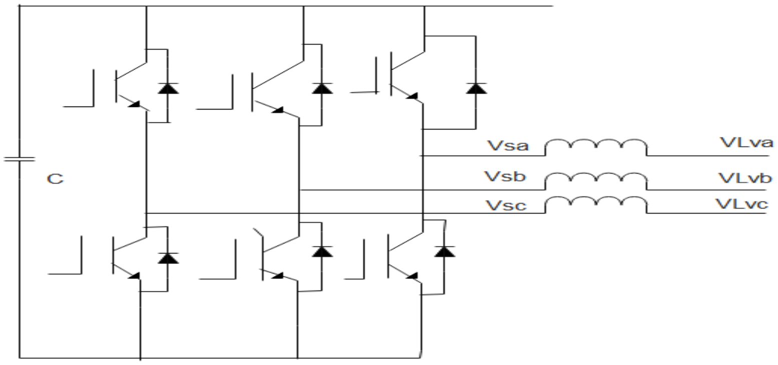


Figure 4: Circuit diagram of STATCOM device

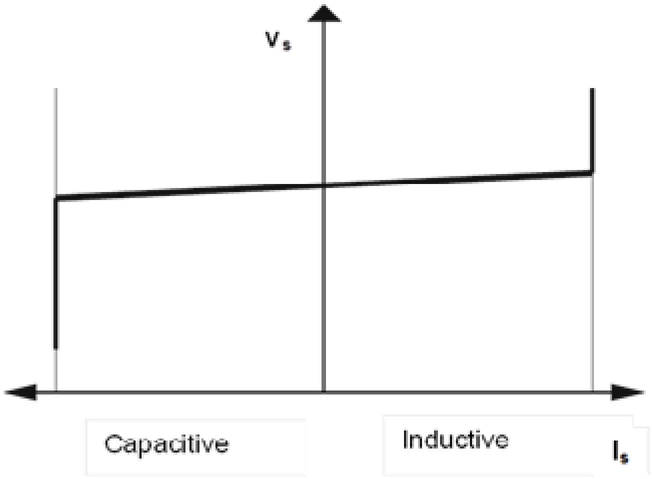


Figure 5: Voltage improvement curve of STATCOM device

➢ UNIFIED POWER FLOW CONTROLLER (UPFC):

Mainly this device is a combination of a static compensation and both static series compensation. The device acts as a phase shifting and as a shunt compensation device simultaneously. A shunt and series transformer is used inside this device and they are connected with two voltage source converters along with a common DC-capacitor. For the use of voltage source converter, protection devices and transformers this device is expensive large space consuming so limits practical applications.

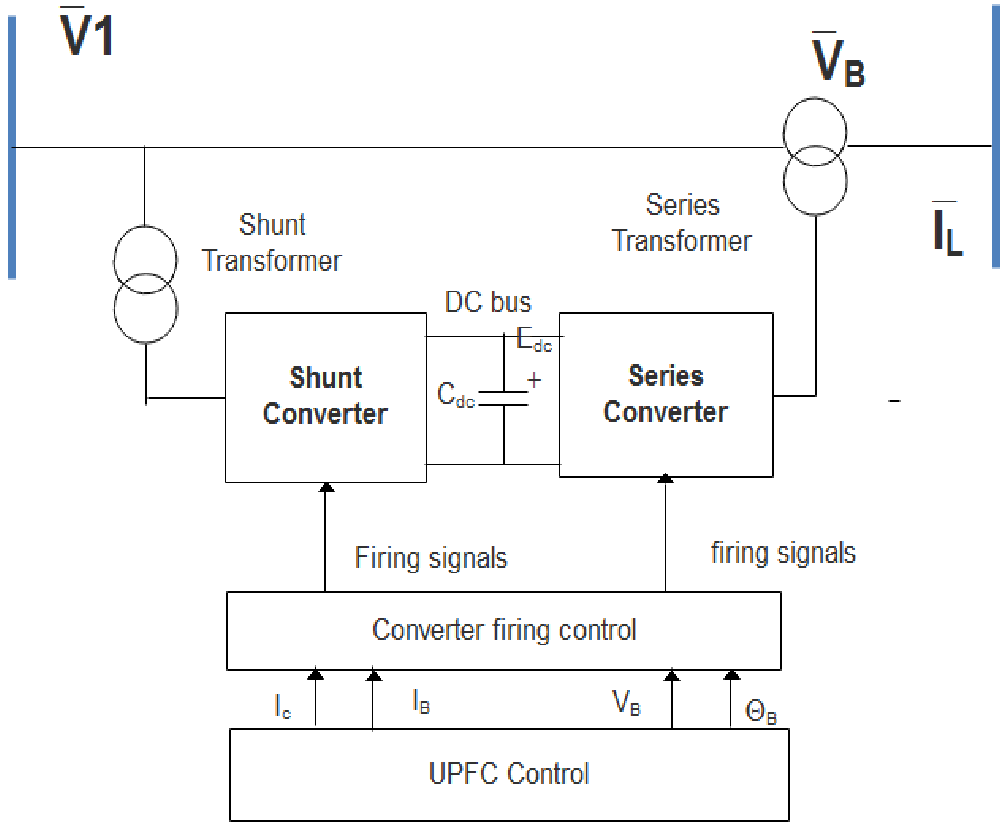


Figure 6: Diagram of UPFC device

1.2. OBJECTIVE OF WORK

The work mainly focuses on the improvement of voltage profile and reduction of congestion to ensure more network reliability. Thus far it is important to know what reliability enhancement brings to the system. Due to the constant load variance nature of power system the losses and voltage deviation rises for each occasion. The main aim of this paper is to minimise the congestion of transmission network and the present voltage deviation by optimal placement of FACTS devices with help of revolutionary algorithm technique. The algorithm techniques used here are Differential Evolution (DE) and Cultural algorithm (CA). Simple modern approach and better rate of convergence are the main reason of choice of this particular techniques. FACTS devices according to their distinctive nature changes power angle or supply necessary active and reactive power shortages in the system to alleviate congestion and to maintain a certain voltage profile for efficient operation. Optimal placement of FACTS devices in the system needs to be determined for best result of reduction of voltage deviation. IEEE 30 BUS data has been taken as system parameter in this thesis.

1.3. CONTRIBUTION OF WORK

In this paper IEEE-30 standard bus data is used as standard system parameter. A survey of the previous works has prompted the use of two different techniques, namely Cultural Algorithm and Differential Evolution (DE) in this work by determining the optimal placement location of Capacitor, STATCOM, and unified power flow controller. UPFC is used to control system power flow and voltage stability to improve system loadability. According to the active and reactive power demand of the system placement of the UPFC device inside the network is determined. Along with UPFC, STATCOM devices Capacitor is also placed optimally in the system as long as the system security, reliability increases with respect to system loadability. The contribution of the works lies in the results which show that due to the placement of these FACTS devices the voltage deviation of standard system is significantly reduced than original voltage deviation of the system and for UPFC device system congestion. A comparative study of the results varying device and optimization inputs is shown in this work. A multi-objective fitness function has been introduced involving loss and voltage deviation for UPFC. The loss part reflects the congestion i.e. real power part whereas the voltage deviation is connected to the reactive power part of UPFC.

1.4. ORGANISATION OF THE THESIS

Chapter 1: In chapter 1, an overview of Indian Energy scenario, drawbacks of the grid system has been given. Various types of FACTS devices their application field is also discussed. At last Objective of the work and contribution of the work are stated.

Chapter 2: In this chapter a brief overview of the previous work on the thesis topic have been reviewed and stated. Various types of use of FACTS devices in congestion management and voltage profile have been discussed. Optimization techniques used previously to solve the problem also has been reviewed. A few modelling work of FACTS devices related to thesis work also reviewed.

Chapter 3: Optimization techniques used for the work, Cultural Algorithm and Differential Evolution, their theory, working principle and flow chart have been briefly discussed. Load flow formulation and the other FACTS device parameter used in the work has been discussed.

Chapter 4: The optimization techniques Differential Evolution, Cultural Algorithm their application on solving objective function and the detailed flow chart of the techniques used in algorithm has been discussed briefly through flow charts.

Chapter 5: Detailed result after varying various algorithm parameters are presented in this chapter for both differential evolution and Cultural algorithm technique. The results outcome have been discussed in details.

Chapter 6: Summary of the thesis, the outcome, objective achievements have been discussed in details. Future scope of work on the thesis topic also has been discussed.

Chapter 2: *TRENDS IN VOLTAGE PROFILE AND CONGESTION IMPROVEMENT METHODS*

2.1. DIFFERENT VOLTAGE PROFILE IMPROVEMENT METHODS

Economic and different environmental condition has severe impact over voltage stability problem. Voltage stability fluctuates with the change of load because of different demand conditions. In power system voltage and reactive powers are related to each other. If voltage decreases reactive power demand increases. If the system is unable to supply required demand then bus voltage decreases further. FACTS device placement in various buses of power system is done to solve this problem.

2.1.1. OPERATING MEASURES TAKEN TO PREVENT VOLTAGE COLLAPSE

Maintaining voltage profile within a permissible limit ensures system security and optimal usage of reactive power sources. Interconnection of the system improves system security and it makes the system complex enough to create problems for the operators. This delays the reaction time from the operator end decrease system efficiency [6] [7]. Optimal Placement of automatic voltage regulator, capacitor and inductor helps system achieve better voltage profile [8]**.** Various measures of operation and system designs are used to minimize voltage collapse of the power system are given as follows [9]:

i. Optimal control and operation of protective devices used
ii. Regulate transformer tap on a regular basis
iii. Systematic control of generator reactive power output and voltage
iv. During low voltage condition decreases load
v. Proper allocation of reactive power compensator devices

2.1.2. SENSITIVITY BASED CONTROL TECHNIQUES

By regulation of tap setting of transformer and by controlling the generator voltages, system loss can be reduced to achieve a better voltage profile. Various resources of reactive power can improve voltage profile [10] [11].A sensitivity based technique is employed here to select control variable to reduce system losses. The adjustment in control variable is decided by using dual linear programming [12]. Enhancement of voltage and reduction of power losses after placing a static capacitor device is done by a new proposed algorithm Mixed Integer Linear Programming (MLIP) [13].

In Newton-Raphson, transfer values of Jacobian matrix were considered to get coefficient values of variables like transformer tap, generator voltages and reactive power[14].First order gradient method has been used to improve voltage profile while reducing total voltage deviation. No change in Jacobian matrix is needed and this makes this process easy and very effective [15].A voltage control method has been proposed for the buses which violates limits and controls margin. This proposed method has been compared with decentralized method to show its highly accurate control scheme [16].

Voltage Stability Assessment Neutral Network (VSANN) is a neural network based methodology proposed to achieve voltage stability quickly. This proposed method enhances voltage stability margin (VSM) by assessing it online. Phasor measurement of the voltage profile of the system is taken as input pattern for VSANN. VSM is dependent on voltage and reactive power compensation of the bus [17].A comparison between theoretical and actual value of reactive power is made to decide voltage deviation and minimize it by reactive power compensating devices. A few methods like Line Quality Factor (LQF), Novel Line Stability Index (NLSI) and Fast voltage stability index has been analysed to distinguish system stability margin [18].

To achieve maximum loading capacity and reduce production cost, use of phase angle regulators to optimize the control parameter of the network optimal location of these devices has been suggested. Sensitivity factors have been effectively used to obtain optimal placement of these devices in the system. This system improve real power loss and hence voltage profile of the system [19].

2.1.3. STRUCTURAL CHARACTERISTICS BASED CONTROL TECHNIQUES

Voltage profile problem of the power system can be solved with structural relationship ideas of various power system parameters.

Y-bus admittance matrix has been partitioned to get the indices characteristics by observing electrical load attraction region, ideal generator and affinity of the generators. These indices are used to obtain optimal location of the new generator in the system. This location is used to determine weakest and greater electrical distance to decide injection of real power [20]. Y-bus admittance partition and circuit theory concept and decomposed values of Eigen Vectors has been used to find optimal location of reactive power compensation devices. The inverse relationship between Eigen vector values and voltage are used to determine the location of VAR compensating devices because these buses are farthest from generator location [21].

2.1.4. IMPROVEMENT BY SECONDARY VOLTAGE CONTROL TECHNIQUES

Previous voltage fluctuation of the system has been investigated to control the secondary voltage of the system. The control instrument used in Static Volt Controller (SVC), which is by result of the operation, is far more superior to conventional voltage control techniques and instruments. Centralized Secondary Voltage Control (CSVC) technique has been proposed which initiates the three step regulation to change generator automatic voltage regulator set point. The time constant of these points has been minimized [22]. Automatic Secondary Voltage Control and change of power system stabilizer parameter, both coordinated to increase system stability margin or help the system to obtain better stability margin. If power system parameters are set accordingly by resetting power stabilizer the system stability margin will increase [23].

SVC device is used as reservoir or supplier of VAR in the system to maintain steady voltage profile. The capacity of SVC is decided by the measure of the margin of control, slopes, references and static voltage characteristic of the system. The output of SVC device is dependent on susceptence increment [24]. Each primary voltage controller is considered as controlling agent, so multi agent theory based on SVR co-ordination is proposed. This method is very effective under system contingency condition [25]. Voltage control using compensation of line drop voltages is proposed. This method can be implemented by a quick response voltage injector device. Secondary voltage control is also a part of the proposed plan [26].

2.1.5. VOLTAGE IMPROVEMENT AND VAR COMPENSATION USING FACTS DEVICES

Synchronous devices is used as dynamic compensator to supply reactive power shortage of the line. This method is compared with other conventional methods to show better performance characteristics for voltage impedance and voltage angle control [27].Synchronous voltage sources exchange active power directly with AC system and provide an independent control scheme of control on system VAR compensators to help system overcome various disturbances [28].

Reactive power dispatch by controlling the settings of FACTS devices have been proposed to minimize the system losses. Optimal placement of thyristor controlled phase angle regulator (TCPAR), static VAR Compensator and thyristor controlled series compensator has been obtained by calculating sensitivity indices. The result shows the superior reduction of loss than other conventional methods. This also increases voltage profile other than reducing system losses. The inversely proportional relation between VAR and Voltage magnitude in buses has been taken into consideration for voltage control and minimizing voltage collapse. This inverse relation has been verified for every optima power flow condition after considering the size and placement for VAR devices [29]. Voltage profile improvement using Fuzzy controller to operate STATCOM device control operation has been proposed. The faster and steady voltage control can be possible using Fuzzy controller. GA can be used for continuous complete and simultaneous control system design [30].

Modelling of FACTS devices like TCSC, SVC, TCPST have been proposed for voltage profile enhancement [31] [32]. Optimal dispatch of VAR by the placement of SVC and its effect to reduce system losses and voltage improvement has been dispatched. Simultaneous control of local and remote devices can be done by SVC device coordination. Voltage and VAR controlled operation can be achieved by coordinated SVC operator. The index performance of SVC over voltage improvement and loss minimization has been discussed [33]. Operation of STATCOM and its effect on improving on voltage profile by active and reactive power control has been analysed. STATCOM effect on different buses before and after fault occurrence also have been analysed [34].

Thyristor controlled phase shifter is used in this paper to decide its optimal number and placement in the power network system to minimize active power losses of transmission line to ensure reliability and stability of the system. In this work, active power losses is calculated using distribution factor. A modified cultural algorithm technique is presented to provide better location of placement of phase shifter. Damping problem solution using phase shifter is also provided. A demonstration has been given to use phase shifter to use as a series dynamic compensator. However the best location of phase shifter placement is monotonous. The algorithm of placement may not work universally on different parameters or machines [35].

IEEE-14 standard bus is used as standard system parameter. Genetic Algorithm is used in this work to maximize system loadability by determining the optimal placement location of unified power flow controller. Unified power flow controller (UPFC) is used to control system power flow and voltage stability to improve system loadability. According to the active and reactive power demand of the system placement of the UPFC device inside the network is determined. The authors have inducted UPFC devices as long as the system security, reliability increases with respect to system loadability. The objective function does not show the exact number of UPFC devices needed for improvement purpose. Fitness function and penalty terms are added with the objective function [36].

Facts devices are used in the system to answer reactive load problems and prevent the system from instability and save it from voltage collapse. Applying Saddle Node Bifurcation after choosing one static compensator (STATCOM) and one unified power flow controller (UPFC) the optimal location of these devices are determined on IEEE bus systems. The determination of suitable bus for the placement of FACTS devices is based on the comparison of maximum voltage drop amongst the buses. So by coupling FACTS devices with weak voltage profiled buses the loadability of the system are increased [37].

SVC and UPFC are used to answer the power flow problem of transmission lines. The devices are used individually to get a comparative result for a better solution. The objective function focuses on minimization of total generation cost. A developed model of SVC and UPFC has been proposed. The FACTS device location is presumed in this work. UPFC device placement and its impact of Optimal Power Flow show that the generation cost has been minimized for presumed different system condition. Sequential quadratic programming (SQP) technique has been used in this paper to solve optimal power flow problem [38].

The initiative taken to modernize the existing grid system in power system by placing few devices to improve its efficiency and reliability. SMART power flow controller (SPEC) is used to control active and reactive power flows and in the same time it minimizes reactive power flow. Also this device can sensibly increase power flow of the transmission line to solve much criticized congestion problem of power lines. Shunt series connection is used in SPEC to compliment point to point power transfer between two networks with different operational parameters [39].

Characterization of unified power flow controller and series power flow controller using two gate turn off thyristor have been discussed. Static condenser based FACT device SPFC can absorb reactive power from transmission line. So these device provide real power interchanging in the transmission line [40].

2.1.6. VOLTAGE IMPROVEMENT USING CAPACITOR BANK

Optimal allocation and size of shunt capacitors in a distributed power system reduces system loss and VAR compensation cost. At distribution system 13% of total generated power is consumed as system power loss [41]. There are two parts of system losses distinguished as branch current, active and reactive component. The branch current's reactive component can be improved with the installation of Shunt capacitor. Capacitive compensation improves system voltage profile, power factor and reduces KVA capacity and the power losses of the system. The optimal location and size of capacitor installed o radial distribution system has been proposed [42] [43].The main component of the power system loss is $I^2 R$ loss. This can be reduced significantly with the installation of capacitor with the system [44].

Optimal allocation of capacitor banks decided after considering loss sensitivity factors (LSF) and voltage sensitivity Index (VSI). The system power loss decreases after installing capacitor bank.

The system load has been varied from Peak load (160%) to light load (50%) [45].Finding the optimal location and size of the capacitor Flower Pollination algorithm considering loss sensitivity factor has been proposed. The result has been compared with other algorithms to show significant reduction of system loss and VAR compensation [46].Optimum location of the shunt capacitor and size of the device has been proposed after considering all the system constraints by Bacterial-Foraging algorithm [47].

So far in the previous cases it’s clear that optimization of voltage profile is needed for stable and reliable system operation, but congestion management is also important to supply load demand and to reduce fluctuation of voltage profile. In the next division different congestion improvement methods have been discussed.

2.2. DIFFERENT OPTIMIZATION TECHNIQUES USED FOR VOLTAGE IMPROVEMENT

From the start of 1990s many different optimization techniques like PSO GA has been developed to solve optimization problems and to produce better convergence rate. All of these techniques have a few advantages and disadvantages when compared with one another. Here in this section a few popular optimization algorithms and their contribution to improve voltage profile has been discussed.

2.2.1. NEWTON-RAPHSON METHOD

Nonlinear programming framework through MATLAB programming is employed to solve load flow problem of power system. Newton Raphson Algorithm is used to acquire corrective FACTS parameters control and minimize voltage violations, average loadability and overloads of highly loaded transmission lines. Optimal location problem of FACTS devices like OUPFC and TCSC has been addressed in this work. IEEE 14 and 30 bus system is considered as standard system parameter [48].

A power flow study program using Newton Raphson Algorithm is considered to develop various FACTS device models. SVC, TCSC and UPFC devices have been modelled employing this algorithm by reducing their different device parameters such as voltage profile, amplitude, phase angle and real reactive power. Iterative use of Newton Raphson method is employed to solve two nonlinear equations simultaneously for optimal placement of the FACTS devices [49].

An iterative method using Newton Raphson Algorithm have been proposed to resolve the series voltage magnitude limit. The power flow equations using resolved UPFC parameter limits like voltage, phase angle and impedance is solved by using the algorithm. The proposed algorithm is employed for resolving the shunt current and voltage magnitude limit [50].

Interline power flow controller (IPFC) and Unified Power flow controller (UPFC) are the voltage source converter (VSC) based FACTS devices which have been used to increase system loadability and thus maximize the power transfer capacity. Newton-Raphson load-flow method is used to determine the placement of FACT devices in particular buses and the size of these devices and the system balanced condition and maximize system loadability using linear programming framework to maximize power transfer through networks are demonstrated in this paper [51].

Branch models considering nodal admittance accessed steady state response of UPFC, Interface Power Controller (IPC) Phase shifter and series compensator have been developed using Newton Raphson load flow method. Newton Raphson method gives strong convergence and it has the ability to find solution by quadratic convergence [52].

This method used equality constant to model series/shunt operation of generalized unified power flow controller (G-UPFC) and IPFC. Impedance compensation technique of transformer-less control of these FACTS devices has also been derived. Series and Shunt equality constant of these devices has also been imposed by newton Raphson algorithm. Number of iterations of NR power flow method is required to achieve better divergence [53].

Mathematical models of UPFC, SSSC and STATCOM has been solved by nonlinear Newton Raphson methods and their numerical results has been used to solve the optimal power flow problem to change existing system parameters [54].

To find the optimal location of TCSC devices to improve voltage stability employing Newton Raphson algorithm. Change of voltage angle, real and reactive power using TCSC device is also being calculated by Newton Raphson method [55].

The total system power loss has been calculated using Newton Raphson method. The minimization of system power loss after connecting FACT devices to the system and by generating new system constants has also been calculated again by this method [56].

A novel formulation of ATC problem considering system parameters like reactive power flow, voltage limits has been provided. Line power flow and voltage collapse has been included in this formulation. The Jacobian matrix parameters has been changed partially by adaption of localized variables to calculate system power flow using Newton Raphson algorithm [57].

Newton-Raphson method is a convenient method for non-linear equation solving but for optimization techniques for finding the best solution it cannot be used conveniently. For optimization problem it is better to use evolutionary or other algorithm techniques. Some of these techniques have many advantages and disadvantages compared with each other, few popular techniques are discussed in the next section.

2.2.2. GENETIC ALGORITHM

Genetic algorithm (GA) has been used to determine the operational parameter of TCSC devices and their placement in transmission line. The importance of TCSC and their effect to enhance total transfer capability is explored employing GA. Different reproduction, mutation and crossover technique has been performed on GA environment and produces good result with enhanced TTC [58].

Probabilistic heuristic multidirectional and parallel characteristics of GA helped to solve the optimal solution of complex optimization techniques. Random selection of variables by this method helps overcome the local minimal problem. GA have been developed further to solve TCSC device allocation problem [59].

The optimization problem using several FACT device to enhance the controllability and ranges of transmission lines has been solved using GA. The maximum range of power transmission limit has been evaluated using this algorithm but the reliability and effectiveness of this algorithm depends on the type of FACTS devices. Coordination of different FACT device to control power flow optimization problem using GA has been proposed [60]

In this paper phase shifters and capacitor devices in series are used to control the power flow of the transmission network and to help reduce the power flows in the heavily congested lines. Genetic Algorithm is used to give best placement of phase shifters or capacitors of given parameters. The objective function used to give best placement is based on the return of investment and cost of devices. The result is compared between one, two and three phase shifters simultaneously used in the network. The objective function of best placement of phase shifters is strongly based on the cost of phase shifters. Multiple phase shifters is used here to either block the weak line flows or to balance the flows between the parallel paths to the transmission line [61].

Although genetic algorithm technique is very popular amongst evolutionary algorithm techniques but it has certain disadvantages as the formulation of this technique is quite complex, has tendency to obtain local minima instead of global minima and the convergence rate is slower than many modern optimization techniques.

2.2.3. ANT COLONY ALGORITHM

A novel congestion management scheme has been solved by demand response with the help of smart ant colony algorithm. The algorithm mixes generation rescheduling and demand response of the connective buses and produces a novel cost effective solution through this meta-heuristic optimization algorithm. Ant colony optimization uses fuzzy technique to give optimized result for the best solution. Ant colony optimization compromise between cost of operation and tolerable congestion for selecting loads for demand response and selecting generators for generator rescheduling [62].

A novel congestion management scheme has been solved by demand response with the help of smart ant colony algorithm. The algorithm mixes generation rescheduling and demand response of the connective buses and produces a novel cost effective solution through this meta-heuristic optimization algorithm. Ant colony optimization uses fuzzy technique to give optimized result for the best solution. Ant colony optimization compromise between cost of operation and tolerable congestion for selecting loads for demand response and selecting generators for generator rescheduling [63].

Ant colony algorithm is very fast and simple technique but local minima problem persists in this technique. Probability distribution function in this techniques changes with iteration. Theoretical decision making is difficult for random decision making ability of this technique also time of convergence varies greatly in this technique.

2.2.4. DIFFERENTIAL EVOLUTION ALGORITHM

K. Price and R. Stron in the year 1995 introduced heuristic evolutionary differential evolution (DE) algorithm to solve optimization problem [64].The crossover mutational selection operations of DE differ from Genetic Algorithm (GA) by mutation mechanism, selection and recombination phases. Greedy Selection method is used to generate new population in DE by weighted difference. DE has fast convergence and few control parameters to solve time variable objective functions. The first step of DE is the presumption of first set of population and the final step is making population iteratively transmutated. Here the population is randomly generated and with every generation existing population vectors converge into target vectors. DE generates a new modified vector by addition of weighted difference between two randomly chosen population vectors to another random third vector [65].

Differential Evolution Optimization has been implemented on a standard IEEE 30 bus system to minimize power loss, investment cost and help improve margin of voltage security [66].

DE algorithm has been implemented to find the dispatch results of optimal reactive power and compare the result with and without FACTs devices such as SSSC. The computational time of DE algorithm is less than other algorithms [67].

The comparison for the minimization of active power loss using two sets of FACTs devices (Set 1- TCSC, SVC; Set 2- SSSC, SVC) has been done using two computational technique- Newton Raphson load flow program and Differential Algorithm. The size and location of the sets of FACTs devices used has been calculated using DE algorithm [68].

DE is used to minimize real power loss and maximize voltage stability of the system. Multiple objectives like reactive power injections, transformer tap position changing after reactive power injection are optimized simultaneously as control variables [69]. Differential Evolution Particle Swarm Optimization (DEPSO) has been proposed to reduce power loss and improve voltage stability by optimal amount of reactive power dispatch. Optimum settings to control the reactive power variables like excitation of generators, shunt compensation from changing transformer tap to minimize loss without disturbing the voltage profile [70].

Differential Evolution Algorithm used to improve multiple objective function, minimization of fuel cost, system loadability and voltage profile improvement with shunt FACT control devices for security thus improving security constraint of network power flow. The IEEE standard 30 bus data taken as system parameter and the simulated result compared with the other technique to show the supremacy of the DE algorithm [71].

Active reactive power and voltage magnitude is considered to improve security margins of power system. With the help of DE algorithm optimal placement of FACT devices has been proposed considering the cost function and the losses of the system [72].DE algorithm method used to find optimal allocation of multiple FACT devices to minimize system losses and enhance system security. It is also used for reactive power planning estimation of system state and economic load dispatch [73] [74] [75].

Differential evolution technique is certainly among of the most modern optimization techniques though data mining and scheduling problem affects this technique. The optimization time and time of convergence is higher for this method than other conventional methods.

2.2.5. PARTICLE SWARM OPTIMIZATION ALGORITHM

In the middle of 1990s James Kennedy and Russell Everthurst proposed PSO technique [76].PSO is another stochastic optimization technique based on population and social behaviour of Fish schooling or Bird flocking [77]. Direct random search to find the optimal solution is an effective part of evolutionary technique PSO algorithm. Application of this technique shows promising results on optimum allocation of FACTS devices [78] [79] [80].

Particle Swarm Optimization (PSO) algorithm used to find optimal placement point of the distributed generation (DG) and find proper size of the DG. Effectiveness stress of the PSO algorithm performed on the standard IEEE 34 bus system. The result shows significant reduction of system losses and marginal improvement of voltage profile [81]. PSO technique used to find optimum allocation of the wind-based unit of DG [82].

PSO techniques used to optimize voltage profile and to resolve economic load dispatch problem. The value of the objective function used gradually reduce to obtain best result [83].

Optimal allocation and the proper size of STATCOM devices have been solved using PSO algorithm. The various types of PSO algorithm technique used to solve optimal allocation and sizing problem of STATCOM device performed on the standard 5 bus platform and the results are compared. The result shows supremacy of particle swarm optimization time varying acceleration coefficient (PSO-TVAC) over other PSO algorithm [84].

Deduction of system losses and optimal solution for the size and location of the FACT devices has been performed using PSO technique. The objective function considers the geographic location of the substation for the allocation of the DG. The results with or without considering DG has been compared to show the reduction of system losses and improvement in voltage profile [85].The optimal location and size of multiple STATCOM devices under variable load condition has been solved by PSO technique [86].

PSO technique is a popular technique but convergence problem persist in this technique. There is no separate theory of convergence for this techniques. To obtain better result change in input parameter and comparison of result with other PSO technique is necessary. Various type of PSO technique is dependent on coordination system.

Modern power system stability and reliability do not necessarily depend only on voltage profile improvement, to supply the ever growing load demand without violating system constraints is important now a days. So congestion management is also an important topic along with voltage profile optimization to maintain smooth operation of the system.

2.3. DIFFERENT CONGESTION IMPROVEMENT METHODS

Evolvement of electrical market from regulated to deregulate one to deduct monopoly cause for necessary restructure of the market with a clear auction strategy for the power market participants, thus reducing locational price spikes of congestion to maintain stability of the system. This process helps maintain market efficiency and equilibrium. Congestion management is scheduled by two methods –cost-free and non-cost-free methods. Cost free method is for transmission system operators who decide whether they are going to add phase shifter FACT devices in the line. This decision making does not involve generation and distribution companies. Non cost free measure include these companies [87].

General Price control scheme, network nodal pricing method have been taken into consideration to solve congestion management problem through evolutionary optimization algorithm, Genetic Algorithm. To solve zonal and nodal congestion and to maintain voltage stability [88].

2.3.1. NODAL PRICING METHOD

Locational Marginal Prices (LMP) has been calculated from the system constraints difference before and after usage. Sensitivity factors based generator cost for each generation have been calculated this way. Another two techniques for LMP calculation from Lagrange multipliers and transpose Jacobian matrix has been proposed [89].Locational Marginal Prices has been varied according to geographic locations and thus lead to the generation of heavy surplus energy which then sold to the contract right holders and given freedom to inject power at a certain point of another transmission network [90].

Author has compared different power dispatches by changing some performance indices by introducing new ones with the installation of capacitor devices in the radial distribution system. These methods applied to different BUS system and results difference has been studied to show consistency of the performed operation [91].

Optimal power balancing and congestion management method has been improved by a proposed novel control technique with the substitution of existing system indices by considering nodal prices of electrical power network. The result has been compared to show minimization of the congestion severity with use of the novel control technique [92].

Sequential network partition and identification of congestion contribution has been considered to develop a novel zonal marginal pricing method. Implementation of this method is tested on standard IEEE-39 bus system [93].

Fuel cost reduction and spot price evolution solved by BAT algorithm. The advantage of BAT algorithm over GA and other linear programming has been discussed to show the reduction in optimal spot price in existing electrical market. LMP consists of cost of transmission congestion and marginal cost of generation [94]**.**

2.3.2. UPLIFT COST

Uplift cost is referred to the system security cost and defined as the difference of un-constrained and constrained cost of supply [90] [94].

Energy uplift cost, reactive uplift cost, unscheduled availability payments are included in uplift cost. Different component of uplift cost are discussed in mathematical terms. The adjustment calculation for any unscheduled generation delay has been provided. If original dispatch is not sufficient and violates security margin then the dispatch is done [90].

Mathematically uplift cost can be written as follows in equation 1 and 2:

$$PPP = Capacity\ payment\ (CP) + SMP \qquad \ldots\ldots (1)$$

$$PSP = PPP + Uplift \qquad \ldots\ldots (2)$$

Here, SMP stands for the marginal unit bid price which is required to meet market period forecasted demands. PPP represents pool purchase price, this price is calculated before the trading day. PSP is the pool selling price. This price is paid to the generators by the buyers. CP is the payment done for any available system capacity. It does not depend on generation of the generators. CP rises at shortage periods and falls when the demand is less than system capacity. Uplift is the type of payment which is covered by transmission costs including system losses. Uplift can be explained by the difference between trading day cost and unconstrained schedule. At last Bid is the variable costs whose price are predetermined [95].

During unconstrained dispatch, if a private generator is ready for generation but not used by system, adjustment calculations are done for compensation in equation 3.

$$\text{Adjustment}_{\text{Constrained OFF}} = (\text{Capacity - Generation}) * (\text{PPP} - \text{Bid price}) \qquad \ldots\ldots. (3)$$

If original dispatch security constraints are violated re-dispatch are needed. In this process PPP is paid to the generators which are lower than bid price. The adjustment calculation then would be

$$\text{Adjustment}_{\text{Constrained ON}} = (\text{Generation}) * (\text{Bid Price - PPP}) \qquad \ldots\ldots.. (4)$$

Later adjustment costs are included in generator incomes

Generator incomes = (Capacity) * (PPP) + adjustment ……… (5)

During congestion the generators are not charged, thus this method is not sufficient for perfect calculation [96].

2.3.3. CONGESTION MANAGEMENT BASED ON ATC

Available transfer capacity is defined as the measure of the transferable extra power capacity of the transmission lines.

ATC = TTC – TRM – (ETC + CBM) ..……. (6)

TTC is the maximum power amount which after satisfying all constraints of security can be transferred over the network. TRM is the required margin for certain system uncertainties. ETC is the transfer commitments already present in the system and CBM is the margin reserved for the serving entities of load for the requirements of generation reliability.

Internal system operators (ISO) tracks ATC of the congested lines. Then it is put into open access same-time information system (OASIS) website which is controlled by ISO. Real power transmission congestion factor (PTCDE), optimal power flow method, line outage distribution factor (LODF) and continuation method are considered while calculating ATC [97].

Optimal power flow method and FACTS device modelling are determined to propose a method to calculate ATC. After adding Sen Transformer and UPFC device, the result shows significant increase in ATC [98].

Particle Swarm Optimization and Genetic Algorithm technique are used for optimization. Available Transfer Capacity (ATC) has been boosted using combination of the devices-Thyristor Control Series Capacitor (TCSC), Unified Power Flow Controller (UPFC) and Static Var Compensator (SVC), to get better result. Standard IEEE 30-bus and IEEE-118 has been used as a platform. The cost function of the paper also includes installation cost of these devices. Some constraints like the placement of FACTS devices are presumed in the paper. Mainly the work focuses on increasing the flexibility of loaded transmission lines [99].

The important of Sen Transformers in bidirectional flow of active and reactive power to control congestion of system has been discussed. A comparison study between Sen Transformer and FACT devices is done to show economical operation of Sen Transformers [100].

2.3.4. CONGESTION MANAGEMENT BASED ON MAXIMIZATION OF TRANSFER CAPABILITY AND TTC

Thyristor controlled series capacitor is used because of this device's capability to control power flow of the network. TCSC has been presented as a variable reactance in the capacitor mode to maximize transfer capability of the network. [101].

Thyristor controlled phase controlled regulator (TCPCR) and thyristor controlled series compensator (TCSC) is used in this paper individually or in combination. The results of uses are compared. The devices placement and result in increase of loadability is determined using Mixed Integer Linear Programming (MILP). The objective function is variable with the number of facts devices used individually. System loadability is used in this paper to determine optimum total transfer capability (TTC) of the system. As long as the loadability is increased the number of individual facts devices increased upon the result. Here the authors have concluded that the maximum loadability combination of three TCPAR and one TCSC or two TCPAR and one TCSC device can be used to obtain high loadability as per demand of the different systems [102].

Voltage sourced converter (VSC) based FACT devices like Unified Power Flow Controller (UPFC) and the interline power flow controller (IPFC) increase system loadability and thus maximize the power transfer capacity [103]. Impacts of FACT devices, such as thyristor controlled switch capacitor and static Var compensator, on minimizing system by improving total transfer capacity have been considered. Optimal power flow problem are used to solve numerical examples of TTC and TTC improvement. TCSC and SVC devices improve power angle and voltage stability of transmission line [104].

2.3.5. CONGESTION MANAGEMENT USING FACTS DEVICES IN THE SYSTEM

Classification of the FACT devices has been made in to three categories-series, shunt and series-shunt controllers**.** Thyristor controlled series capacitor (TCSC), static synchronous series capacitor(SSSC) and thyristor controlled phase angle regulator are the series FACTS devices which controls over loading of the line and significantly increased transfer capability of transmission line. Static VAR Compensator (SVC) and astatic synchronous compensator are the shunt FACTS devices which controls reactive power flows of the line to help compensate line voltage. Series shunt compensator devices like UPFC controls line over loading and reactive power flow both [105].

Variant types of security measures have been taken into consideration to solve the optimal location problem of the FACTs devices through the evolutionary optimization technique. Difference between FACTs devices operating under contingency condition and normal condition has been discussed in this paper. The proposed method has been implemented on IEEE 57 BUS system [106].

Maximum time period of operation of FACTs devices has been proposed by considering losses of the system. Optimal placement solution provided that has the coverage rate dependent upon the operation time of the FACTs devices [107].

Congestion management can be performed using different combination of FACTs devices and optimization methods. FACTs devices enhance line power flow thus enhancing power transfer capability to reduce congestion of the system keeping voltage deviation within a certain permissible limit and regard security constraints. Security constraints can also be done using FACTs devices [108].

Optimal location of the FACTs devices STATCOM and randomly located IPFC device’s capability to elevate congestion problem with the help of Evolutionary Algorithm technique have been proposed. An artificial intelligence technique to find security constraints and optimal system parameter has been developed to ensure voltage stability and reduce congestion [109].

Two separate methods of sensitivity have been suggested to optimally place TCSC devices in the power system. Reduction of VAR losses and real power index of the system have been the main aim of the objective function. The result has been shown considering TCSC cost and sensitivity factor based on 57 BUS system [110].

Sequential quadratic programming (SQP) used to install FACTs devices in the transmission network to evaluate static security margin and elevate congestion. An evolutionary optimization technique has been used to solve the problem [111].

The improvement in line transfer capacity with the use of FACTs devices has been considered to propose a performance index of the system to reduce total VAR loss of the transmission system [112].

Operating cost, transient stability margin and voltage have been taken as principal operator in the objective function to solve congestion problem of the system. The size and optimal location of the FACTs devices has been calculated by the priority of locational marginal prices (LMP) listing [113].

IEEE 14-bus has been used here as a standard system and FACTS devices has been used as an Independent System Operator (ISO). Transmission Congestion problem beyond a certain point threatens the security. ISO decides on solution of congestion problem. Two standard market model of bilateral contracts and multilayer contracts has been studied here. Different combination of FACTS devices has been used to solve congestion problem. SVC and TCSC FACTS models are used as variable reactance to answer congestion problem. Also, the loss variable for adapted market model has been considered in the object function. Trial and error method is used to decide optimal location of FACTS devices. FACTS device optimal placement has been decided over the improvement of the objective function [114].

Customized security constrained optimal power flow (SCOPF) program are used here without selecting a global minima. FACTS devices are used here as control variable constrains in SCOPF formulation. One TCSC, four TCPS and one UPFC devices are used in this paper to answer loadability problem and to minimize congestion. Penalty function also has been considered by the author in the objective function. Linear Programming Method also has been used in this paper to locate individually one TCSC, one UPFC and four TCPS device. Total generation cost and total usage cost of the devices are also taken into consideration. Here global optimum variable is used in linear programming method to avoid considered usage of local minima [115].

In this paper a mixed integer non-linear programming (MINLP) based model is used to determine the optimal placement of FACTS devices. The standard system used here is IEEE 14-bus system. The problem of congestion is tackled by locating different FACTS devices in the system to get improved results. Thyristor Controlled Phase Shifter (TCPS), TCSC and SVC devices are used individually to solve congestion problem. The active and reactive power costs minimization and the role of FACTS devices in this process have been studied in this paper. The number of FACTS devices are increased as long as the system loadability increases. This paper show effective cost minimization by optimally placing TCSC and TCPAR devices in the system [116].

An alternative way to relieve the highly loaded lines by reducing the power flows with the help of FACT devices increases the loadability, minimizes the loss, improves the stability of the network and lower the production cost of power networks. The optimal placement of FACT devices are determined by the minimization of active and reactive power losses with reference to the performance of real power index of the system. More commonly used FACT devices like TCSC relieve the highly loaded line with power flow control. In this paper three sensitivity based methods are proposed [117].

There is an alternative way to minimize system loss, stability improvement and reduction of cost of production and significantly reduce power flows in highly loaded lines employing FACT devices. Recent researches and developments of power electronics apparatus have made FACT devices very cost effective. This paper proposes a sensitivity based approach to find optimal placement of FACT devices. Real power loss sensitivity factor calculation and reduction of the real power loss have been considered to find replacement of UPFC device [118].

A smart and efficient way to change network parameters of power system is FACT devices. These devices help running optimal operation of the power system by controlling the power flow, circuit impedance and voltage angle effectively. Optimal power flow problem has been solved in this paper by Newton’s method. Static Synchronous Compensator (STATCOM) is a FACT device which controls transmission voltage by shunt compensation of reactive power. An inverter, a coupling transformer and DC capacitor are main components of STATCOM device. STATCOM effectively exchanges reactive power from AC system [119].

2.3.6. CONGESTION MANAGEMENT IN HYBRID MARKET

Integration of wind firm as renewable energy sources provides uncertainties in the line thus increasing congestion. A model has been proposed to relieve congestion of hydro thermal power plant [120].

Hybrid electricity market congestion management by proposed Bender's decomposition (BD) method has been discussed. Although BD method shows better convergence criteria but its impact over congestion cost is not discussed [121].

Constant impedance, current, power have been considered to obtain congestion cost and reduction of congestion by generator rescheduling with three bid block structures has been discussed. A comparison study of reduction of congestion cost between PQ model and proposed model has been done to point out economical advantage of the later [122].

In the previous section different control techniques and devices to maintain stable voltage profile and congestion reduction has been discussed. These techniques have been implemented in the system after optimization with different optimization techniques. Different optimization technique to optimize voltage stability margin and congestion reduction has been discussed in the next sections.

2.4. DIFFERENT OPTIMIZATION TECHNIQUES USED FOR CONGESTION MANAGEMENT

2.4.1. GAME THEORY METHOD

Benefits of cooperation amongst operators of transmission system are necessary for congestion management of power grid. To introduce coordination an intuitive method using generalized Nash equilibrium model has been developed using transmission network constraints. To reduce line overflows re-dispatch of cost minimized objective function using different transmission system operator has been modelled [123].

The network congestion game based on power networks to provide finite number of solutions has been solved by Nash equilibrium method by adapting dynamic pricing strategy to control peak hour power demand thus achieving controllability of power network and reducing congestion of electric grid. An efficient and scalable management of power outage has been proposed. A scheme that proposes capacity to manage their power demand to minimize peak hours demand curve has been evaluated [124].

2.4.2. BACTERIAL FORAGING ALGORITHM

Darwin’s ‘survival for the fittest’ concept has been implemented by the author in the bacterial foraging algorithm by observing *Escherichia coli* bacteria and their behaviour. Their behaviour has been categorized into four parts namely swarming, chemo-taxis, reproduction, and elimination-dispersal, dispersed by their tendency to survive in human intestine. This method has been used to solve congestion problem with the help of another method called Nelder-Mead. A comparative study has been done against GA and Swarm’s algorithm to show the relevancy of this method [125].

Optimal reschedule of active power generation for congestion management is been done by a new approach called Fuzzy Adaptive Bacterial Foraging (FABF). Here the generator placement on congestion is decided by evaluating generator’s sensitivity factor. A last a comparative study is done by the author amongst bacterial foraging and new proposed method to show its relevancy [126].

2.4.3. EVOLUTIONARY STRATEGIES

The most undisturbed state of transmission lines has been considered by evaluating every possibilities of transmission network to avoid multiple congestion condition. Corrective generator switching by mixed integer linear programming has been decided to construct a Congestion Management System (CMS) to alleviate congestion [127].

A hybrid model for congestion management has been proposed. An optimal algorithm is used to decide the specified amount of reactive and real power. Then for finding the optimal transaction strategy fuzzy logic has been used [128].

Minimal cost function which has been decided for evaluating relative electrical distance (RED) concept and incremental fuel cost has been used for rescheduling of generators to solve congestion problem [129].

Available Transfer Capacity (ATC) estimation has been calculated by newly proposed hybrid mutation PSO (HMPSO) algorithm. To enhance capacity SVC and TCSC devices has been used [130].

Hybrid Immune Algorithm techniques has been used to find the optimal location of UPFC devices in the system to regulate better power flow condition. Minimum cost function which is decide from active and reactive power production, has been used for congestion management [131].

Fuzzy logic concept has been used to find optimal location of SVC, TCSC devices to reduce congestion of system. Other evolutionary optimization techniques has been compared with fuzzy logic to improve its efficiency [132].

Predictability concept's importance and its measure has been used as an index to warn power operators for system redundancy. STATCOM and SSSC devices have been used to predict system condition [133].

2.4.4. GENETIC ALGORITHM

Insufficient capacity to supply all power demand rises congestion in transmission lines. As congestion threatens security of the power system, Independent System Operator (ISO) rises electricity price which decreases system efficiency. For proper congestion management it is necessary for the ISO to decide active and reactive power re-scheduling generator scheduling. Real coded genetic algorithm (RCGA) technique and particle swarm optimization used to propose active and reactive power flow re-schedule by considering Transmission congestion distribution factors (TCDFs). This method is useful for congestion management at a lower cost. The superiority of PSO algorithm over RCGA method has also been discussed [134].

The ability of the TCSC device to control line flow directly, improves transmission operation. A novel genetic algorithm technique has been proposed to find the optimal size and location of the device. The test results compared with or without using FACTS device on an IEEE 14 bus system [135].

Optimal choice of FACTS devices between TCSC and SVC devices, their optimal allocation and size problem has been solved using multi-objective genetic algorithm. The result shows significant reduction in line losses and improvement in voltage stability. The allocation of FACTS devices while solved using single objective functions, changes while optimizing multi-objective function [136].

In a pool market model UPFC device has been installed to solve congestion of transmission lines. The modelling of UPFC device and its parameter using genetic algorithm also have been proposed. At last genetic algorithm used to find optimal location of UPFC device [137].

So far different devices and optimization techniques for voltage profile optimization and congestion reduction have been discussed, but facts device modelling by optimization of different facts device parameter to control system parameters is also important for proper operation of the system, thus a few facts device modelling techniques has been discussed in the next section.

2.4.5. VARIOUS OTHER ALGORITHM TECHNIQUES FOR CONGESTION ISSUES

2.4.5.1. TECHNIQUES TO DETERMINE PRICE OF CONGESTION

Distribution Congestion Price (DCP) is a market mechanism type algorithm to reduce congestion in distribution system. Operators of distribution system and aggregators interact to schedule the responses of electric demand. Load pool spot market structure has been used for calculating DCP. DCP has been adhered from locational marginal pricing concept which gives us the extra cost from congestion, losses and marginal cost from each node of the network [138]. Transmission congestion cost management has been studied and two ways are proposed to manage cost management-nodal pricing and pool modelling. First model is analysed in nodal pricing and tested on a large scale system and the second is a cost allocation approach. The first model is inspired by a free market competition strategy of an electricity market and this full model is inspired by the special characterization of the power networks. A comparison has been drawn between these two methods. The similarity between the two models being the congestion cost is paid by the customer [139].

2.4.5.2. OPTIMIZATION TECHNIQUES USED FOR FACTS PLACEMENT

Optimization problem formulation using UPFC and SVC has been solved by sequential quadratic programming. This method has two convergence criteria and the quadratic sub-problem has been solved by four different methods. The results show a clear effect on transmission pricing and cost of congestion [140].

Fuel cost and penalty for cost of emission has been considered to optimally locate TCSC device in the transmission network. The objective function focuses on decreasing the fuel and emission penalty cost of system generators. Neldor-Nead and bacterial forging method is implied to minimize the objective function. These algorithms are stochastic optimization algorithm covering a wide search region with a low convergence speed [141].

Disparity line utilization factor (DLUF) has been used to solve congestion problem by proper allocation of interline power flow controller (IPFC) devices in a transmission line. These method solves the difference between percentages MVA utilization of lines connected to the same bus. The IPFC device is allocated when the line have maximum DLUF. This technique also reduces active power loss, thus, minimizing total voltage deviation of the system. Number of IPFC device to be allocated with the line is evaluated using Differential Evolution (DE) [142].

The regulation problem of optimal power flow of transmission line has been solved using predictor corrector interior point non-linear programming algorithm. This technique can be effectively used to solve congestion problem of the network. Linear point algorithm solves optimal power flow problem using by Newton approach [143].

Cultural algorithm has been performed to find the optimal number and allocation of STATCOM and SSSC in the network. STATCOM is used as a parallel and SSSC as a series FACTS device. Mean and variance nodal prices of the power system have been taken into consideration to solve alleviated congestion problem of the network. The test results on the system show SSSC is superior to STATCOM in solving congestion problems [144].

2.4.5.3. OTHER METHODS USED FOR OPTIMIZATION OF CONGESTION

Three different type of functions like total transfer capability (TTC), capacity benefit margin (CBM), transmission reliability margin (TRM) has been considered for the calculation of available transfer capacity (ATC). A probabilistic method which proposes allocation of CBM and the rules and procedure of allocation has been used to derive the values of TRA. TRM and CBM are directly proportional to the reliability of the system. Thus transfer based security constraint OPF has been shown more advantageous than conventional security constraint OPF (SCOPF). Monte Caro simulation method is used to calculate the basic function of DTC. This method is a probabilistic method which considers single area generation reliability calculation for the calculation of CBM [145].

Performance index of the transmission line has been calculated with Newton Raphson load flow methods and radial basis function neural network to ensure the system safety and the contingency situation. A proposal is given for contingency selection and ranking with bounding criteria to analyse and reduce the number of buses. Performance parameter indexes of voltage and power has been used to calculate the condition of the contingency by Radial basis function method [146].

After through theoretical analysis Differential Evolution (DE) and Cultural Algorithm (CA) technique is selected for optimization of problem function. DE technique has several advantages like it requires a very fewer parameter, random search technique used here is convenient for better result. Various dimensional and complex problem of optimization can be solved easily by this technique. Convergence rate is better compared to other techniques.

CA techniques also have a few advantages of its own. Multi objecting problem solving is possible with this method. Mining of data and scheduling is less compared to the other techniques. Convergence rate is also faster and time of optimization is lower than other techniques.

2.5. FACTS DEVICE MODELLING

Power flow can be controlled by manipulating voltage angle, magnitude and system reactance. Different FACT devices have different control parameters, different design of circuits. From the overall research papers and books there are only two types of FACT devices [88] series and shunt. Recent studies has developed another type of FACTS devices like UPFC, which has both series and shunt compensation.

2.5.1. UNIFIED POWER FLOW CONTROLLER MODELING:

A comprehensive mathematical model of unified power flow controller (UPFC) considering steady state Eigen values and transient stability condition has been proposed. The optimal parameter and location and the strategy of controlling UPFC devices is studied. Electromagnetic transient program (ENTP) is used to analyse time domain simulation to verify the accuracy of the developed model. The power system operating condition is symmetrical and balanced three-phase condition has been assumed [147].UPFC has dynamic controlled mechanism to control transmission line parameters like phase angle, voltage and line impedance. Shunt and series control of UPFC device has been discussed and the mathematical model has been analysed and tested on ENTP platform [148].

UPFC controls transmitted active (P) and reactive (Q) power both simultaneously. UPFC device has been described as P and Q controller and compared with thyristor controlled series capacitor (TCSC) and thyristor controlled phase angle regulator (TCPAR). The performance of the UPFC device under different condition of the system has also been studied [149].The versatility of the UPFC device for controlling the power flow of the transmission system is unparalleled. The protection and control of the UPFC device has been discussed. The operation of the device under various system condition. Various shunt techniques like shunt inverter control and series inverter control has also been studied [150].

Modelling technique of UPFC device using ENTP simulation technique has been proposed. UPFC device have two voltage source inverter connected through a DC-capacitor bank and every inverter is coupled with a transformer. The two voltage source inverters are STATCOM and SSSC devices. STATCOM can inject variable magnitude sinusoidal current and SSSC inject variable magnitude sinusoidal voltage to the transmission line. The real power is exchanged between the inverters through capacitor bank [151].

UPFC can increase the magnitude of power transfer between large power system models. The control technique for the UPFC shunt inverter to control injected current limits, power exchanges between inverters, limit of voltage injection for the series inverter has been discussed. Dynamic control ranges and system critical system parameters need to be accessed during modelling [152].

2.5.2. STATCOM DEVICE MODELLING

A circuit model has been proposed to add static compensator (STATCOM) with power system. STATCOM absorbs and delvers radioactive power by using variable frequency switching method. The working principle, simulation result of this device has been analysed under various system conditions like transient and steady state. A PSpice model of STATCOM model has been demonstrated. State space equation used to design the shunt connected variable frequency switching devices. An operator has been introduced in the mathematical model has been introduced to control the operation state of the device. Voltage ripple correction technique has also been considered in the mathematical model and the final result shows a better and faster simulation result [153].

Most of the studies related to power system like load flow studies and others are done in frequency domain. Power electronic devices like FACTS devices can be modelled by state space equation in time domain. To apply this model in frequency domain alternative measures need to be taken. Time domain model of STATCOM has been used to eliminate switching ripples of high frequency. A novel average neutral model of STATCOM has been proposed by extending existing models which connects between time and frequency domain. Radial Basis Function (RBF) has been studied as a part of neural networks and gamma model has been developed. The models are compared with the practical system to show advantages and implemented on IEEE 14 BUS system [154]. Power flow analysis has been made to evaluate steady state operating conditions of proposed STATCOM model. Power flow control by STATCOM, active and reactive power control has been studied. The proposed time domain model of STATCOM considers the controller losses for better result [155].

Time domain STATCOM modelling is done using state-space equation. As time-domain modelling of STATCOM cannot be applied for power system analysis. The proposed model connects time and frequency domain. Dynamic neural network (DNN) and multi layered perception (MLP), these two neural network identifier model have been performed and the result is compared with average STATCOM model to show its advantages [156].

CONCLUSION

In this chapter previous works related to the topic has been briefly discussed. After through literature review it can be stated that a combination work of voltage profile improvement and congestion management of the transmission system with STATCOM, UPFC and capacitor has not been attempted before. Therefore an attempt has been made in this WORK to determine proper size of the FACTS devices mentioned previously and capacitors to be placed in the transmission system to reduce congestion and improve voltage profile of the power system.

Chapter 3: *Overview of the Cultural Algorithm, Differential Evolution, Load Flow & UPFC operation*

3.1 CULTURAL ALGORITHM

For many years researchers have inducted natural evolvement process to solve computational problems. Cultural algorithm is adopted from the natural behaviour of the societies towards the environment adaption at a higher rate that outpace their biological evolution based on inheritance of genetics. The objective of the cultural algorithm is to improve the processing of information by improving the convergence by evolution technique. There are three major components of cultural algorithm-population space, belief space and communication protocol. The two prime levels of cultural algorithm, population level where distinctive selection of the individuals are done by evolutionary search technique and their objective functions are calculated to solve the optimization problem and the second level- the cultural level the knowledge acquired by the population is stored and these information is used to upgrade the current generation of population. The last part, communication protocol defines the exchange of knowledge between population space and belief space, gathers experience from these exchanges.

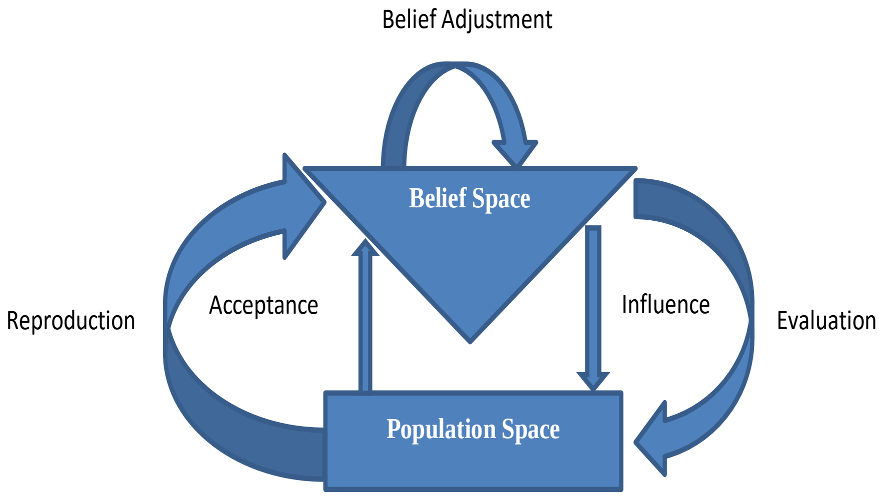


Figure 7: Moderate framework of Cultural Algorithm [93]

The knowledge existing in the population space after a due selection process is accepted and then passed to belief space. These knowledge's influence next generation population. The experienced population are kept in separate categories called mappa and are used for forecasting future experiences. These mappas are merged and specialized according to the need and thus groups of mappas are formed.

3.1.1 SELECTION

Here the individuals of population are selected according to their behaviour or traits and the values and experiences of mappa are modified. In this process a certain individual in a population can be lost or added. In the optimization problem set of individuals in the population space is selected and each individual provides solution and experience for the selected problem.

3.1.2 BELIEF SPACE

The best among the individuals are selected and kept in the belief space. The numbers of best individuals to be selected are based on the problem variation and the mappas of these individuals in belief space are necessary and are sometimes merged with individual mappas if certain conditions are fulfilled. If the conditions are not met then they are not merged and are kept in belief space.

3.1.3 SELECTION OPERATION

When the population individuals are merged with mappa their performance are also combined with them. If the mappa performance is less than acceptable limit then the mappa is discarded from belief space. The discarded mappa can be placed in the population then no other belief space individuals of same group are allowed in the population. But if the mappa is added to the population group then belief space individual can appear again in future in the population.

Now the current belief space individuals can be used to modify the performance and the behaviour of population set. After that the current population is used as a parent to produce next generation population through various application operators to modify their behaviour or performance. The process of merging and discarding with combined acceptance function determines the selection of belief space individuals.

CULTURAL ALGORITHM FLOW-CHART

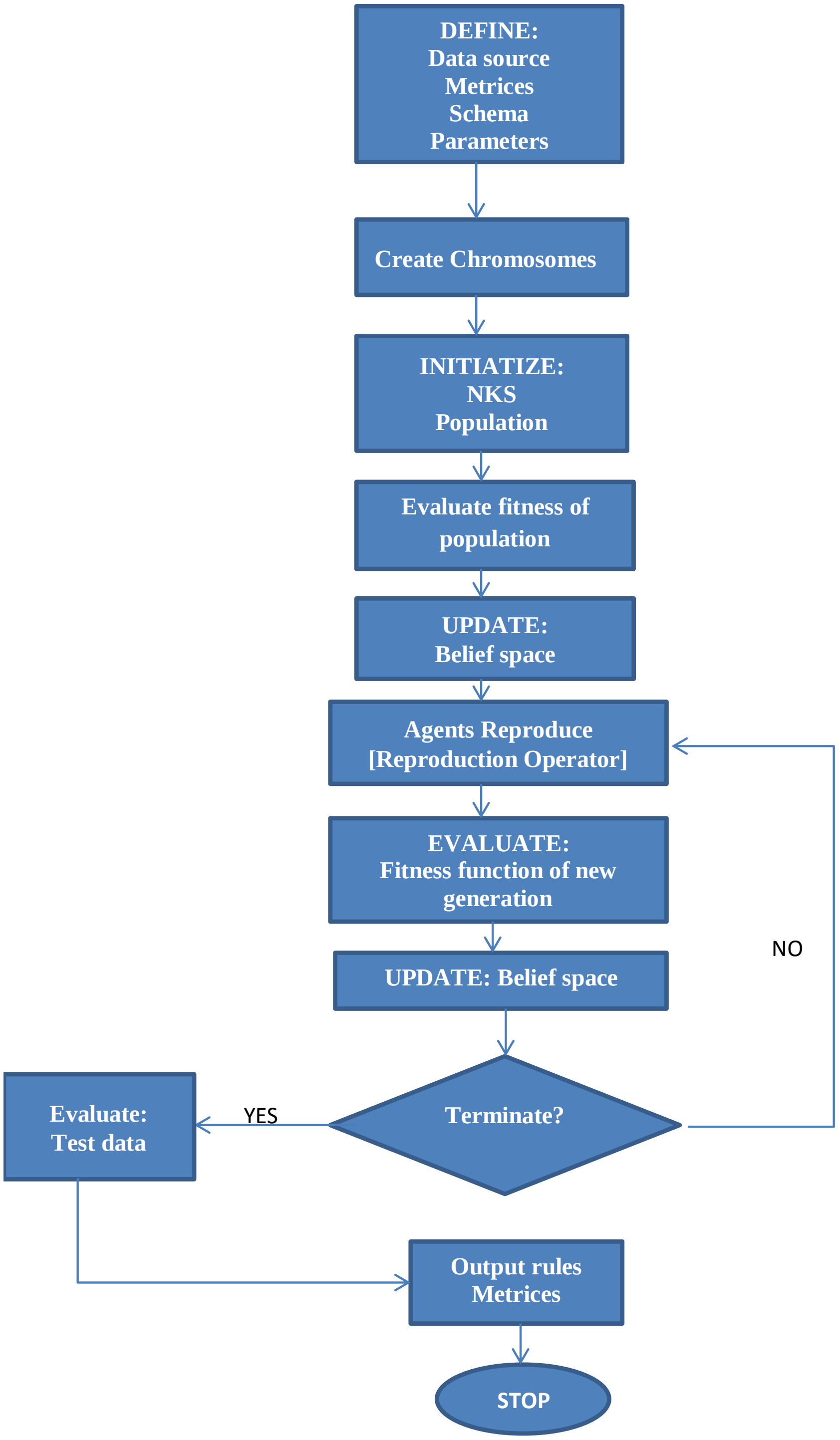


Figure 8: Normal operation of Cultural Algorithm [134]

3.2. Differential Evolution (DE) Theory

One of the important evolutionary algorithm techniques is stochastic search based technique differential evolution (DE). This algorithm was developed from Darwin's theory of human evolution. This technique has better convergence rate with the use of very few control variables. In the year 1995 Storn and Price introduced this technique. At the start of optimization this technique generates randomly generated population within the entire search space of dimension D. Among this population of best individual, population is chosen. On iteration the individual gets replaced by a new better individual. Thus through DE technique the population moves towards global optimum solution after thorough repetition of mutation, crossover and selection cycle [157] [158].

3.2.1. STEPS OF DE ALGORITHM:

3.2.2. INITIALIZATION:

Let, the initial generated population has N number of individual and each individual represents a vector X_i. This population will be varied for a number of generations G then the i_{th} population individual can be termed as $X_{i,}$ G. The lower and upper boundaries of the population space are X_L and X_U respectively. So after initialization, the initial population produces solution and the j_{th} component (j=1, 2…, D) of individual i (i=1, 2… N) are as follows:

$$x_{j,i}^{zero} = x_{j,L} + rand * (x_{j,U} - x_{j,L}) \qquad \text{……….} (7)$$

Where, rand is a randomly chosen number between 0 and 1 [158].

3.2.3. MUTATION:

Here, DE generates a new parameter vector by adding the difference of two population vector to a third vector. This operation is called mutation. Detailed discussion of the procedures are as follows:

After initializing the population, DE produces a mutant vector $m_{i,j}$ for every individual , $I_{i,j}$ (target vector) of the population set . Now by mutation strategy at j_{th} generation of target vector, $I_{i,j}$, produces mutant vector $M_{i,j.}$ A few mutation strategies are given below [159]:

- DE/rand/1: $m_{i,j} = I_{i,j}^{r1} + F*(I_j^{r2} - I_j^{r3})$
- DE/current-2-rand/1: $m_{i,j} = M_j^{r1} + K*(I_j^{r1} - I_j^{r3}) + F*(I_j^{r4} - I_j^{r5})$
- DE/best/2: $m_{i,j} = I_j^{best} + F*(I_j^{r1} - I_j^{r2}) + F*(I_j^{r3} - I_j^{r4})$
- DE/rand 2 best/1: $m_{i,j} = I_j^{r1} + K*(I_j^{best} - I_j^{r3}) + F*(I_j^{r4} - I_j^{r5})$

In the above equation,

r1, r2, r3, r4, r5 are randomly chosen values within population range which are generated from mutant vectors.

F is the control parameter (positive) used to scale difference vector

I_j^{best} is the fitness of best individual of the population

K is a randomly chosen value between 0 and 1

Fig. 7 shows the gradual decrease the area of operation with iteration number and finally produces the population with better result.

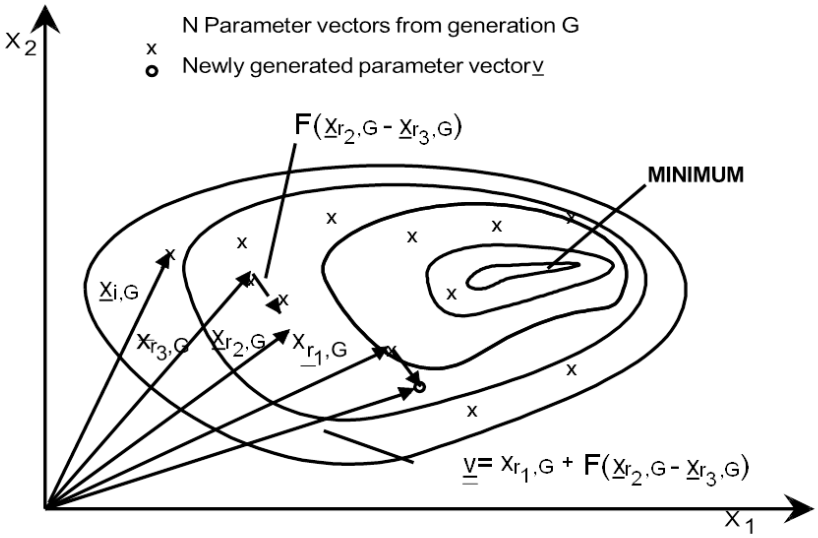


Figure 9: Two dimensional example of an objective function showing its contour lines [159]

3.2.4 CROSSOVER OPERATION

Crossover operation is done to increase the diversity of the parameter vectors to generate a trial vector $t_{i,j}=t_{i,1},t_{i,2},\ldots\ldots.t_{i,D.}$

$$t_{i,j}=\{\begin{matrix} m_{i,j} \\ I_{i,j} \end{matrix} \text{ if } \begin{matrix} t_{i,j} < B_i \\ t_{i,j} > C_i \end{matrix} \qquad \ldots\ldots\ldots. (8)$$

Where,

CR is the crossover ratio

i=1,2,3…...N

j=1,2,3,…..D

If the trial vector $t_{i,j}$ violates boundary condition then a reset is done

$$t_{i,j}=\{\begin{matrix} B_i+rand(0,1)*(C_i-B_i) \\ C_i-rand(0,1)*(C_i-B_i) \end{matrix} \text{ if } \begin{matrix} rand_j(0,1)<CR \\ Otherwise \end{matrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where,

i=1,2,3…..,N

j=,2,3,…….,D

B represents the lower limit of the population in search space

C represents the upper limit of the population in search space

3.2.5 SELECTION OPERATION:

It is done to select better target vector I_i and trial vector $t_{i,j}$ to generate new set of population.

$$I_{i,j}=\{\begin{matrix} t_{i,j} \\ I_{i,j} \end{matrix} \text{ if } \begin{matrix} f(t_{i,j})<f(I_{i,j}) \\ otherwise \end{matrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where,

i=1,2,3…..,N

j=1,2,3,…….,D.

DIFFERENTIAL EVOLUTION FLOW CHART

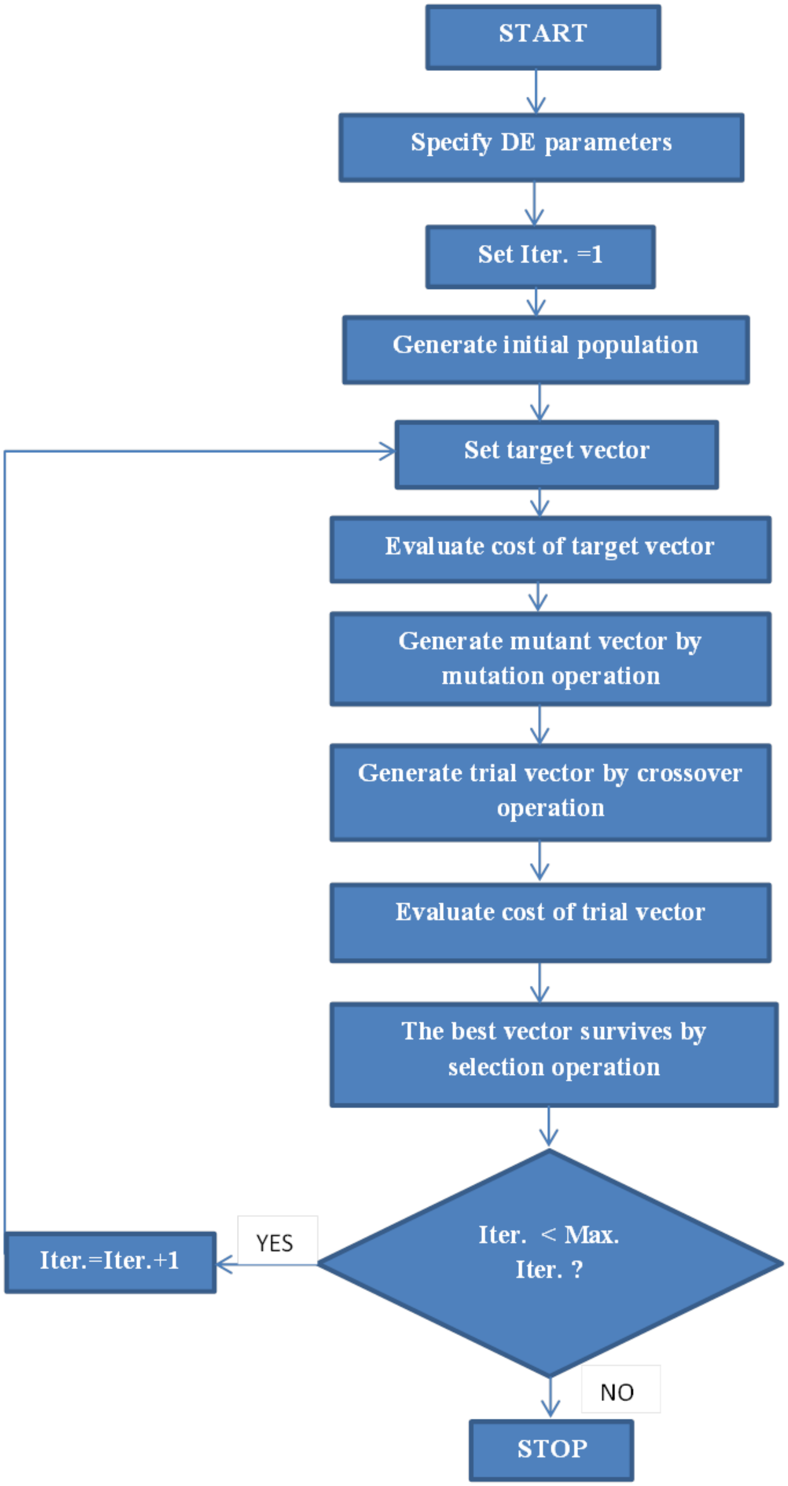


Figure 10: Flowchart of normal DE Operation [158]

3.3 LOAD FLOW

There are four types of buses in the power system-slack bus, load bus, generator bus and voltage control bus.

- **SLACK BUS**

  In these types of buses the real and reactive power are not specified but voltage magnitude and phase angle are specified. In the system there are only one slack bus. In the load flow study the slack bus is numbered as 1.

- **LOAD BUS**

Load buses are also known as PQ bus as real power P and reactive power Q are specified in these buses. From load forecasting load real power (PD) and load reactive power (QD) are known and the generated active power (PG) and generated reactive power (QG) are known. Voltage magnitude and angle are also unknown. Almost 80% of the total buses are PQ buses.

- **GENERATOR BUS**

These buses are also known as PV buses as generated real power PG and voltage magnitude V are specified for this bus and the load active power is specified from load forecasting. The reactive power (Q) and voltage angle (δ) are unknown. 10% of the total buses of the system are PV buses.

- **VOLTAGE CONTROLLED BUS**

Voltage controlled bus and PV controlled bus are almost similar types of buses. Voltage controlled bus have slight physical and calculative difference. This bus can control voltage with the use of tap adjustable transformer or static VAR compensator in places of generator. For these buses real power (P) is equal to negatively related to load real power (PD). Also reactive power (Q) is negatively related to load reactive power (QD). So voltage magnitude is specified for these buses and the voltage angle is unknown.

3.3.1 LOAD FLOW PROBLEM

Let us assume a source is supplying complex power to the ith bus of the system. The system is

$$G_i = Pi + jQ_i = V_i I_i^*, i = 1, 2, ..., n \qquad \text{……….} (11)$$

Where,

G_i represents the power of the bus

P_i represents the real power of the ith bus

I_i represents the current of the ith bus

Q_i represents the reactive power of the ith bus

V_i represents the voltage of the ith bus

Now, from the above equation we only take the complex conjugate I_i in place of I_i^* in equation 12.

$$Pi - jQ_i = V^*{}_i I_{i,}\, i = 1, 2, ..., n \qquad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

From network model formulation of the system we know, y is the admittance of the bus. So the total admittance of the buses are represented in a matrix $Y_{i,j,}$ the admittance of the ith and jth bus connected together, then V_j is the voltage of the jth bus. Then $I_{i\ can}$ be represented as in equation 13,

$$I_i = (\textstyle\sum_{j=1}^{n}(Y_{ij}Vj)) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Then substituting this equation 2 in 1 we have in equation 14,

$$Pi - jQ_i = V^*{}_i(\textstyle\sum_{j=1}^{n}(Y_{ij}Vj))_{,}\, i = 1, 2, ..., n \qquad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Now if we equate the real and imaginary part of the above equation in equation 15 and 16

$$P_i - jQ_i = \mathrm{Re}\, al(V^*{}_i(\textstyle\sum_{k=1}^{n}(Y_{ik}V_k))), i = 1, 2, ..., n \qquad \ldots\ldots\ldots\ldots (15)$$

$$Q_i(\mathrm{Re}\, activepower) = -\mathrm{Im}\, aginary(V^*{}_i(\textstyle\sum_{k=1}^{n}(Y_{ik}V_k)) \qquad \ldots\ldots\ldots\ldots (16)$$

Let,

$$V_i = |V_i|^{e^{j\delta_i}}, V_k = |V_k|^{e^{j\delta_k}}$$

$$Y_{ik} = |Y_{ik}|\, e^{j\theta_{ik}}$$

Then equation 10 and 11 respectively becomes equation 17 and 18

$$P_i(\mathrm{Re}\, activepower) = |V_i| \textstyle\sum_{k=1}^{n} |V_k||Y_{ik}| \cos(\theta_{ik} + \delta_k - \delta_i), i = 1, 2, ..., n \qquad \ldots. (17)$$

$$Q_i(\mathrm{Re}\, activePower) = -|V_i| \textstyle\sum_{k=1}^{n} |V_k||Y_{ik}| \cos(\theta_k + \delta_k + \delta i) i = 1, 2, ..., n \qquad \ldots. (18)$$

These two equation are known as power flow equations. So from these equations we can see there are four variables, $|V_i|$, $|\delta_i|$,P_i ,Q_i. If we keep all the variables on the same side the equations 19 would be f(x, y) =0 ……………………………………………… (19)

f(2n*1) vector function

x=dependent or state vector of 2n*1 dimension.

y= independent variable vector of dimension 2n*1.

Independent variables stored in x can manipulate a few state variables. So they are called control variables. Independent vector are called fixed parameters and they control independent variables which can be stored in two partitions stored in x in equation 20.

$$x = [\begin{matrix} u \\ p \end{matrix}] \quad \text{………………………………… (20)}$$

All state and control variables must remain within practical limit. The limits are described below:

1. Inequality constraints must be satisfied by voltage magnitude $|V_i|$ in equation 21.

   $$|V_i|_{\min} \le |V_i| \le |V_i|_{\max} \quad \text{……………………………… (21)}$$

2. Particular state variable must satisfy the following condition in equation 22

   $$|\delta_i - \delta_k| \le |\delta_i - \delta_k|_{\max} \quad \text{………………………………… (22)}$$

Maximum permissible angle of power between *i* and *j* transmission lines are imposed by stability consideration.

3. The physical limitations of active and reactive power sources are as follows in equation 23 and 24:

   $$P_{Gi,\min} \le P_{Gi} \le P_{Gi,\max} \quad \text{……………………….. (23)}$$

   $$Q_{Gi,\min} \le Q_{Gi} \le Q_{Gi,\max} \quad \text{……………………… (24)}$$

   Thus we say that the general real and active power would be

   $$\sum_i P_{Gi} = \sum_i (P_{Di}) + P_L \quad \text{……………………….. (25)}$$

   $$\sum_i Q_{Gi} = \sum_i (Q_{Di}) + Q_L \quad \text{………………………}$$

   (26)

   Where P_L and Q_L are active and reactive power losses.

4. For UPFC device, both voltage deviation and loss are considered for fitness calculation according to the relation,

*Fitness value= 0.5*loss + 0.5* voltage deviation* ………. (27)

Total voltage deviation of the system is calculated by the formula in eq. 28

Voltage deviation=sum (abs (ones (30, 1)-V)); …………… (28)

3.4. UPFC Operation

For UPFC modelling, the basic procedure for fitness calculation and the various techniques of DE are followed. However, utilization of UPFC device helps to reduce flow of power of heavy loads of energy transmission lines. The UPFC devices are energy flow controllers capable of controlling active (P) and reactive power (Q) to the bus lines [160]. The injected power (both active and reactive) is supplied to the two connected buses i and j following the relations given below as shown in Fig no. 12.

$$P_i = -b_s r V_i V_j \sin(\theta_i - \theta_j + \gamma) \qquad \text{………….} (29)$$

$$Q_i = -b_s r V_i^2 (r + 2\cos(\gamma)) + b_s r V_i V_j \cos(\theta_i - \theta_j + \gamma) \qquad \text{………….} (30)$$

$$\mathbf{P}_j = -P_s \qquad \text{……………} (31)$$

$$Q_j = +b_s r V_i V_j \cos(\theta_i - \theta_j + \gamma) \qquad \text{…………….} (32)$$

Where,

P_i , P_j represents the active power to bus i and j respectively

Q_i , Q_j represents the reactive power to bus i and j respectively

r represents the the radius of the UPFC operating region

γ represents the UPFC phase angle

bs is the inverse of X_s (reactance of the total circuit i.e. reactance of the transmission and the reactance of the injecting transformer)

Vi, is the voltage magnitude of bus i

Vj is the voltage magnitude of bus j

θi are voltage angle of bus i

θj are the voltage angle of bus j

UPFC device modelling with DE has also been applied for congestion management which takes into consideration the loss factor. This requires load flow estimation through the transmission line by evaluating bus current injection and line current flow from which the power flow through the lines can be gathered. These calculations provide the power loss through the power line.

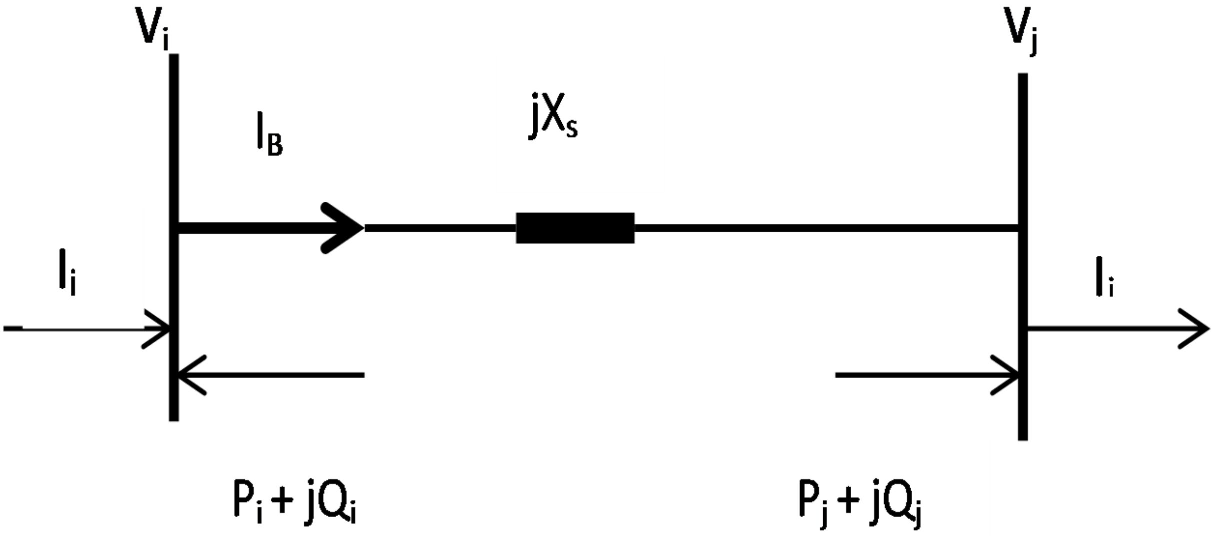


Figure 11: UPFC Model

Let us assume there are two buses in the system V_i and V_j, their current is I_i and I_j respectively. Then UPFC device will inject real and reactive power in both the buses if necessary. Pi and Pj will be injected active power in bus I and j respectively. Q_i and Q_j will be injected reactive power in bus i and j respectively.

CONCLUSION

From the above discussion of the optimization techniques, load flow and UPFC operation it can be stated that these techniques can be effectively used to solve the objective function and to provide desired result. Both optimisation techniques provide better convergence and have low local minima selection problem, thus these techniques are perfect selection for the optimisation in this work. The load flow equations have been solved using Newton-Raphson algorithm to produce voltage deviation for IEEE-30 bus system under normal operating condition. Then the loads have been changed, with the experiment sometimes it has been reduced gradually or increased according to the need. These load flow equations through Newton-Raphson has been introduced into differential evolution or cultural algorithm as fitness function calculation to get optimized voltage deviation as results. UPFC device injects both real and reactive power of the system and changes power angle to reduce congestion as well as voltage deviation of the system.

Chapter 4: *Details of the optimisation techniques* and *application procedure*

4.1 CULTURAL ALGORITHM

Cultural algorithm is employed in this work to optimize the voltage deviation of the power line for different buses on connection of different devices. The device perform differently according to the set parameters for each device. The optimization depends on the cultural algorithm parameters like the number of individuals taken into consideration for application, the number of individuals in the belief space of cultural algorithm, mutation factor, cross over ratio and the number of iterations done to check for the optimum value. All the mentioned parameters are varied to check for the optimum performing bus. Cultural algorithm requires to define the number of individual in the population space and the number of individual in the belief space. A set of population for each bus is generated in the population space and their performance is evaluated as their objective function. Selected number of best performing individuals are taken in the belief space.

The performance of the population space is compared to a set standard. If the performance of the population space does not satisfy the standard limit, the population space and the belief space are merged to generate off springs. This is also known as mutation. The merging is also characterized by mutation factor. If individuals in the population space satisfies the set standard, then cross over operation is done. If the performance of the selected individual from the belief space is better than the set standard of crossover ratio then the belief space individual is selected as the offspring, else n individual from the population space is selected as an offspring.

The generated off springs are kept within the parameter limit. The next generation population is selected from the generated off springs. The best individual performance from the merged population space and the off springs are considered for the next generation. They are evaluated on their performance. From this temporary set of next generation offsprings, next generation belief space are again created by selecting the best performing individuals. Thus, next generation belief space are created. From the merged temporary next generation population space the individuals with maximum performance are selected to create the next generation population.

The generation of next generation population and next generation belief space are iterated 100 times in this work to optimize and select the best performing individual.

Finally, from the ultimate belief space, the individuals providing the minimum voltage deviation is selected. Thus the optimized minimal individual or parameter in the given parametric range is determined which will provide the minimal voltage deviation for a particular bus in the provided working parameters.

For this work, two devices were selected –STATCOM and Capacitor. UPFC device is modelled to consider the fitness value based on both loss and voltage deviation. The operating parameters are given below in Table I**.**

Table I: Operating Parameters employed in Cultural Algorithm

Device	Parameter		Mutation factor		Crossover Ration		Number of Individual		Number of Belief Space	
STATCOM	-100 to 100	-160 to 160	0.45	0.55	0.75	0.65	100	50	10	5
Capacitor	0.1 to 1	0 to 1.5	0.45	0.55	0.75	0.65	100	50	10	5
UPFC	[0 -1], [-180-180]		0.45	0.55	0.75	0.65	100	50	10	5

4.1.1 CULTURAL ALGORITHM CONCEPT USED IN THIS WORK

- Selection of device
    - STATCOM
    - CAPACITOR
    - UPFC
- Selection of parameters according to the device

Device	Parameter	
STATCOM	-100 to 100	-160 to 160
CAPACITOR	0.1 to 1	0 to 1.5
UPFC	[0 -1], [-180- 180]	

For UPFC [0 – 1] is the range of the device and [-180 – 180] is the phase angle of UPFC device.

- Initialization of Operational parameters
    - Mutation Factor
    - Crossover ratio
    - Number of individuals
    - Number of individuals in the belief space

Operational Parameter	**Parameters considered**	
Mutation Factor	0.45	0.55
Crossover Ratio	0.75	0.65
Number of individuals	100	50
Number of individuals in the belief space	10	5

4.1.2 STEPS of Implementation of Cultural Algorithm

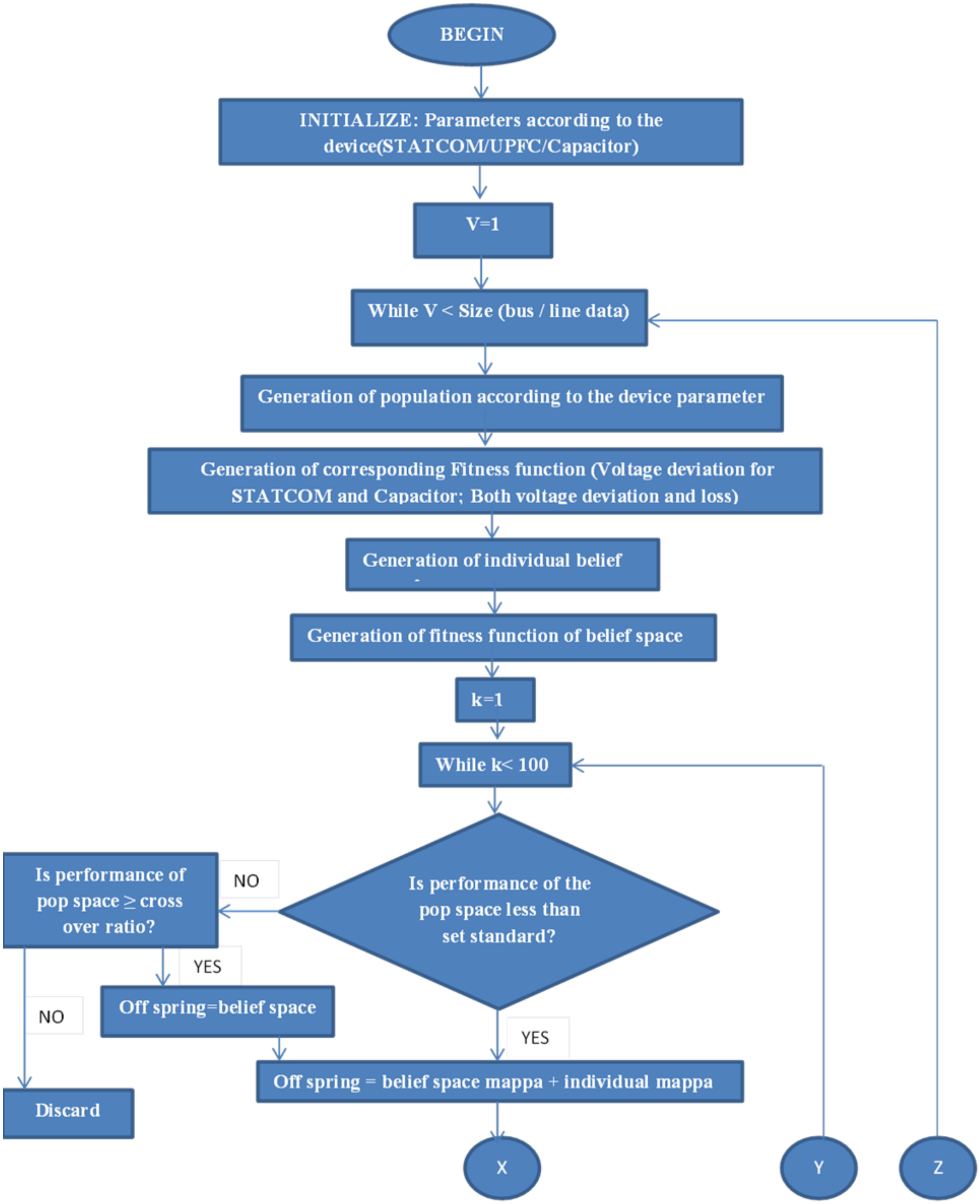
- Generation of population randomly within the parameter limit of the selected device (STATCOM/CAPACITOR/UPFC).
- Corresponding generation of the fitness function of the population employing Newton Raphson's technique. Voltage deviation of the bus line is considered as the fitness value when connecting STATCOM and Capacitor device.
  For UPFC device, voltage deviation and loss are both considered to evaluate the fitness function according to the given relation below.
  Fitness value=0.5*loss+0.5*voltage deviation.

- Selection of the best individuals according to their fitness function to form the belief space of pre-defined size.
- Generation of offspring based on the belief space mappa and individual mappa according to the following relation.
  Off-spring = population space + belief space- population space * mutation-factor

- Restructuring the offspring within the defined parameter limit of the selected device (STATCOM/CAPACITOR/UPFC).
- Selecting the best offspring
- Creating a new set of population by merging belief space and best offspring
- Selection of next generation belief space individuals and evaluate their corresponding fitness function according to the device.
- Forming the final belief space
- Selecting the individual with minimum fitness function from the belief space.
- OUTPUT: Evaluating the voltage deviation of the bus line on employing the selected device (STATCOM/CAPACITOR/UPFC) with the selected individual.

The Flow Chart of the Cultural algorithm is shown below.

CULTURAL ALGORITHM FLOW CHART USED IN THESIS



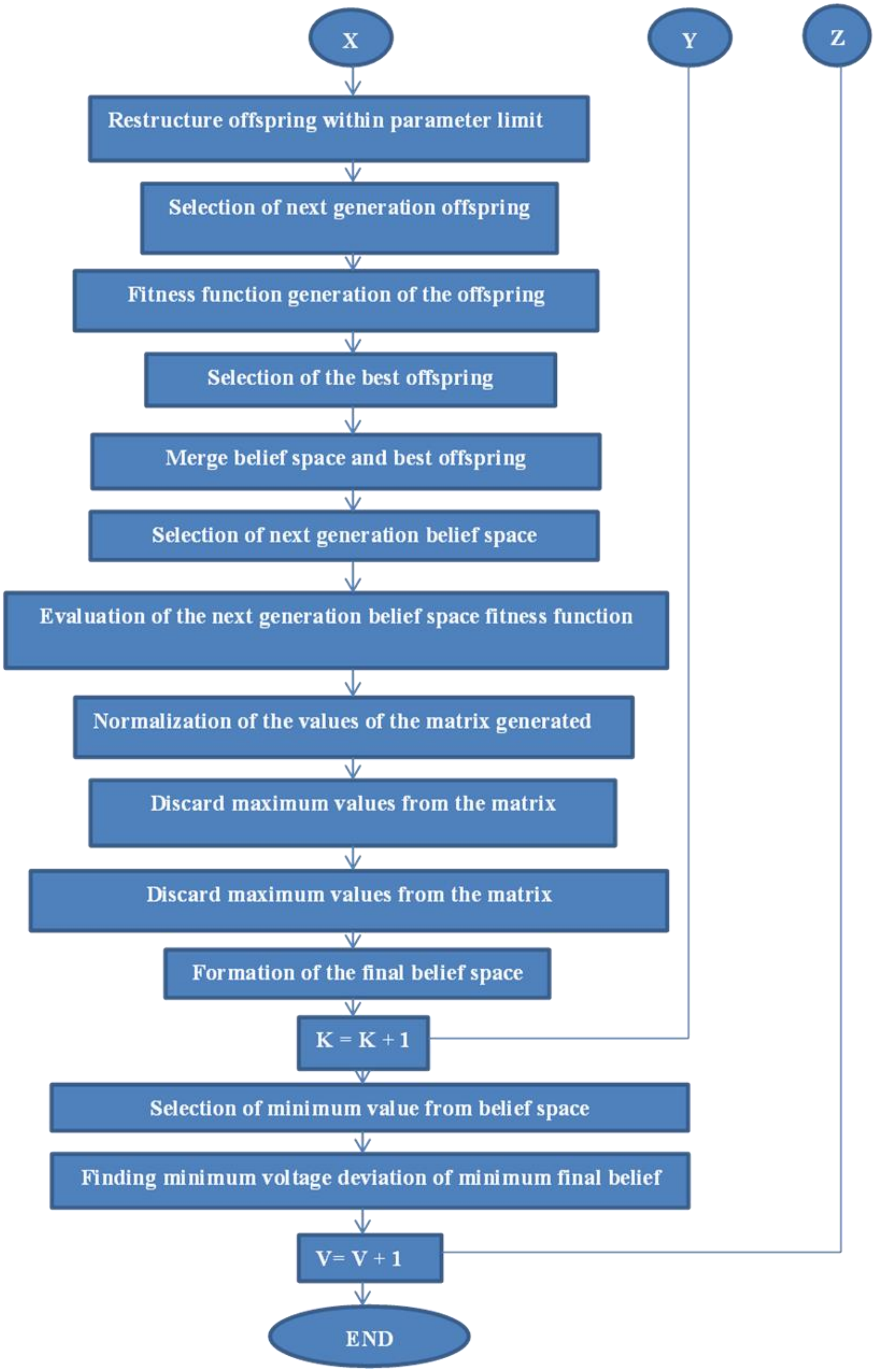


Figure 12: Flowchart of Cultural Algorithm used in the work

4.2 DIFFERENTIAL EVOLUTION ALGORITHM

Differential Evolution Algorithm is employed to optimize the voltage deviation while applying various devices and to select the best performing BUS. Initially the parameters of the devices are defined. A population of individuals is created randomly defined within the parameter limit. The minimum voltage deviation is calculated for each population applying Newton Raphson's technique. This creates a Jacobian matrix having four elements- derivative of real power injections with angles (J1), derivative of real power injections with voltage (J2), derivative of reactive power injections with angles(J3) and derivative of reactive power injections with voltage (J4).

Correction vector is created with the help of the Jacobian matrix which provides the measure of voltage magnitude and angle. A tolerance limit is set and the voltage optimization is done until the tolerance condition is satisfied. Newton Raphson thus provides the optimum voltage deviation for the entire population for each BUS data. This optimum voltage deviation can be considered as the objective function value of each individual. The differential evolution algorithm comes into function to determine the best individual in the population based on their objective function value. The target problem of DE is to optimize the voltage deviation to its best possible outcome. The first step is mutation to generate a new set of population whose performance would be better than the best individual. Thus, a new generation of population created which are again defined within the set parameters and having their performance better than the best individual. The population is selected based on a standard set limit defined by cross over ratio.

The crossover ratio defines the inclusion of individuals in the new generation from either the population generated after mutation operation or the initially generated population. The selection operation evaluates the fitness value or the voltage deviation of the population generated after crossover and generates the next generation population by including individuals either from the population generated after crossover or the initial population by comparing their fitness values. Finally, the individual with the minimum voltage deviation is selected to operate with the busdata. This determines the population or the exact parametric value of the selected device providing best performance for the busdata with the device. The final minimum voltage deviation is evaluated taking into consideration the parametric value and the selected device with the busdata. The entire procedure is iterated 100 times for each bus and the best value providing minimum voltage deviation is selected. The devices considered for this operation are STATCOM, Capacitor and UPFC. The parameters considered for the work are tabulated in Table II.

Table II: Operating Parameters employed in Differential Algorithm

Device	Parameter		Mutation factor		Crossover Ration		Number of Individual	
STATCOM	-100 to 100	-160 to 160	0.85	0.9	0.65	0.75	100	50
Capacitor	0.1 to 1	0 to 1.5	0.85	0.9	0.65	0.7	100	50
UPFC	[0 -1], [-180- 180]		0.85	0.9	0.65	0.75	100	50

4.2.1 CONCEPT OF THE DIFFERENTIAL EVOLUTION TECHNIQUES USED IN THESIS

- Selection of device
    - STATCOM
    - CAPACITOR
    - UPFC
- Selection of parameters according to the device

Device	Parameter	
STATCOM	-100 to 100	-160 to 160
CAPACITOR	0.1 to 1	0 to 1.5
UPFC	[0 -1], [-180- 180]	

- Initialization of Operational parameters
    - Mutation Factor
    - Crossover ratio
    - Number of individuals

Operational Parameter	**Parameters considered**	
Mutation Factor	0.85	0.9
Crossover Ratio	0.65	0.75
Number of individuals	100	50

- Generation of population randomly within the parameter limit of the selected device (STATCOM/CAPACITOR/UPFC).
- Corresponding generation of the fitness function of the population employing Newton Raphson's technique. Voltage deviation of the bus line is considered as the fitness value when connecting STATCOM and Capacitor device.

  For UPFC device, voltage deviation and loss are both considered to evaluate the fitness function according to the given relation below.

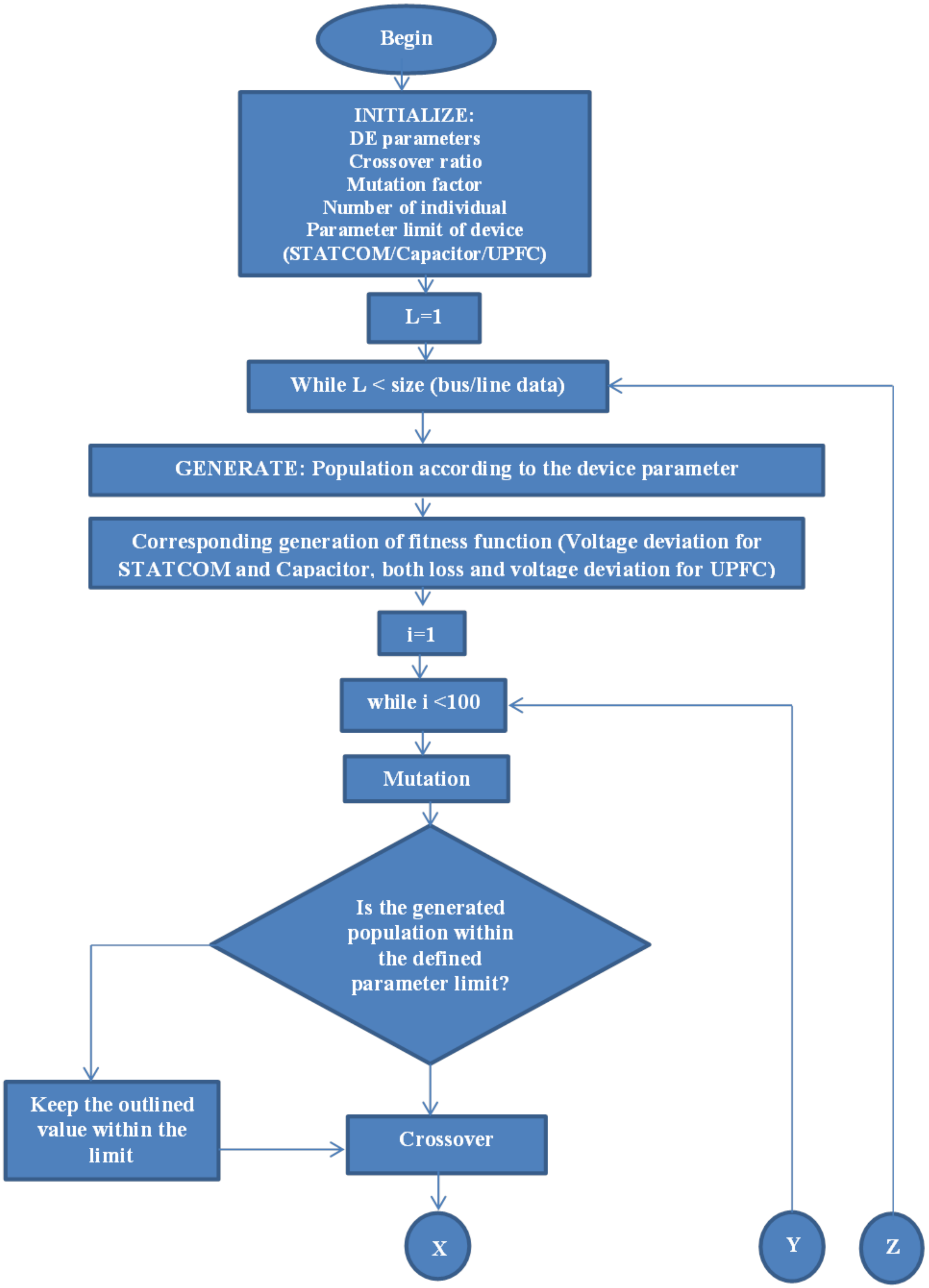
  Fitness value=0.5*loss+0.5*voltage deviation.
- Iteratively find the best population having optimum fitness function employing steps of Differential evolution (DE).
  - Mutation Operation: A new set of population is generated by updating the generated population by the following relation.

    Population-after-mutation= best individual + mutation-factor*population1-population2.

    Where, best individual is the population with minimum fitness value

    Population 1 and population 2 are two distinct randomly selected individual from the population set. The outlined value of the population generated after mutation are kept within the parameter limit of the selected device (STATCOM/Capacitor/UPFC).
  - Crossover Operation: If the performance of the mutated population is fit for crossover (i.e. performance level of the mutation population < cross over ratio), that population is crossed over to the next generation else the original population is selected for inclusion in the crossed over population.
  - Selection Operation: The crossed over population with optimum fitness function is selected for further operation.
- Generation of new generation population and their corresponding fitness function.
- Iteration Result: Population with minimum fitness function
- OUTPUT: Voltage deviation/fitness of the bus line after connecting the selected device.

FLOW CHART OF DIFFERENTIAL EVOLUTION TECHNIQUES USED IN THESIS



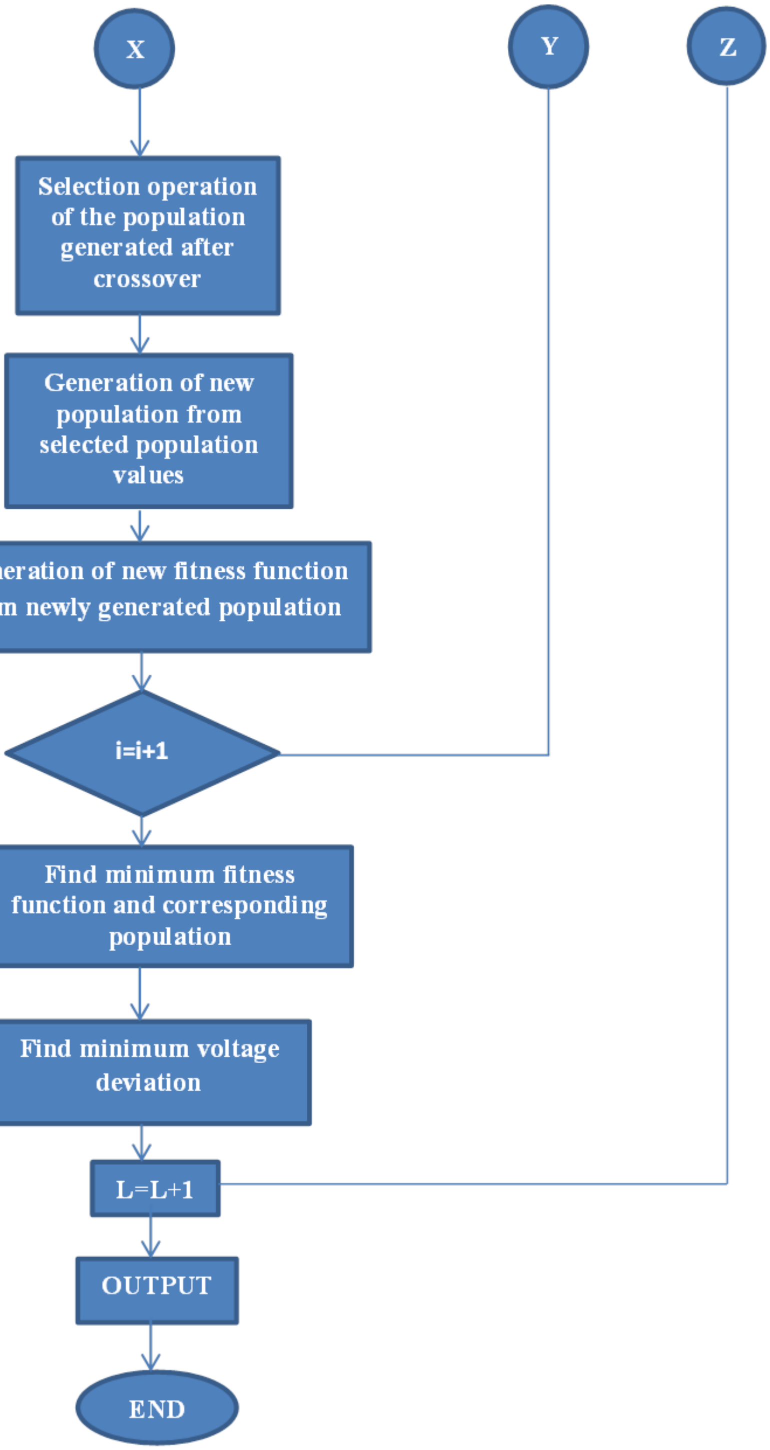


Figure 13: Flowchart of DE employed in the work

CONCLUSION:

Implementation of Cultural algorithm and Differential Evolution techniques to solve the objective of the work have been discussed in this chapter. Flow-chart to show the steps of the techniques also presented. The steps of both of the algorithm have been discussed in details. The parameters of both the algorithms have been varied as suited for the work to observe the variation in output result. In the next chapter detailed results of the algorithm techniques have been discussed to justify the objective of the work.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 STANDARD IEEE BUS DATAS AND CHANGED LOAD VALUES

IEEE Standard 30 bus linedata has been provided in Table III, where *R* is the resistance, *X* is the reactance *B* is susceptence of the line and last column is the tap changing ratio. Most of the FACTS devices are connected with buses, a few changes reactance of the line and changes linedata value to provide desired result.

Table III: IEEE STANDARD 30 BUS LINEDATA [48]

LINE No.	FROM BUS	TO BUS	R Pu	X pu	B/2 Pu	X'mer TAP (a)
1	1	2	0.01920	0.05750	0.02640	1
2	1	3	0.04520	0.16520	0.02040	1
3	2	4	0.05700	0.17370	0.01840	1
4	3	4	0.01320	0.03790	0.00420	1
5	2	5	0.04720	0.19830	0.02090	1
6	2	6	0.05810	0.17630	0.01870	1
7	4	6	0.01190	0.04140	0.00450	1
8	5	7	0.04600	0.11600	0.01020	1
9	6	7	0.02670	0.08200	0.00850	1
10	6	8	0.01200	0.04200	0.00450	1
11	6	9	0	0.20800	0	0.97800
12	6	10	0	0.55600	0	0.96900
13	9	11	0	0.20800	0	1
14	9	10	0	0.11000	0	1
15	4	12	0	0.25600	0	0.93200
16	12	13	0	0.14000	0	1
17	12	14	0.12310	0.25590	0	1
18	12	15	0.06620	0.13040	0	1
19	12	16	0.09450	0.19870	0	1
20	14	15	0.22100	0.19970	0	1
21	16	17	0.08240	0.19230	0	1
22	15	18	0.10730	0.21850	0	1
23	18	19	0.06390	0.12920	0	1
24	19	20	0.03400	0.06800	0	1
25	10	20	0.09360	0.20900	0	1
26	10	17	0.03240	0.08450	0	1
27	10	21	0.03480	0.07490	0	1
28	10	22	0.07270	0.14990	0	1
29	21	23	0.01160	0.02360	0	1
30	15	23	0.10000	0.20200	0	1

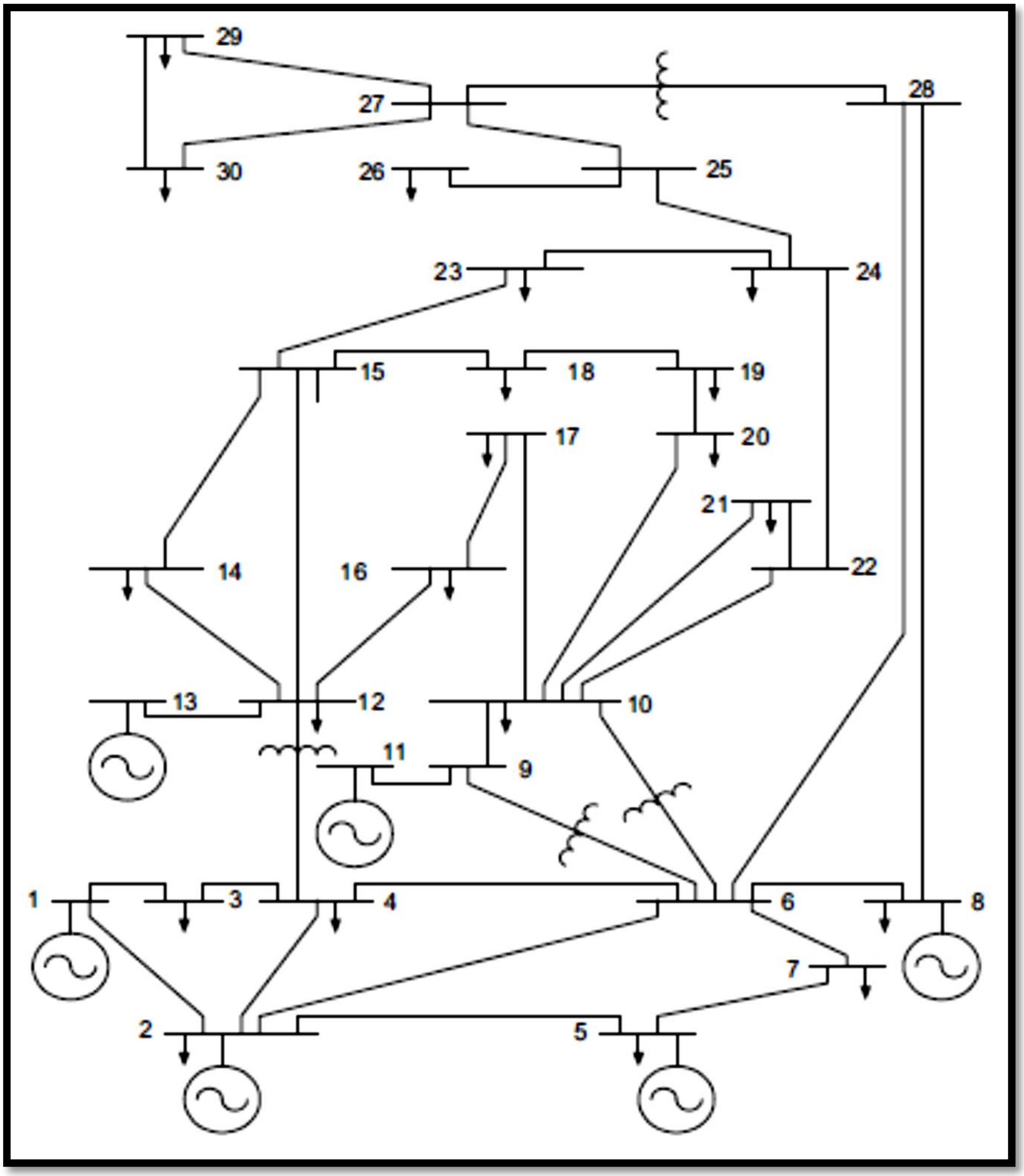


Figure 7: IEEE STANDARD BUS RADIAL DISTRIBUTION SYSTEM [37]

The above figure is the presentation of IEEE standard radial distribution system, the connection diagram of buses are presented. Generator placement in the buses is shown in the picture. In IEEE standard 30 bus data V_{sp} is specified bus voltage Theta is the angle of bus, P_{Gi} and P_{Qi} are generated real and reactive power. Q_{min} and Q_{max} are specified reactive power limit.

Table IV: IEEE STANDARD 30 BUSDATA [48]

BUS No.	TYPE	Vsp	THETA	PGi	QGi	PLi (MW)	QLi(MVar)	Qmin	Qmax
1	1	1.060	0	0	0	0	0	0	0
2	2	1.043	0	40	50	21.70	12.70	-40	50
3	3	1	0	0	0	2.400	1.200	0	0
4	3	1.060	0	0	0	7.600	1.600	0	0
5	2	1.010	0	0	37	94.20	19	-40	40
6	3	1	0	0	0	0	0	0	0
7	3	1	0	0	0	22.80	10.90	0	0
8	2	1.010	0	0	37.30	30	30	-10	40
9	3	1	0	0	0	0	0	0	0
10	3	1	0	0	19	5.800	2	0	0
11	2	1.082	0	0	16.20	0	0	-6	24
12	3	1	0	0	0	11.20	7.500	0	0
13	2	1.07	0	0	10.60	0	0	-6	24
14	3	1	0	0	0	6.200	1.600	0	0
15	3	1	0	0	0	8.200	2.500	0	0
16	3	1	0	0	0	3.500	1.800	0	0
17	3	1	0	0	0	9	5.800	0	0
18	3	1	0	0	0	3.200	0.900	0	0
19	3	1	0	0	0	9.500	3.400	0	0
20	3	1	0	0	0	2.200	0.700	0	0
21	3	1	0	0	0	17.50	11.20	0	0
22	3	1	0	0	0	0	0	0	0
23	3	1	0	0	0	3.200	1.600	0	0
24	3	1	0	0	4.300	8.700	6.700	0	0
25	3	1	0	0	0	0	0	0	0
26	3	1	0	0	0	3.500	2.300	0	0
27	3	1	0	0	0	0	0	0	0
28	3	1	0	0	0	0	0	0	0
29	3	1	0	0	0	2.400	0.900	0	0
30	3	1	0	0	0	10.60	1.900	0	0

In this thesis work real and reactive power of load is increased and decreased up to 90% of standard value to check system performance under high or low load condition and to evaluate system voltage deviation in those condition. The high and low busdata are given below in table V and VI respectively.

Table V: 30 BUSDATA WITH HIGH LOAD

BUS No.	TYPE	Vsp	THETA	PGi	QGi	PLi (MW)	QLi (MVar)	Qmin	Qmax
1	1	1.060	0	0	0	0	0	0	0
2	2	1.043	0	40	50	21.70	12.7	-40	50
3	3	1	0	0	0	4.600	2.20	0	0
4	3	1.060	0	0	0	14.60	2.60	0	0
5	2	1.010	0	0	37	94.20	19	-40	40
6	3	1	0	0	0	3	1	0	0
7	3	1	0	0	0	42.8	20.9	0	0
8	2	1.010	0	0	37.30	30	30	-10	40
9	3	1	0	0	0	4	1	0	0
10	3	1	0	0	19	10.8	4	0	0
11	2	1.082	0	0	16.20	0	0	-6	24
12	3	1	0	0	0	22.2	14.5	0	0
13	2	1.07	0	0	10.60	0	0	-6	24
14	3	1	0	0	0	12.20	2.60	0	0
15	3	1	0	0	0	16.20	4.50	0	0
16	3	1	0	0	0	3.500	2.80	0	0
17	3	1	0	0	0	9	10.8	0	0
18	3	1	0	0	0	3.2	0.90	0	0
19	3	1	0	0	0	9.5	3.40	0	0
20	3	1	0	0	0	2.2	0.70	0	0
21	3	1	0	0	0	17.5	11.2	0	0
22	3	1	0	0	0	0	0	0	0
23	3	1	0	0	0	3.2	1.60	0	0
24	3	1	0	0	4.300	8.7	6.7	0	0
25	3	1	0	0	0	0	0	0	0
26	3	1	0	0	0	3.5	2.3	0	0
27	3	1	0	0	0	0	0	0	0
28	3	1	0	0	0	0	0	0	0
29	3	1	0	0	0	2.4	0.9	0	0
30	3	1	0	0	0	10.6	1.9	0	0

Table V is IEEE 30 bus data after load modification, where the system load has been increased than its normal values in bus no. 3,4,7,9,10,12,14 and 15. The increased loads are yellow marked in the table. Table VI represents the low load data.

Table VI: 30 BUSDATA WITH LOW LOAD

BUS No.	TYPE	Vsp	THETA	PGi	QGi	PLi (MW)	QLi (MVar)	Qmin	Qmax
1	1	1.060	0	0	0	0	0	0	0
2	2	1.043	0	40	50	21.70	12.70	-40	50
3	3	1	0	0	0	0.600	0.200	0	0
4	3	1.060	0	0	0	4.600	0.600	0	0
5	2	1.010	0	0	37	94.20	19	-40	40
6	3	1	0	0	0	0	0	0	0
7	3	1	0	0	0	12.80	5.900	0	0
8	2	1.010	0	0	37.30	30	30	-10	40
9	3	1	0	0	0	0	0	0	0
10	3	1	0	0	19	2.800	1	0	0
11	2	1.082	0	0	16.20	0	0	-6	24
12	3	1	0	0	0	8.200	3.500	0	0
13	2	1.07	0	0	10.60	0	0	-6	24
14	3	1	0	0	0	2.200	0.600	0	0
15	3	1	0	0	0	4.200	0.500	0	0
16	3	1	0	0	0	2.500	0.800	0	0
17	3	1	0	0	0	5	2.800	0	0
18	3	1	0	0	0	3.200	0.900	0	0
19	3	1	0	0	0	9.500	3.400	0	0
20	3	1	0	0	0	2.200	0.700	0	0
21	3	1	0	0	0	17.50	11.20	0	0
22	3	1	0	0	0	0	0	0	0
23	3	1	0	0	0	3.200	1.600	0	0
24	3	1	0	0	4.300	8.700	6.700	0	0
25	3	1	0	0	0	0	0	0	0
26	3	1	0	0	0	3.500	2.300	0	0
27	3	1	0	0	0	0	0	0	0
28	3	1	0	0	0	0	0	0	0
29	3	1	0	0	0	2.400	0.900	0	0
30	3	1	0	0	0	10.60	1.900	0	0

The above tables represents the IEEE standard 30 bus data without load, with high load and low load conditions respectively. The loads of buses have been almost 90% increased or decreased on the first eleven generator buses to show voltage deviations on different load conditions in the system. The highlighted portion on table V and VI shows the changed value of loads on buses. At bus no. 3, 4,7,10,12,14,15 and 16 the loads has been decreased than their normal values.

Table VII: DIFFERENT VOLTAGE CONDITIONS ACCORDING TO LOAD

BUS No.	AT NORMAL LOADCONDITION	AT HIGH LOAD CONDITION	AT LOW LOAD CONDITION
1	1.06000	1.06000	1.06000
2	1.04300	1.02300	1.04300
3	1.02167	0.99286	1.02743
4	1.01292	0.97930	1.01900
5	1.01000	0.98000	1.01000
6	1.01208	0.97746	1.01636
7	1.00346	0.96161	1.01016
8	1.01000	0.98000	1.01000
9	1.05072	1.01517	1.05692
10	1.04375	1.00207	1.05377
11	1.08200	1.06200	1.08200
12	1.05760	1.01713	1.06750
13	1.07100	1.05100	1.07100
14	1.04287	0.99283	1.05882
15	1.03844	0.99180	1.05182
16	1.04451	1.00043	1.05769
17	1.03865	0.99308	1.05223
18	1.02815	0.98274	1.04047
19	1.02521	0.98064	1.03686
20	1.02906	0.98520	1.04030
21	1.02926	0.98613	1.03993
22	1.03528	0.99348	1.04505
23	1.02913	0.98573	1.03997
24	1.02365	0.98179	1.03300
25	1.02015	0.98157	1.02656
26	1.00253	0.96322	1.00904
27	1.02651	0.99024	1.03111
28	1.01086	0.97652	1.01454
29	1.00674	0.96966	1.01144
30	0.99531	0.95777	1.00006

Now, from the Table VII, few points related to voltage profile improvement and congestion management can be mentioned:

- In the chosen network (IEEE 30-bus system), Newton-Raphson based load flow analysis has been conducted considering high and low load conditions. The observations show violation of stable voltage profile (0.95 – 1.05 p.u) in some of the buses as highlighted in the table VII. This also increases the voltage deviation while leading to current flow in the network. Thus the power loss also has been increased.
- According to the observations, at bus no. 9, 11, 12 and 13 of high load data are found to be violated. Further, the bus no. 9,11,12,13,14,15,16 and 17 for the low load values are observed to violate the stable voltage profile.
- The voltage deviation by Newton-Raphson load flow study for high load condition is found 0.6471p.u and for low load condition is determined 1.1162 p.u.
- Line current by Newton-Raphson load flow study is 29.1818 KA for high load and 19.4748 KA for low load condition.

This required closer investigations in terms of optimal Var compensations.

Therefore this problem is solved through real and reactive power compensation with capacitor, STATCOM and UPFC devices. As UPFC device can inject both real and reactive power to the system and changes power angle of the buses thus reduces system losses and current flow through the line to reduce congestion.

5.2. TABULATED RESULT OF CULTURAL ALGORITHM (CA) WITH CAPACITOR DEVICES PARAMETER (0.1 to 1 MVar) BY CHANGING CROSSOVER RATIO (CR), MUTATION FACTOR (MF) NO. OF INDIVIDUAL (IN) AND BELIEF SPACE (BS)

TABLE VIII: RESULT AFTER PLACING CAPACITOR (0.1 to 1 MVar) IN HIGH LOAD WITH FIXED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSSOVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	10	0.65	0.45	0	0	**O.6471**	0	0
2	100	10	0.65	0.45	21.70	12.70		1.0708	0.9340
3	100	10	0.65	0.45	4.600	2.200		1.0709	0.0145
4	100	10	0.65	0.45	14.60	2.600		1.0708	0.0060
5	100	10	0.65	0.45	94.20	19		1.0708	0.4773
6	100	10	0.65	0.45	3	1		1.0708	0.0048
7	100	10	0.65	0.45	42.80	20.90		1.0708	0.0011
8	100	10	0.65	0.45	30	30		1.0708	0.4868
9	100	10	0.65	0.45	4	1		1.0657	0.6061
10	100	10	0.65	0.45	10.80	4		1.0710	0.0109
11	**100**	**10**	**0.65**	**0.45**	**0**	**0**		**1.0608**	**0.2537**
12	100	10	0.65	0.45	22.20	14.50		1.0708	0.0025
13	100	10	0.65	0.45	0	0		1.0708	0.9576
14	100	10	0.65	0.45	12.20	2.600		1.0710	0.0140
15	100	10	0.65	0.45	16.20	4.500		1.0708	0.0005
16	100	10	0.65	0.45	3.500	2.800		1.0709	0.0077
17	100	10	0.65	0.45	9	10.80		1.0714	0.0377
18	100	10	0.65	0.45	3.200	0.900		1.0708	0.0002
19	100	10	0.65	0.45	9.500	3.400		1.0720	0.0635
20	100	10	0.65	0.45	2.200	0.700		1.0709	0.0039
21	100	10	0.65	0.45	17.50	11.20		1.0708	0.0003
22	100	10	0.65	0.45	0	0		1.0711	0.0168
23	100	10	0.65	0.45	3.200	1.600		1.0715	0.0431
24	100	10	0.65	0.45	8.700	6.700		1.0710	0.0079
25	100	10	0.65	0.45	0	0		1.0721	0.0551
26	100	10	0.65	0.45	3.500	2.300		1.0709	0.0040
27	100	10	0.65	0.45	0	0		1.0710	0.0070
28	100	10	0.65	0.45	0	0		1.0708	0.0060
29	100	10	0.65	0.45	2.400	0.900		1.0710	0.0049
30	100	10	0.65	0.45	10.6	1.9		1.0720	0.0422

Here, IEEE 30 busdata with high load values have been optimized using a capacitor of range between (0.1 – 1 MVar) with cultural algorithm technique. The observations are shown in table VII where Capacitor injects extra reactive power to the system. The results shows bus no.11 provides the lowest total voltage deviation values after 100th iterations among all the buses. Therefore, it improves voltage deviation from 0.6471 p.u to 1.0608 p.u compared to other buses. Here the optimum size of the allocated device is found 0.2537 MVar. It can be stated that 11th bus of the system is the best bus for optimal placement of capacitor device to minimize total voltage deviation of the system. Since the observations are found optimum the CA based parameters like *CR*, *IN*, *BS* and *MF* are kept fixed for the next optimization.

Table IX: RESULT AFTER PLACING CAPACITOR (0.1-1 MVar) IN LOW LOAD WITH FIXED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	10	0.65	0.45	0	0	**1.1162**	0	0
2	100	10	0.65	0.45	21.70	12.70		1.1161	0.3808
3	100	10	0.65	0.45	0.600	0.200		1.1134	0.9956
4	100	10	0.65	0.45	4.600	0.600		1.1132	0.9893
5	100	10	0.65	0.45	94.20	19		1.1161	0.3658
6	100	10	0.65	0.45	0	0		1.1135	0.9972
7	100	10	0.65	0.45	12.80	5.900		1.1141	0.9925
8	100	10	0.65	0.45	30	30		1.1161	0.6160
9	100	10	0.65	0.45	0	0		1.1092	0.9936
10	100	10	0.65	0.45	2.800	1		1.1044	0.9836
11	100	10	0.65	0.45	0	0		1.1161	0.2669
12	100	10	0.65	0.45	8.200	3.500		1.1089	0.9899
13	100	10	0.65	0.45	0	0		1.1161	0.2332
14	100	10	0.65	0.45	2.200	0.600		1.1055	0.9998
15	100	10	0.65	0.45	4.200	0.500		1.1048	0.9890
16	100	10	0.65	0.45	2.500	0.800		1.1054	0.9990
17	100	10	0.65	0.45	5	2.800		1.1041	0.9928
18	100	10	0.65	0.45	3.200	0.900		1.1014	0.9977
19	100	10	0.65	0.45	9.500	3.400		1.1007	0.9993
20	100	10	0.65	0.45	2.200	0.700		1.1011	0.9978
21	100	10	0.65	0.45	17.50	11.20		1.1028	0.9976
22	100	10	0.65	0.45	0	0		1.1018	0.9896
23	100	10	0.65	0.45	3.200	1.600		1.1026	0.9955
24	100	10	0.65	0.45	8.700	6.700		1.1004	0.9985
25	100	10	0.65	0.45	0	0		1.0988	0.9887
26	**100**	**10**	**0.65**	**0.45**	**3.500**	**2.300**		**1.0944**	**0.9943**
27	100	10	0.65	0.45	0	0		1.1019	0.9983
28	100	10	0.65	0.45	0	0		1.1124	0.9972
29	100	10	0.65	0.45	2.400	0.900		1.1004	0.9978
30	100	10	0.65	0.45	10.60	1.900		1.1035	0.9924

Here, IEEE 30 busdata with modified low load has been optimized with a capacitor of range between (0.1 – 1 MVar) by cultural algorithm (CA) technique. The observation are shown in the table IX. After closer observation it can be shown that bus no. 26 provides the lowest total voltage deviation values than other buses in the system. Here, it improves the voltage deviation from 1.1162 p.u to 1.0994 p.u. in this work, the optimum size of the capacitor has been found as 0.9943 MVar. Now, to obtain even better results, the optimization parameters are changed in the following cases.

Table X: RESULT AFTER PLACING CAPACITOR (0.1-1 MVar) IN HIGH LOAD WITH CHANGED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	5	0.75	0.55	0	0	**0.6471**	0	0
2	50	5	0.75	0.55	21.70	12.70		1.0708	0.8280
3	50	5	0.75	0.55	4.600	2.200		1.0712	0.1248
4	50	5	0.75	0.55	14.60	2.600		1.0713	0.1320
5	50	5	0.75	0.55	94.20	19		1.0708	0.6865
6	50	5	0.75	0.55	3	1		1.0711	0.1002
7	50	5	0.75	0.55	42.80	20.90		1.0711	0.1174
8	50	5	0.75	0.55	30	30		1.0708	0.2035
9	50	5	0.75	0.55	4	1		1.0717	0.1146
10	50	5	0.75	0.55	10.80	4		1.0724	0.1139
11	**50**	**5**	**0.75**	**0.55**	**0**	**0**		**1.0608**	**0.2553**
12	50	5	0.75	0.55	22.20	14.50		1.0720	0.1435
13	50	5	0.75	0.55	0	0		1.0708	0.8958
14	50	5	0.75	0.55	12.20	2.600		1.0728	0.1636
15	50	5	0.75	0.55	16.20	4.500		1.0722	0.1058
16	50	5	0.75	0.55	3.500	2.800		1.0726	0.1398
17	50	5	0.75	0.55	9	10.80		1.0730	0.1504
18	50	5	0.75	0.55	3.200	0.900		1.0725	0.1003
19	50	5	0.75	0.55	9.500	3.400		1.0733	0.1421
20	50	5	0.75	0.55	2.200	0.700		1.0733	0.1403
21	50	5	0.75	0.55	17.50	11.20		1.0724	0.1029
22	50	5	0.75	0.55	0	0		1.0729	0.1221
23	50	5	0.75	0.55	3.200	1.600		1.0727	0.1155
24	50	5	0.75	0.55	8.700	6.700		1.0736	0.1439
25	50	5	0.75	0.55	0	0		1.0735	0.1100
26	50	5	0.75	0.55	3.500	2.300		1.0750	0.1440
27	50	5	0.75	0.55	0	0		1.0734	0.1172
28	50	5	0.75	0.55	0	0		1.0715	0.1302
29	50	5	0.75	0.55	2.400	0.900		1.0738	0.1083
30	50	5	0.75	0.55	10.6	1.9		1.0748	0.1400

Here, IEEE 30 bus radial system data with high load value modification has been optimized with a capacitor of range between (0.1 – 1 MVar) by cultural algorithm technique. After optimization the results have been presented in the table X. from the observations, it can be shown that bus no. 11 provides the lowest total voltage deviation values than other buses in the system. Here, it improves the voltage deviation from 0.6471 p.u to 1.0608 p.u. The optimal size of the reactive power compensator is obtained 0.2553 MVar. Since the improved responses are observed, the CA based optimization parameters are remained fixed for the next case study of low load voltage profile improvement.

Table XI: RESULT AFTER PLACING CAPACITOR (0.1-1 MVar) IN LOW LOAD WITH CHANGED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	5	0.75	0.55	0	0	**1.1162**	0	0
2	50	5	0.75	0.55	21.70	12.70		1.1161	0.8926
3	50	5	0.75	0.55	0.600	0.200		1.1134	0.9881
4	50	5	0.75	0.55	4.600	0.600		1.1132	0.9997
5	50	5	0.75	0.55	94.20	19		1.1161	0.3687
6	50	5	0.75	0.55	0	0		1.1136	0.9884
7	50	5	0.75	0.55	12.80	5.900		1.1142	0.9485
8	50	5	0.75	0.55	30	30		1.1161	0.5205
9	50	5	0.75	0.55	0	0		1.1092	0.9899
10	50	5	0.75	0.55	2.800	1		1.1043	0.9927
11	50	5	0.75	0.55	0	0		1.1161	0.3030
12	50	5	0.75	0.55	8.200	3.500		1.1088	0.9962
13	50	5	0.75	0.55	0	0		1.1161	0.4847
14	50	5	0.75	0.55	2.200	0.600		1.1055	0.9985
15	50	5	0.75	0.55	4.200	0.500		1.1051	0.9662
16	50	5	0.75	0.55	2.500	0.800		1.1055	0.9944
17	50	5	0.75	0.55	5	2.800		1.1043	0.9740
18	50	5	0.75	0.55	3.200	0.900		1.1016	0.9832
19	50	5	0.75	0.55	9.500	3.400		1.1008	0.9892
20	50	5	0.75	0.55	2.200	0.700		1.1011	0.9964
21	50	5	0.75	0.55	17.50	11.20		1.1033	0.9598
22	50	5	0.75	0.55	0	0		1.1021	0.9691
23	50	5	0.75	0.55	3.200	1.600		1.1027	0.9917
24	50	5	0.75	0.55	8.700	6.700		1.1004	0.9951
25	50	5	0.75	0.55	0	0		1.0987	0.9933
26	**50**	**5**	**0.75**	**0.55**	**3.500**	**2.300**		**1.0943**	**0.9991**
27	50	5	0.75	0.55	0	0		1.1022	0.9792
28	50	5	0.75	0.55	0	0		1.1124	0.9992
29	50	5	0.75	0.55	2.400	0.900		1.1004	0.9935
30	50	5	0.75	0.55	10.60	1.900		1.1034	0.9950

In table XI, the observations for the IEEE 30 busdata with low load values have been shown where the capacitor is chosen within the 0.1 – 1 MVar by cultural algorithm technique. After through observation of the results, it can be shown after 100th iteration of each buses, bus no. 26 provides the lowest total voltage deviation values than other buses in the system. This helped to improve the voltage deviation from 1.1162 p.u to 1.0943 p.u. The optimum size of the capacitor is found as 0.9991 MVar. Now, to achieve improved results, the optimization parameters like CR, IN BS and MF are changed in the subsequent cases.

A comparative study of table VIII and XI shows that for high load values even with the change of optimization parameter the bus no. 11 is observed best bus to provide optimum response. Moreover, from table IX and X it can be stated that bus no. 26 is the best position for optimal capacitor placement even after change of parameters (*IN*=50). Here, the voltage deviation varies in a small quantity likely 1.0944 to 1.0943.

5.3. TABULATED RESULT OF CULTURAL ALGORITHM (CA) WITH CAPACITOR DEVICES PARAMETER (0 – 1.5) MVar BY CHANGING CROSSOVER RATIO (*CR*), MUTATION FACTOR (*MF*) NO. OF INDIVIDUAL (*IN*) AND BELIEF SPACE (*BS*)

TABLE XII: RESULT AFTER PLACING CAPACITOR (0-1.5 MVar) IN HIGH LOAD WITH FIXED *MF*, *CR*, *IN* AND *BS* (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	10	0.65	0.45	0	0	0.6471	0	0
2	100	10	0.65	0.45	21.70	12.70		1.0708	1.2220
3	100	10	0.65	0.45	4.600	2.200		1.0708	0.0052
4	100	10	0.65	0.45	14.60	2.600		1.0709	0.0129
5	100	10	0.65	0.45	94.20	19		1.0708	1.4695
6	100	10	0.65	0.45	3	1		1.0709	0.0177
7	100	10	0.65	0.45	42.80	20.90		1.0709	0.0181
8	100	10	0.65	0.45	30	30		1.0708	1.4557
9	100	10	0.65	0.45	4	1		1.0657	0.6060
10	100	10	0.65	0.45	10.80	4		1.0701	0.0035
11	**100**	**10**	**0.65**	**0.45**	**0**	**0**		**1.0608**	**0.2521**
12	100	10	0.65	0.45	22.20	14.50		1.0709	0.0040
13	100	10	0.65	0.45	0	0		1.0708	0.2318
14	100	10	0.65	0.45	12.20	2.600		1.0709	0.0071
15	100	10	0.65	0.45	16.20	4.500		1.0709	0.0046
16	100	10	0.65	0.45	3.500	2.800		1.0709	0.0055
17	100	10	0.65	0.45	9	10.80		1.0713	0.0317
18	100	10	0.65	0.45	3.200	0.900		1.0709	0.0047
19	100	10	0.65	0.45	9.500	3.400		1.0709	0.0018
20	100	10	0.65	0.45	2.200	0.700		1.0709	0.0030
21	100	10	0.65	0.45	17.50	11.20		1.0712	0.0248
22	100	10	0.65	0.45	0	0		1.0710	0.0121
23	100	10	0.65	0.45	3.200	1.600		1.0710	0.0132
24	100	10	0.65	0.45	8.700	6.700		1.0710	0.0071
25	100	10	0.65	0.45	0	0		1.0708	0.0011
26	100	10	0.65	0.45	3.500	2.300		1.0709	0.0014
27	100	10	0.65	0.45	0	0		1.0708	0.0005
28	100	10	0.65	0.45	0	0		1.0708	0.0021
29	100	10	0.65	0.45	2.400	0.900		1.0709	0.0020
30	100	10	0.65	0.45	10.6	1.9		1.0716	0.0257

In this study, the proposed problem with high load values have been optimized using a capacitor of range between (0 – 1.5 MVar) by cultural algorithm technique. The observations are shown in table XII. After closer observations, the bus no. 11 is observed to provide the lowest total voltage deviation values amongst all the buses in the system. This helped to improve voltage deviation from 0.6471 p.u to 1.0608 p.u. Here, the size of the capacitor is obtained as 0.2521 MVar. As, the results show improvement, the optimization parameters likely *CR*, *IN*, *BS* and *MF* are kept fixed for the next case of low load based optimization.

TABLE XIII: RESULT AFTER PLACING CAPACITOR (0 – 1.5 MVar) IN LOW LOAD WITH FIXED *MF*, *CR*, *IN* AND *BS* (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	10	0.65	0.45	0	0	1.1162	0	0
2	100	10	0.65	0.45	21.70	12.70		1.1161	1.4927
3	100	10	0.65	0.45	0.600	0.200		1.1121	1.4821
4	100	10	0.65	0.45	4.600	0.600		1.1118	0.4431
5	100	10	0.65	0.45	94.20	19		1.1161	1.4954
6	100	10	0.65	0.45	0	0		1.1123	1.4875
7	100	10	0.65	0.45	12.80	5.900		1.1131	0.8601
8	100	10	0.65	0.45	30	30		1.1161	1.4894
9	100	10	0.65	0.45	0	0		1.1058	1.4727
10	100	10	0.65	0.45	2.800	1		1.0987	0.2781
11	100	10	0.65	0.45	0	0		1.1161	1.4832
12	100	10	0.65	0.45	8.200	3.500		1.1053	0.2220
13	100	10	0.65	0.45	0	0		1.1161	1.4997
14	100	10	0.65	0.45	2.200	0.600		1.1002	1.4816
15	100	10	0.65	0.45	4.200	0.500		1.0992	1.4983
16	100	10	0.65	0.45	2.500	0.800		1.1001	1.4880
17	100	10	0.65	0.45	5	2.800		1.0981	1.4962
18	100	10	0.65	0.45	3.200	0.900		1.0941	1.4989
19	100	10	0.65	0.45	9.500	3.400		1.0930	1.4964
20	100	10	0.65	0.45	2.200	0.700		1.0936	1.4961
21	100	10	0.65	0.45	17.50	11.20		1.0961	1.4826
22	100	10	0.65	0.45	0	0		1.0948	1.4925
23	100	10	0.65	0.45	3.200	1.600		1.0959	1.4975
24	100	10	0.65	0.45	8.700	6.700		1.0925	1.4812
25	100	10	0.65	0.45	0	0		1.0902	1.4906
26	**100**	**10**	**0.65**	**0.45**	**3.500**	**2.300**		**1.0871**	**1.4972**
27	100	10	0.65	0.45	0	0		1.0948	1.4954
28	100	10	0.65	0.45	0	0		1.1106	1.4963
29	100	10	0.65	0.45	2.400	0.900		1.0925	1.4873
30	100	10	0.65	0.45	10.60	1.900		1.0972	0.4680

After CA based optimal sizing and placement of the capacitor device (0 – 1.5 MVar) in the IEEE 30 bus radial system data with low load value modification, the results are shown in table XIII. The observations show that bus no. 26 provides the lowest total voltage deviation values compared to all other buses in the system. It improves the voltage deviation from 1.1162 p.u to 1.0871 p.u with capacitor device size 1.4972 MVar. These optimization parameters like *CR, IN BS* and *MF* are further changed to obtain better results.

TABLE XIV: RESULT AFTER PLACING CAPACITOR (0-1.5 MVar) IN HIGH LOAD WITH CHANGED *MF*, *CR*, *IN* AND *BS* (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	5	0.75	0.55	0	0	**0.6471**	0	0
2	50	5	0.75	0.55	21.70	12.70		1.070	0.5634
3	50	5	0.75	0.55	4.600	2.200		1.070	0.0014
4	50	5	0.75	0.55	14.60	2.600		1.071	0.0586
5	50	5	0.75	0.55	94.20	19		1.070	0.4767
6	50	5	0.75	0.55	3	1		1.071	0.0786
7	50	5	0.75	0.55	42.80	20.90		1.070	0.0022
8	50	5	0.75	0.55	30	30		1.070	0.7702
9	50	5	0.75	0.55	4	1		1.071	0.0208
10	50	5	0.75	0.55	10.80	4		1.071	0.0117
11	**50**	**5**	**0.75**	**0.55**	**0**	**0**		**1.070**	**0.1271**
12	50	5	0.75	0.55	22.20	14.50		1.070	0.0027
13	50	5	0.75	0.55	0	0		1.070	0.2243
14	50	5	0.75	0.55	12.20	2.600		1.072	0.1123
15	50	5	0.75	0.55	16.20	4.500		1.071	0.0111
16	50	5	0.75	0.55	3.500	2.800		1.071	0.0199
17	50	5	0.75	0.55	9	10.80		1.070	0.0019
18	50	5	0.75	0.55	3.200	0.900		1.071	0.0632
19	50	5	0.75	0.55	9.500	3.400		1.070	0.0041
20	50	5	0.75	0.55	2.200	0.700		1.071	0.0084
21	50	5	0.75	0.55	17.50	11.20		1.071	0.0187
22	50	5	0.75	0.55	0	0		1.071	0.0500
23	50	5	0.75	0.55	3.200	1.600		1.071	0.0445
24	50	5	0.75	0.55	8.700	6.700		1.071	0.0448
25	50	5	0.75	0.55	0	0		1.071	0.0079
26	50	5	0.75	0.55	3.500	2.300		1.073	0.0852
27	50	5	0.75	0.55	0	0		1.071	0.0433
28	50	5	0.75	0.55	0	0		1.071	0.0445
29	50	5	0.75	0.55	2.400	0.900		1.071	0.0160
30	50	5	0.75	0.55	10.6	1.9		1.072	0.0425

In this work, IEEE 30 bus radial system data with high load value modification has been optimized with a capacitor ranging to 0 – 1.5 MVar by cultural algorithm technique. The observations are shown in table XIV. The observations show that bus no. 11 provides the lowest total voltage the response is found to be improved, the optimization parameters are remained fixed for the next case study. Deviation values compared to other buses in the system. It improves the voltage deviation from 0.6471 p.u to 1.070 p.u. Here, the optimal sizing of the capacitor has been found as 0.1271 MVar.

TABLE XV: RESULT AFTER PLACING CAPACITOR (0-1.5 MVar) IN LOW LOAD WITH CHANGED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	5	0.75	0.55	0	0	**1.1162**	0	0
2	50	5	0.75	0.55	21.70	12.70		1.1161	1.4324
3	50	5	0.75	0.55	0.600	0.200		1.1121	1.4957
4	50	5	0.75	0.55	4.600	0.600		1.1118	1.4852
5	50	5	0.75	0.55	94.20	19		1.1161	1.1839
6	50	5	0.75	0.55	0	0		1.1124	1.4811
7	50	5	0.75	0.55	12.80	5.900		1.1132	1.4822
8	50	5	0.75	0.55	30	30		1.1161	0.6363
9	50	5	0.75	0.55	0	0		1.1060	1.4648
10	50	5	0.75	0.55	2.800	1		1.0985	1.4877
11	50	5	0.75	0.55	0	0		1.1161	0.0465
12	50	5	0.75	0.55	8.200	3.500		1.1054	1.4763
13	50	5	0.75	0.55	0	0		1.1161	1.4393
14	50	5	0.75	0.55	2.200	0.600		1.1006	1.4605
15	50	5	0.75	0.55	4.200	0.500		1.0992	1.4842
16	50	5	0.75	0.55	2.500	0.800		1.1005	1.4617
17	50	5	0.75	0.55	5	2.800		1.0982	1.4812
18	50	5	0.75	0.55	3.200	0.900		1.0943	1.4820
19	50	5	0.75	0.55	9.500	3.400		1.0945	1.4000
20	50	5	0.75	0.55	2.200	0.700		1.0946	1.4320
21	50	5	0.75	0.55	17.50	11.20		1.0967	1.4514
22	50	5	0.75	0.55	0	0		1.0955	1.4328
23	50	5	0.75	0.55	3.200	1.600		1.0966	1.4413
24	50	5	0.75	0.55	8.700	6.700		1.0935	1.4377
25	50	5	0.75	0.55	0	0		1.0914	1.4122
26	**50**	**5**	**0.75**	**0.55**	**3.500**	**2.300**		**1.0871**	**1.4809**
27	50	5	0.75	0.55	0	0		1.0957	1.4344
28	50	5	0.75	0.55	0	0		1.1107	1.4747
29	50	5	0.75	0.55	2.400	0.900		1.0926	1.4899
30	50	5	0.75	0.55	10.60	1.900		1.0978	1.4369

In table XV, the observations for the test system IEEE 30 busdata with low load values have been shown. Here, the size of the capacitor is chosen within the range between 0 – 1.5 MVar with cultural algorithm technique. After closer observation the bus no. 26 provides the lowest total voltage deviation values than other buses in the system. This improves the voltage deviation from 1.1162 p.u to 1.0871 p.u. Here, the optimum size of the capacitor is obtained as 1.4809 MVar.

Now, a capacitor based comparative study is made between Table (VII - XI) and Table (XII - XV). This indicated that with the increase in capacitor device, the percentage of total voltage deviation also has been increasing for each cases. These are already forecasted in Table VIII and XII, Table IX and XIII, Table XI and XV.

Since, capacitive Var compensations provide improved response however it has certain limitations due to its static behavior. Therefore, to generate realistic and sustainable results, few advanced dynamic Var compensators as STATCOM, UPFC are incorporated in the network.

5.4. TABULATED RESULT OF CULTURAL ALGORITHM (CA) WITH STATCOM DEVICES PARAMETER (-100 to 100) MVar BY CHANGING CROSSOVER RATIO (*CA*), MUTATION FACTOR (*MF*) NO. OF INDIVIDUAL (*IN*) AND BELIEF SPACE (*BS*)

Table XVI: RESULT AFTER PLACING STATCOM (-100 to 100 MVar) IN HIGH LOAD WITH FIXED *MF*, *CR*, *IN* AND *BS* (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	10	0.65	0.45	0	0	0.6471	0	0
2	100	10	0.65	0.45	21.70	12.70		0.5889	-74.6026
3	100	10	0.65	0.45	4.600	2.200		0.5326	-47.0242
4	100	10	0.65	0.45	14.60	2.600		0.5182	-38.1487
5	100	10	0.65	0.45	94.20	19		0.4965	-95.0978
6	100	10	0.65	0.45	3	1		0.4881	-45.1606
7	**100**	**10**	**0.65**	**0.45**	**42.80**	**20.90**		**0.4508**	**-37.1658**
8	100	10	0.65	0.45	30	30		0.4840	-63.5531
9	100	10	0.65	0.45	4	1		0.5980	-22.7899
10	100	10	0.65	0.45	10.80	4		0.5964	-17.0447
11	100	10	0.65	0.45	0	0		0.6395	-40.4000
12	100	10	0.65	0.45	22.20	14.50		0.6270	-19.0421
13	100	10	0.65	0.45	0	0		0.6875	-44.4370
14	100	10	0.65	0.45	12.20	2.600		0.6734	-16.8135
15	100	10	0.65	0.45	16.20	4.500		0.6758	-17.5045
16	100	10	0.65	0.45	3.500	2.800		0.6387	-17.6395
17	100	10	0.65	0.45	9	10.80		0.6217	-14.3912
18	100	10	0.65	0.45	3.200	0.900		0.6570	-14.7603
19	100	10	0.65	0.45	9.500	3.400		0.6574	-14.2529
20	100	10	0.65	0.45	2.200	0.700		0.6778	-17.2953
21	100	10	0.65	0.45	17.50	11.20		0.6126	-14.7204
22	100	10	0.65	0.45	0	0		0.6304	-18.4356
23	100	10	0.65	0.45	3.200	1.600		0.6105	-14.5118
24	100	10	0.65	0.45	8.700	6.700		0.5726	-16.8464
25	100	10	0.65	0.45	0	0		0.5371	-14.6609
26	100	10	0.65	0.45	3.500	2.300		0.5962	-15.7427
27	100	10	0.65	0.45	0	0		0.5362	-13.8624
28	100	10	0.65	0.45	0	0		0.4650	-40.1712
29	100	10	0.65	0.45	2.400	0.900		0.6061	-14.9025
30	100	10	0.65	0.45	10.6	1.9		0.5962	-13.1383

Here, the proposed work has been optimized using a STATCOM device ranging to (-100 to100 MVar) with cultural algorithm technique. The observations are shown in table XVI. The observations show that bus no. 7 provides the lowest total voltage deviation values after 100th iteration of each buses. It improves the voltage deviation from 1.1162 p.u to 0.4508 p.u. Here, the optimal size of the STATCOM is determined as -37.1658 MVar. Since the observations are found improving, the next case study for low load optimizations are conducted with same set of optimization parameters.

Table XVII: RESULT AFTER PLACING STATCOM (-100 - 100 MVar) IN LOW LOAD (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	10	0.65	0.45	0	0	**1.1162**	0	0
2	100	10	0.65	0.45	21.70	12.70		0.9649	75.0289
3	100	10	0.65	0.45	0.600	0.200		0.8405	99.0312
4	100	10	0.65	0.45	4.600	0.600		0.8008	97.6247
5	100	10	0.65	0.45	94.20	19		0.9496	56.9410
6	100	10	0.65	0.45	0	0		0.8170	88.1045
7	100	10	0.65	0.45	12.80	5.900		0.9086	70.5474
8	100	10	0.65	0.45	30	30		0.8683	84.0636
9	100	10	0.65	0.45	0	0		0.4852	53.8474
10	100	10	0.65	0.45	2.800	1		0.5943	46.5826
11	100	10	0.65	0.45	0	0		0.5321	53.6972
12	**100**	**10**	**0.65**	**0.45**	**8.200**	**3.500**		**0.4555**	**61.9478**
13	100	10	0.65	0.45	0	0		0.4909	58.5353
14	100	10	0.65	0.45	2.200	0.600		0.5951	52.4571
15	100	10	0.65	0.45	4.200	0.500		0.5830	52.0147
16	100	10	0.65	0.45	2.500	0.800		0.5413	54.2199
17	100	10	0.65	0.45	5	2.800		0.5757	47.7475
18	100	10	0.65	0.45	3.200	0.900		0.7411	49.0021
19	100	10	0.65	0.45	9.500	3.400		0.7623	46.2992
20	100	10	0.65	0.45	2.200	0.700		0.7351	44.5538
21	100	10	0.65	0.45	17.50	11.20		0.6504	44.9218
22	100	10	0.65	0.45	0	0		0.7368	43.9553
23	100	10	0.65	0.45	3.200	1.600		0.6617	46.4861
24	100	10	0.65	0.45	8.700	6.700		0.8381	30.3528
25	100	10	0.65	0.45	0	0		1.0251	10.0017
26	100	10	0.65	0.45	3.500	2.300		1.0573	6.88557
27	100	10	0.65	0.45	0	0		1.0464	11.1951
28	100	10	0.65	0.45	0	0		0.8968	51.2110
29	100	10	0.65	0.45	2.400	0.900		1.0805	3.75687
30	100	10	0.65	0.45	10.60	1.900		1.0847	3.02057

In this work, the results with STATCOM for the IEEE 30 bus radial system data with modified low load value modification has been shown in the table XVII. From the observations, it can be found that the bus no. 12 provides the lowest total voltage deviation values among all the buses in the network. Here, the voltage deviation is found 1.1162 p.u to 0.4555 p.u. The optimum size of the proposed device is 61.9478 MVar. Further, to obtain improved responses, the optimization parameters like *CR*, *IN BS* and *MF* are varied in the following cases.

Table XVIII: RESULT AFTER PLACING STATCOM (-100 - 100 MVar) IN HIGH LOAD WITH CHANGED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	5	0.75	0.55	0	0	**0.6471**	0	0
2	50	5	0.75	0.55	21.70	12.70		0.5889	-59.7897
3	50	5	0.75	0.55	4.600	2.200		0.5326	-47.0026
4	50	5	0.75	0.55	14.60	2.600		0.5183	-38.1140
5	50	5	0.75	0.55	94.20	19		0.4965	-92.3926
6	50	5	0.75	0.55	3	1		0.4881	-45.1485
7	**50**	**5**	**0.75**	**0.55**	**42.80**	**20.90**		**0.4508**	**-37.1658**
8	50	5	0.75	0.55	30	30		0.4840	-63.2872
9	50	5	0.75	0.55	4	1		0.5980	-23.2945
10	50	5	0.75	0.55	10.80	4		0.6510	-21.7158
11	50	5	0.75	0.55	0	0		0.6395	-40.9616
12	50	5	0.75	0.55	22.20	14.50		0.6271	-19.0970
13	50	5	0.75	0.55	0	0		0.6875	-45.5767
14	50	5	0.75	0.55	12.20	2.600		0.6722	-16.6437
15	50	5	0.75	0.55	16.20	4.500		0.6761	-17.3432
16	50	5	0.75	0.55	3.500	2.800		0.6845	-19.5486
17	50	5	0.75	0.55	9	10.80		0.6221	-14.5099
18	50	5	0.75	0.55	3.200	0.900		0.6612	-14.0699
19	50	5	0.75	0.55	9.500	3.400		0.6539	-13.8922
20	50	5	0.75	0.55	2.200	0.700		0.6450	-13.6864
21	50	5	0.75	0.55	17.50	11.20		0.61513	-15.1521
22	50	5	0.75	0.55	0	0		0.5784	-16.4525
23	50	5	0.75	0.55	3.200	1.600		0.6188	-15.8384
24	50	5	0.75	0.55	8.700	6.700		0.6176	-15.8806
25	50	5	0.75	0.55	0	0		0.5391	-14.9031
26	50	5	0.75	0.55	3.500	2.300		0.5979	-15.8985
27	50	5	0.75	0.55	0	0		0.5347	-13.1210
28	50	5	0.75	0.55	0	0		0.4614	-32.3830
29	50	5	0.75	0.55	2.400	0.900		0.5972	-13.9786
30	50	5	0.75	0.55	10.6	1.9		0.6130	-14.8037

Here, the observations for the CA based STATCOM implemented (-100 to 100 MVar) are shown in table XVIII. The observations show that the bus no. 7 provides the lowest total voltage deviation values amongst all the buses in the system. This improves the voltage deviation from 0.6471 p.u to 0.4508 p.u. where the optimal size of the allocated Var compensator is found as -37.1658 MVar. Since, the results show improvement, the optimization parameters like *CR, IN BS* and *MF* are remained fixed for the case studies with low load optimizations.

Table XIX: RESULT AFTER PLACING STATCOM (-100 - 100 MVar) IN LOW LOAD WITH CHANGED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	5	0.75	0.55	0	0	**1.1162**	0	0
2	50	5	0.75	0.55	21.70	12.70		0.9649	75.5446
3	50	5	0.75	0.55	0.600	0.200		0.8405	98.8221
4	50	5	0.75	0.55	4.600	0.600		0.8017	95.8611
5	50	5	0.75	0.55	94.20	19		0.9496	55.2897
6	50	5	0.75	0.55	0	0		0.8170	88.1044
7	50	5	0.75	0.55	12.80	5.900		0.9086	70.5459
8	50	5	0.75	0.55	30	30		0.8683	84.8831
9	50	5	0.75	0.55	0	0		0.4852	53.8448
10	50	5	0.75	0.55	2.800	1		0.5943	46.5826
11	50	5	0.75	0.55	0	0		0.5321	53.7210
12	**50**	**5**	**0.75**	**0.55**	**8.200**	**3.500**		**0.4555**	**61.9426**
13	50	5	0.75	0.55	0	0		0.4909	58.2287
14	50	5	0.75	0.55	2.200	0.600		0.5999	50.4524
15	50	5	0.75	0.55	4.200	0.500		0.5830	52.0146
16	50	5	0.75	0.55	2.500	0.800		0.5339	53.2505
17	50	5	0.75	0.55	5	2.800		0.5757	47.7464
18	50	5	0.75	0.55	3.200	0.900		0.7414	45.6286
19	50	5	0.75	0.55	9.500	3.400		0.7630	46.4294
20	50	5	0.75	0.55	2.200	0.700		0.7403	45.7034
21	50	5	0.75	0.55	17.50	11.20		0.6503	44.8617
22	50	5	0.75	0.55	0	0		0.7303	42.5179
23	50	5	0.75	0.55	3.200	1.600		0.6617	46.4862
24	50	5	0.75	0.55	8.700	6.700		0.8397	32.9497
25	50	5	0.75	0.55	0	0		1.0248	8.98207
26	50	5	0.75	0.55	3.500	2.300		1.0612	5.43344
27	50	5	0.75	0.55	0	0		1.0436	10.3122
28	50	5	0.75	0.55	0	0		0.8968	51.1908
29	50	5	0.75	0.55	2.400	0.900		1.0847	6.4770
30	50	5	0.75	0.55	10.60	1.900		1.0839	4.2246

The optimization results for the STATCOM based case study for low load are presented in table XIX. Here, the operating range of the proposed device is chosen as -100 to 100 MVar which are optimized by the CA. After closer observation, it is found that the optimum results come for the 12th bus amongst all the buses in the network after 100th iteration. It helps to improve voltage deviation from 1.1162 p.u to 0.4555 p.u. Here, the optimal size of the STATCOM is found as 61.9426 MVar. Now, to achieve better response the optimization parameters like *CR*, *IN BS* and *MF* are changed for the subsequent case studies.

5.5. TABULATED RESULT OF CULTURAL ALGORITHM (CA) WITH STATCOM DEVICES PARAMETER (-160 – 160) MVar BY CHANGING CROSSOVER RATIO (CA), MUTATION FACTOR (MF) NO. OF INDIVIDUAL (IN) AND BELIEF SPACE (BS)

Table XX: RESULT AFTER PLACING STATCOM (-160 - 160 MVar) IN HIGH LOAD WITH FIXED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	10	0.65	0.45	0	0	**0.6471**	0	0
2	100	10	0.65	0.45	21.70	12.70		0.5074	-114.2542
3	100	10	0.65	0.45	4.600	2.200		0.5326	-47.0069
4	100	10	0.65	0.45	14.60	2.600		0.5182	-38.1487
5	100	10	0.65	0.45	94.20	19		0.4964	-112.1827
6	100	10	0.65	0.45	3	1		0.5008	-34.0901
7	**100**	**10**	**0.65**	**0.45**	**42.80**	**20.90**		**0.4608**	**-37.2176**
8	100	10	0.65	0.45	30	30		0.4840	-56.2257
9	100	10	0.65	0.45	4	1		0.5980	-23.0033
10	100	10	0.65	0.45	10.80	4		0.6174	-17.3396
11	100	10	0.65	0.45	0	0		0.6395	-43.4840
12	100	10	0.65	0.45	22.20	14.50		0.6273	-19.2656
13	100	10	0.65	0.45	0	0		0.6875	-42.9964
14	100	10	0.65	0.45	12.20	2.600		0.6785	-17.5968
15	100	10	0.65	0.45	16.20	4.500		0.6842	-18.2757
16	100	10	0.65	0.45	3.500	2.800		0.6374	-17.3122
17	100	10	0.65	0.45	9	10.80		0.6230	-14.7447
18	100	10	0.65	0.45	3.200	0.900		0.6662	-15.7559
19	100	10	0.65	0.45	9.500	3.400		0.6590	-14.4264
20	100	10	0.65	0.45	2.200	0.700		0.6932	-19.0086
21	100	10	0.65	0.45	17.50	11.20		0.6127	-14.7380
22	100	10	0.65	0.45	0	0		0.6326	-18.6538
23	100	10	0.65	0.45	3.200	1.600		0.6148	-15.2066
24	100	10	0.65	0.45	8.700	6.700		0.6161	-16.1071
25	100	10	0.65	0.45	0	0		0.5391	-14.8999
26	100	10	0.65	0.45	3.500	2.300		0.6666	-14.2776
27	100	10	0.65	0.45	0	0		0.5364	-13.8984
28	100	10	0.65	0.45	0	0		0.4697	-31.9151
29	100	10	0.65	0.45	2.400	0.900		0.5966	-13.9159
30	100	10	0.65	0.45	10.6	1.9		0.5962	-13.1374

Now, the CA based STATCOM device ranging to -160 to 160 MVar are incorporated in the IEEE 30 busdata with high load values. The optimal results are shown in table XX. Here, the observation shows that the bus no. 7 provides the lowest total voltage deviation values than other buses in the system after 100th iteration of each buses. This helps to obtain the improved voltage deviation from 0.6471 p.u to 0.4608 p.u. The optimal size of the Var compensator is found as -37.2176 MVar. Optimization parameters like *CR*, *IN BS* and *MF* are fixed. Since, the results are observed to be improving, the CA based optimal parameters are kept constant for the next case study.

Table XXI: RESULT AFTER PLACING STATCOM (-160 - 160 MVar) IN LOW LOAD WITH FIXED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	10	0.65	0.45	0	0	**1.1162**	0	0
2	100	10	0.65	0.45	21.70	12.70		0.8418	123.0381
3	100	10	0.65	0.45	0.600	0.200		0.8124	116.6112
4	100	10	0.65	0.45	4.600	0.600		0.7738	105.2585
5	100	10	0.65	0.45	94.20	19		0.9496	56.6159
6	100	10	0.65	0.45	0	0		0.8170	88.1052
7	100	10	0.65	0.45	12.80	5.900		0.9186	70.5794
8	100	10	0.65	0.45	30	30		0.8683	91.7329
9	100	10	0.65	0.45	0	0		0.4852	53.8495
10	100	10	0.65	0.45	2.800	1		0.5946	46.7917
11	100	10	0.65	0.45	0	0		0.5321	53.9911
12	**100**	**10**	**0.65**	**0.45**	**8.200**	**3.500**		**0.4686**	**63.3123**
13	100	10	0.65	0.45	0	0		0.4909	58.6219
14	100	10	0.65	0.45	2.200	0.600		0.5891	51.1449
15	100	10	0.65	0.45	4.200	0.500		0.5897	52.5833
16	100	10	0.65	0.45	2.500	0.800		0.5437	53.1741
17	100	10	0.65	0.45	5	2.800		0.5757	47.5450
18	100	10	0.65	0.45	3.200	0.900		0.7414	45.6591
19	100	10	0.65	0.45	9.500	3.400		0.7656	46.9091
20	100	10	0.65	0.45	2.200	0.700		0.7346	44.4061
21	100	10	0.65	0.45	17.50	11.20		0.6590	47.9030
22	100	10	0.65	0.45	0	0		0.7326	43.0288
23	100	10	0.65	0.45	3.200	1.600		0.6746	45.3740
24	100	10	0.65	0.45	8.700	6.700		0.8372	30.7932
25	100	10	0.65	0.45	0	0		1.0246	8.01499
26	100	10	0.65	0.45	3.500	2.300		1.0776	11.9553
27	100	10	0.65	0.45	0	0		1.0441	10.4622
28	100	10	0.65	0.45	0	0		0.8968	51.1961
29	100	10	0.65	0.45	2.400	0.900		1.0820	3.31176
30	100	10	0.65	0.45	10.60	1.900		1.0893	6.63245

In this case, the CA based STATCOM integration ranging between -160 to 160 MVar to the network has been considered. The observations are presented in Table XXI. Here, bus no. 12 provides the lowest total voltage deviation values than other buses in the system. This further improves the voltage deviation from 1.1162 p.u to 0.4686 p.u for device size 63.3123 MVar. Now, to achieve better responses, the optimization parameters are varied in the following case studies.

Table XXII: RESULT AFTER PLACING STATCOM (-160 - 160 MVar) IN HIGH LOAD WITH CHANGED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSSOVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	5	0.75	0.55	0	0	0.6471	0	0
2	50	5	0.75	0.55	21.70	12.70		0.5074	-150.2292
3	50	5	0.75	0.55	4.600	2.200		0.5326	-47.0221
4	50	5	0.75	0.55	14.60	2.600		0.5182	-38.1478
5	50	5	0.75	0.55	94.20	19		0.4964	-111.0329
6	50	5	0.75	0.55	3	1		0.4887	-44.5165
7	**50**	**5**	**0.75**	**0.55**	**42.80**	**20.90**		**0.4616**	**-38.3571**
8	50	5	0.75	0.55	30	30		0.4840	-39.3251
9	50	5	0.75	0.55	4	1		0.5980	-23.5858
10	50	5	0.75	0.55	10.80	4		0.6773	-22.5502
11	50	5	0.75	0.55	0	0		0.6395	-42.6590
12	50	5	0.75	0.55	22.20	14.50		0.6284	-20.1573
13	50	5	0.75	0.55	0	0		0.6875	-40.8488
14	50	5	0.75	0.55	12.20	2.600		0.6737	-16.8691
15	50	5	0.75	0.55	16.20	4.500		0.6874	-18.7495
16	50	5	0.75	0.55	3.500	2.800		0.7146	-16.3294
17	50	5	0.75	0.55	9	10.80		0.6241	-15.0467
18	50	5	0.75	0.55	3.200	0.900		0.6605	-13.7278
19	50	5	0.75	0.55	9.500	3.400		0.6575	-14.2636
20	50	5	0.75	0.55	2.200	0.700		0.6476	-13.9702
21	50	5	0.75	0.55	17.50	11.20		0.6463	-14.6595
22	50	5	0.75	0.55	0	0		0.6626	-21.6815
23	50	5	0.75	0.55	3.200	1.600		0.6153	-15.2884
24	50	5	0.75	0.55	8.700	6.700		0.6162	-16.0796
25	50	5	0.75	0.55	0	0		0.5430	-15.3699
26	50	5	0.75	0.55	3.500	2.300		0.6436	-20.1192
27	50	5	0.75	0.55	0	0		0.5660	-17.7528
28	50	5	0.75	0.55	0	0		0.4655	-39.4009
29	50	5	0.75	0.55	2.400	0.900		0.6083	-15.1337
30	50	5	0.75	0.55	10.6	1.9		0.6276	-16.2846

Alike the previous case studies, the CA based STATCOM device incorporation is conducted here for the IEEE 30-bus system. The observations are shown in table XXII. Here, the range of the proposed device is chosen as -160 to 160 MVar. Here, the optimal response has been observed in the 7th bus after considering 100 iterations for each buses. The improvement in the total system voltage deviation has been minimized from 0.6471 to 0.4616 with STATCOM device of size -38.3571 MVar. Since, the results are found satisfactorily, the observations considering fixed optimal parameters are further continued for the following case studies.

Table XXIII: RESULT AFTER PLACING STATCOM (-160 to 160 MVar) IN LOW LOAD WITH CHANGED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	5	0.75	0.55	0	0	**1.1162**	0	0
2	50	5	0.75	0.55	21.70	12.70		0.8418	126.0301
3	50	5	0.75	0.55	0.600	0.200		0.8124	116.6106
4	50	5	0.75	0.55	4.600	0.600		0.7738	105.3202
5	50	5	0.75	0.55	94.20	19		0.9496	56.8080
6	50	5	0.75	0.55	0	0		0.8170	88.1048
7	50	5	0.75	0.55	12.80	5.900		0.9086	70.5582
8	50	5	0.75	0.55	30	30		0.8683	82.5762
9	50	5	0.75	0.55	0	0		0.4876	56.2267
10	50	5	0.75	0.55	2.800	1		0.5948	45.8645
11	50	5	0.75	0.55	0	0		0.5321	53.8832
12	**50**	**5**	**0.75**	**0.55**	**8.200**	**3.500**		**0.4660**	**61.1107**
13	50	5	0.75	0.55	0	0		0.4909	57.8051
14	50	5	0.75	0.55	2.200	0.600		0.5998	50.3398
15	50	5	0.75	0.55	4.200	0.500		0.5897	49.6429
16	50	5	0.75	0.55	2.500	0.800		0.5398	53.8638
17	50	5	0.75	0.55	5	2.800		0.5765	46.6421
18	50	5	0.75	0.55	3.200	0.900		0.7414	45.7050
19	50	5	0.75	0.55	9.500	3.400		0.7677	44.4597
20	50	5	0.75	0.55	2.200	0.700		0.7384	44.0590
21	50	5	0.75	0.55	17.50	11.20		0.6514	45.2947
22	50	5	0.75	0.55	0	0		0.7336	43.2524
23	50	5	0.75	0.55	3.200	1.600		0.6753	44.7655
24	50	5	0.75	0.55	8.700	6.700		0.8378	31.3390
25	50	5	0.75	0.55	0	0		1.0261	13.0379
26	50	5	0.75	0.55	3.500	2.300		1.0564	7.2094
27	50	5	0.75	0.55	0	0		1.0446	9.2143
28	50	5	0.75	0.55	0	0		0.8968	51.1907
29	50	5	0.75	0.55	2.400	0.900		1.1146	11.5794
30	50	5	0.75	0.55	10.60	1.900		1.0850	4.7063

Here, IEEE 30 bus radial system data with low load value modification has been optimized with a STATCOM device of range between (-160 to 160 MVar) by cultural algorithm technique. The results are demonstrated in the table XXIII. After a thorough investigation, it can be shown that bus no. 12 provides the lowest total voltage deviation values than other buses in the system. The proposed placement of the STATCOM of 61.1107 MVar helps to improve the voltage deviation from 1.1162 p.u to 0.4660 p.u.

Now, considering a comparative study for the Table (XVI - XIX) and Table (XX - XXIII), it can be noticed that with the increasing size of the STATCOM device, the percentage of total voltage deviation has also been improved for each cases. These are already illustrated in Table XVI and XX, Table XVII and XXI, Table XVIII and XXII, Table XIX and XXIII.

Now, the STATCOM based results are found better compared to capacitor based results however, it has some limitations such load management issue1s. These problem can be treated efficiently by incorporating UPFC device. The UPFC can inject both real and reactive power and changes the power angles of the buses. This helps to improve voltage deviation and congestion of the system.

5.6. TABULATED RESULT OF CULTURAL ALGORITHM (CA) WITH UPFC DEVICE BY CHANGING CROSSOVER RATIO (CA), MUTATION FACTOR (MF) NO. OF INDIVIDUAL (IN) AND BELIEF SPACE (BS)

Table XXIV: RESULT AFTER PLACING UPFC (0 to 1 & -180 to 180) IN HIGH LOAD WITH FIXED MF, CR AND IN (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSSOVER RATIO	MUTATION FACTOR	LOAD		CONGESTION BEFORE UPFC PLACEMENT		CONGESTION OBSERVED AFTER UPFC PLACEMENT			
					P	Q	CURRENT (KA)	FITNESS	FITNESS	CURRENT (KA)	DEVICE SIZE 1 (MVA)	DEVICE SIZE 2 (rad)
1	100	10	0.65	0.45	0	0	**29.1818**	**14.5295**	0		0	0
2	100	10	0.65	0.45	21.70	12.70			1.7230	27.0853	0.9844	-1.5580
3	100	10	0.65	0.45	4.600	2.200			10.4463	26.1467	0.9948	-1.6929
4	100	10	0.65	0.45	14.60	2.600			12.0957	27.5278	0.9887	-1.7145
5	**100**	**10**	**0.65**	**0.45**	**94.20**	**19**			**1.2416**	**26.9363**	**0.9957**	**-1.5746**
6	100	10	0.65	0.45	3	1			6.9787	26.6488	0.9830	-1.9775
7	100	10	0.65	0.45	42.80	20.90			12.2533	25.7579	0.9842	-1.4466
8	100	10	0.65	0.45	30	30			14.7120	25.6598	0.9708	0.6293
9	100	10	0.65	0.45	4	1			13.1900	26.3026	0.9894	-1.4239
10	100	10	0.65	0.45	10.80	4			14.1987	25.8362	0.9863	-1.4867
11	100	10	0.65	0.45	0	0			12.2479	25.9258	0.9792	-1.9036
12	100	10	0.65	0.45	22.20	14.50			13.1896	25.7742	0.9732	-2.1307
13	100	10	0.65	0.45	0	0			14.4896	25.4454	0.7123	2.7239
14	100	10	0.65	0.45	12.20	2.600			13.9329	25.9089	0.9494	-1.3409
15	100	10	0.65	0.45	16.20	4.500			8.1096	26.4134	0.9784	-2.1310
16	100	10	0.65	0.45	3.500	2.800			14.6448	25.6934	0.8471	2.8021
17	100	10	0.6	0.4	9	10.			14.7295	25.6700	0.9885	-1.2214

			5	5		80						
18	100	10	0.65	0.45	3.200	0.900			14.5726	25.6786	0.9773	-1.1898
19	100	10	0.65	0.45	9.500	3.400			14.9315	25.6155	0.9451	-0.5985
20	100	10	0.65	0.45	2.200	0.700			15.0727	25.4163	0.9910	2.6719
21	100	10	0.65	0.45	17.50	11.20			15.0260	25.4391	0.9726	-0.5826
22	100	10	0.65	0.45	0	0			15.0178	25.4129	0.9848	-1.2266
23	100	10	0.65	0.45	3.200	1.600			15.1201	25.3887	0.9917	1.4670
24	100	10	0.65	0.45	8.700	6.700			14.9137	25.8172	0.8749	1.4499
25	100	10	0.65	0.45	0	0			14.8756	25.5121	0.9924	-1.3419
26	100	10	0.65	0.45	3.500	2.300			14.8007	25.6069	0.9880	-0.3519
27	100	10	0.65	0.45	0	0			14.7462	25.5917	0.9722	-1.0750
28	100	10	0.65	0.45	0	0			14.9459	25.4377	0.9898	-0.5475
29	100	10	0.65	0.45	2.400	0.900			15.0316	25.8274	0.9342	-0.2575
30	100	10	0.65	0.45	10.6	1.9			15.0428	25.4141	0.9916	0.2046

IEEE 30 bus radial system data with low load value modification has been optimized with a UPFC device of range between (0 – 1 device sizes in MVA, -180 – 180 phase angle in rad) by cultural algorithm technique in the table XXIV. After optimization the results and through observation it can be shown that bus no. 5 provides the lowest fitness values than other buses in the system, as it improves fitness from 14.5295 p.u to 1.2416 p.u with UPFC device size . Improvement in congestion is marked by a change of current from 29.1818 KA to 26.9363 KA and the phase angle of UPFC device is -1.5746 rad. So bus no. 5 is the best bus to place UPFC device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are fixed for this optimization.

Table XXV: RESULT AFTER PLACING UPFC (0 to 1 & -180 to 180) IN LOW LOAD WITH FIXED MF, CR AND IN (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSSOVER RATIO	MUTATION FACTOR	LOAD		CONGESTION BEFORE UPFC PLACEMENT		CONGESTION OBSERVED AFTER UPFC PLACEMENT			
					P	Q	CURRENT (KA)	FITNESS	FITNESS	CURRENT (KA)	DEVICE SIZE 1 (MVA)	DEVICE SIZE 2 (rad)
1	100	10	0.65	0.45	0	0	**19.4748**	**7.3081**	0	0	0	0
2	100	10	0.65	0.45	21.70	12.70			1.2433	18.6731	0.9876	-1.6004
3	100	10	0.65	0.45	0.600	0.200			5.6037	18.0366	0.9990	-1.4959
4	100	10	0.65	0.45	4.600	0.600			5.7738	18.8238	0.9828	-1.3148
5	**100**	10	**0.65**	**0.45**	**94.20**	**19**			**-0.7079**	**18.7934**	**0.9985**	**-1.5707**
6	100	10	0.65	0.45	0	0			3.8622	18.3330	0.9968	-1.4948
7	100	10	0.65	0.45	12.80	5.900			5.6891	18.2910	0.9433	-1.5570
8	100	10	0.65	0.45	30	30			6.7814	17.7549	0.9966	1.2890
9	100	10	0.65	0.45	0	0			6.4941	18.0057	0.9733	-1.6774
10	100	10	0.65	0.45	2.800	1			7.0523	18.3525	0.9955	-1.4564
11	100	10	0.65	0.45	0	0			6.2456	17.9169	0.9411	-1.7450
12	100	10	0.65	0.45	8.200	3.500			6.5308	17.7116	0.9638	-1.9173
13	100	10	0.65	0.45	0	0			7.2070	17.5391	0.5572	2.6492
14	100	10	0.65	0.45	2.200	0.600			6.9396	17.7366	0.9792	-1.3012
15	100	10	0.65	0.45	4.200	0.500			4.4027	18.1769	0.9974	-1.9127
16	100	10	0.65	0.45	2.500	0.800			7.2909	17.5078	0.9730	1.7237
17	100	10	0.65	0.45	5	2.800			7.2460	17.5362	0.9891	-1.2881
18	100	10	0.65	0.45	3.200	0.900			7.0854	17.7065	0.9798	-1.1495
19	100	10	0.65	0.45	9.500	3.400			7.2371	17.6962	0.9912	-0.7352
20	100	10	0.65	0.45	2.200	0.700			7.3059	17.4894	0.2928	1.7077
21	100	10	0.65	0.45	17.50	11.20			7.2760	17.6364	0.9830	-0.3873
22	100	10	0.65	0.45	0	0			7.2219	17.6069	0.9968	-1.1090
23	100	10	0.65	0.45	3.200	1.600			7.2950	17.5318	0.9906	-0.8108
24	100	10	0.65	0.45	8.700	6.700			7.3134	17.8004	0.1727	-1.5312
25	100	10	0.65	0.45	0	0			7.1869	17.6961	0.9895	-1.0160
26	100	10	0.65	0.45	3.500	2.300			7.3860	17.5292	0.0561	2.0585
27	100	10	0.65	0.45	0	0			6.9778	17.5001	0.9907	-0.8013
28	100	10	0.65	0.45	0	0			7.3029	17.7068	0.9476	-1.6124
29	100	10	0.65	0.45	2.400	0.900			7.3084	18.4947	0.0385	1.0224
30	100	10	0.65	0.45	10.60	1.900			7.2628	17.5333	0.9972	0.2145

For table XLVI cultural algorithm technique has been implemented with UPFC of parameter limit between (0 – 1 device sizes in MVA, -180 – 180 phase angle in rad). The algorithm technique has been implemented for low load condition with the variation of optimization techniques parameters as well to achieve various improvement conditions. Bus no. 5 provides the lowest fitness values than other buses in the system, as it improves voltage deviation from 7.3081 p.u to -0.7079 p.u for device size 0.9985 and -1.5707 respectively. Congestion is noticed to have improved with decrease in the current level from 19.4748 KA to 18.7934 KA and the phase angle of UPFC device is -1.5707 rad. Thus it can be stated that bus no. 5 is the best bus to connect UPFC device to minimize congestion of the system. Optimization parameters like CR, IN BS and MF are fixed values.

Table XXVI: RESULT AFTER PLACING UPFC (0 to 1 & -180 to 180) IN HIGH LOAD WITH CHANGED MF, CR AND IN (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSSOVER RATIO	MUTATION FACTOR	LOAD		CONGESTION BEFORE UPFC PLACEMENT		CONGESTION OBSERVED AFTER UPFC PLACEMENT				
					P	Q	CURRENT (KA)	FITNESS	FITNESS	POWER	CURRENT (KA)	DEVICE SIZE 1 (MVA)	DEVICE SIZE 2 (rad)
1	50	5	0.75	0.55	0	0	**29.1818**	**14.5295**	0	0		0	0
2	**50**	**5**	**0.75**	**0.55**	**21.70**	**12.70**			**0.6307**	**4.4220**	**26.9435**	**0.9597**	**-1.0028**
3	50	5	0.75	0.55	4.600	2.200			10.4537	22.4824	26.3865	0.9965	-1.7077
4	50	5	0.75	0.55	14.60	2.600			11.9513	5.5919	26.8986	0.9421	-1.6604
5	50	5	0.75	0.55	94.20	19			1.5561	23.6675	**26.9968**	0.9958	-1.2696
6	50	5	0.75	0.55	3	1			7.1027	21.4481	26.6392	0.9779	-1.2571
7	50	5	0.75	0.55	42.80	20.90			12.5680	14.5116	26.8464	0.9912	-1.6583
8	50	5	0.75	0.55	30	30			14.9483	88.9992	25.6086	0.9824	0.5543
9	50	5	0.75	0.55	4	1			13.7288	5.3775	26.1046	0.9901	-0.7930
10	50	5	0.75	0.55	10.80	4			14.6501	7.0459	25.5934	0.9768	-0.8974
11	50	5	0.75	0.55	0	0			12.8033	4.2595	25.8906	0.9560	-2.2123
12	50	5	0.75	0.55	22.20	14.50			13.1812	4.0107	25.7076	0.9831	-1.9186
13	50	5	0.75	0.55	0	0			14.7178	4.7553	25.5379	0.8309	2.2635
14	50	5	0.75	0.55	12.20	2.600			14.2521	8.0787	25.7296	0.9352	-1.1873
15	50	5	0.75	0.55	16.20	4.500			8.2258	14.3675	26.3397	0.9591	-1.9270
16	50	5	0.75	0.55	3.500	2.800			14.6255	20.7074	25.6829	0.8537	2.9100
17	50	5	0.75	0.55	9	10.80			14.7840	23.6264	25.5531	0.9910	-2.1196
18	50	5	0.75	0.55	3.200	0.900			14.5418	18.75955	25.8740	0.9566	-1.1578
19	50	5	0.75	0.55	9.500	3.400			15.0488	21.0637	25.5072	0.9017	0.4513

20	50	5	0.75	0.55	2.200	0.700			15.0373	11.2527	25.5172	0.9813	-2.9117
21	50	5	0.75	0.55	17.50	11.20			15.0342	1.0529	23.4395	0.9733	-0.6629
22	50	5	0.75	0.55	0	0			15.0088	17.7128	25.3779	0.98680	-1.7569
23	50	5	0.75	0.55	3.200	1.600			15.0631	3.9126	25.3840	0.9524	0.7635
24	50	5	0.75	0.55	8.700	6.700			15.0141	11.2574	25.6085	0.9478	1.2894
25	50	5	0.75	0.55	0	0			14.9150	10.5630	25.5526	0.9780	-1.5539
26	50	5	0.75	0.55	3.500	2.300			14.8993	3.1227	25.6447	0.9739	-0.5051
27	50	5	0.75	0.55	0	0			14.7903	17.1859	25.5318	0.9071	-0.9250
28	50	5	0.75	0.55	0	0			14.9874	6.4543	25.5983	0.9836	-1.1913
29	50	5	0.75	0.55	2.400	0.900			15.0277	17.7450	25.6156	0.9956	-1.0800
30	50	5	0.75	0.55	10.6	1.9			15.0530	14.8957	25.5098	0.9803	0.4013

In table XLIV the 30 busdata with high load values have been optimized using a UPFC device of range between (0 – 1 device sizes in MVA, -180 – 180 phase angle in rad) with differential evolution technique. UPFC injects both real and reactive power to the system, changes power angle of buses to reduce congestion. After observation of the results it can be shown after 100th iteration of each buses, bus no. 2 provides the lowest total fitness value than other buses in the system, as it improves fitness from 14.5295 p.u to 0.6307 p.u for device range and phase angle. Improved congestion is noticed by a marked decrease in the current from 29.1818 KA to 26.9435 KA and the phase angle of UPFC device is -1.0028 rad. Thus it can be stated that bus no. 2 is the best bus to connect UPFC device to minimize fitness of the system. Optimization parameters like CR, IN BS and MF are changed from fixed values.

Table XXVII: RESULT AFTER PLACING UPFC (0 to 1 & -180 to 180) IN LOW LOAD WITH CHANGED MF, CR AND IN (CA)

BUS No.	No. OF INDIVIDUAL	No. OF BELIEF SPACE	CROSSOVER RATIO	MUTATION FACTOR	LOAD		CONGESTION BEFORE UPFC PLACEMENT		CONGESTION OBSERVED AFTER UPFC PLACEMENT			
					P	Q	CURRENT (KA)	FITNESS	FITNESS	CURRENT (KA)	DEVICE SIZE 1 (MVA)	DEVICE SIZE 2 (rad)
1	50	5	0.75	0.55	0	0	**19.4748**	**14.5295**	0	0	0	0
2	50	5	0.75	0.55	21.70	12.70			1.5913	18.6177	0.9554	-2.0254
3	50	5	0.75	0.55	0.600	0.200			5.7957	17.9271	0.9754	-1.4951
4	50	5	0.75	0.55	4.600	0.600			6.1273	17.9841	0.9295	-1.2463
5	**50**	**5**	**0.75**	**0.55**	**94.20**	**19**			**-0.6517**	**18.8672**	**0.9998**	**-1.4712**
6	50	5	0.75	0.55	0	0			4.1407	18.1342	0.9726	-1.4764
7	50	5	0.75	0.55	12.80	5.900			5.8016	18.6622	0.9999	-1.5691
8	50	5	0.75	0.55	30	30			6.9255	17.9930	0.9802	1.1835
9	50	5	0.75	0.55	0	0			6.5588	18.0099	0.8864	-1.5613
10	50	5	0.75	0.55	2.800	1			6.9569	18.1853	0.9804	-1.4825
11	50	5	0.75	0.55	0	0			5.8603	17.8557	0.983	-2.0178
12	50	5	0.75	0.55	8.200	3.500			6.4665	17.6689	0.9835	-1.8920
13	50	5	0.75	0.55	0	0			7.1297	17.5285	0.9970	2.6380
14	50	5	0.75	0.55	2.200	0.600			7.1002	17.5662	0.9303	-1.1696
15	50	5	0.75	0.55	4.200	0.500			4.5660	17.9829	0.99655	-1.4133
16	50	5	0.75	0.55	2.500	0.800			7.3066	17.5265	0.9076	1.6347
17	50	5	0.75	0.55	5	2.800			7.2727	17.5301	0.99998	-2.1983
18	50	5	0.75	0.55	3.200	0.900			7.1660	17.6321	0.9107	-0.4624

19	50	5	0.75	0.55	9.500	3.400			7.2461	17.6104	0.9516	-0.8846
20	50	5	0.75	0.55	2.200	0.700			7.3071	17.4949	0.2972	1.5673
21	50	5	0.75	0.55	17.50	11.20			7.2715	17.6470	0.9517	-0.8134
22	50	5	0.75	0.55	0	0			7.2237	17.5849	0.9293	-0.8358
23	50	5	0.75	0.55	3.200	1.600			7.3003	17.4209	0.7380	-1.2235
24	50	5	0.75	0.55	8.700	6.700			7.3079	17.5062	0.0963	-1.4740
25	50	5	0.75	0.55	0	0			7.1969	17.4588	0.9867	-1.1472
26	50	5	0.75	0.55	3.500	2.300			7.3133	17.5197	0.0071	2.2497
27	50	5	0.75	0.55	0	0			7.0453	17.9164	0.9567	-0.8184
28	50	5	0.75	0.55	0	0			7.2581	17.5811	0.9849	-0.9944
29	50	5	0.75	0.55	2.400	0.900			7.3252	18.3289	0.0355	-1.3398
30	50	5	0.75	0.55	10.60	1.900			7.2602	17.5358	0.9816	0.4014

IEEE 30 bus radial system data with low load value modification has been optimized with a UPFC device of range between (0 – 1 device sizes in MVA, -180 – 180 phase angle in rad) by cultural algorithm technique in the table XXVI. After optimization the results and through observation it can be shown that bus no. 5 provides the lowest fitness values than other buses in the system, as it improves fitness from 14.5295 p.u to -0.6517 p.u with UPFC device size of 0.9998 and 1.4712. So bus no. 5 is the best bus to place UPFC device to minimize fitness of the system. Optimization parameters like CR, IN BS and MF are kept unchanged for this optimization. Improved congestion can be showed by a marked decrease in the current from 19.4748 KA to 18.8672 KA and the phase angle of UPFC device is -1.4712 rad.

As seen in Table XXIV and XXVII, the fitness in bus number 2 is improved with increased UPFC parameter. Again, in Table XXV and XXV1I, the voltage deviation is improved in bus number 5 with increased UPFC parameter. The results of the algorithm shows significant reduction in fitness, thus it can be stated with the use of UPFC device both losses and voltage deviation have been minimized. UPFC also minimises line current values to reduce current flow of the congested lines.

5.7. TABULATED RESULT OF DIFFERENTIAL EVOLUTION (DE) WITH CAPACITOR DEVICE PARAMETER (0.1 - 1 MVar) BY CHANGING CROSSOVER RATIO (CA), MUTATION FACTOR (MF) NO. OF INDIVIDUAL (IN)

Table XXVIII: RESULT AFTER PLACING CAPACITOR (0.1 - 1 MVar) IN HIGH LOAD WITH FIXED MF, CR, IN (DE)

BUS No.	No. OF INDIVIDUAL	CROSSOVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
				P	Q	VOLTAGE DEVIATION p.u	VOLTAGE DEVIATION p.u	DEVICE SIZE (MVar)
1	100	0.65	0.85	0	0	**0.6471**	0	0
2	100	0.65	0.85	21.70	12.70		1.0708	0.2401
3	100	0.65	0.85	4.600	2.200		1.0711	0.1052
4	100	0.65	0.85	14.60	2.600		1.0712	0.1282
5	100	0.65	0.85	94.20	19		1.0708	0.3256
6	100	0.65	0.85	3	1		1.0711	0.1087
7	100	0.65	0.85	42.80	20.90		1.0712	0.1707
8	100	0.65	0.85	30	30		1.0708	0.8615
9	100	0.65	0.85	4	1		1.0750	0.5258
10	100	0.65	0.85	10.80	4		1.0723	0.1056
11	**100**	**0.65**	**0.85**	**0**	**0**		**1.0708**	**0.1183**
12	100	0.65	0.85	22.20	14.50		1.0719	0.1223
13	100	0.65	0.85	0	0		1.0708	0.2143
14	100	0.65	0.85	12.20	2.600		1.0721	0.1020
15	100	0.65	0.85	16.20	4.500		1.0723	0.1148
16	100	0.65	0.85	3.500	2.800		1.0721	0.1000
17	100	0.65	0.85	9	10.80		1.0723	0.1004
18	100	0.65	0.85	3.200	0.900		1.0725	0.1000
19	100	0.65	0.85	9.500	3.400		1.0737	0.1630
20	100	0.65	0.85	2.200	0.700		1.0726	0.1000
21	100	0.65	0.85	17.50	11.20		1.0746	0.2376
22	100	0.65	0.85	0	0		1.0725	0.1000
23	100	0.65	0.85	3.200	1.600		1.0724	0.1000
24	100	0.65	0.85	8.700	6.700		1.0733	0.1260
25	100	0.65	0.85	0	0		1.0734	0.1095
26	100	0.65	0.85	3.500	2.300		1.0738	0.1046
27	100	0.65	0.85	0	0		1.0733	0.1100
28	100	0.65	0.85	0	0		1.0713	0.1000
29	100	0.65	0.85	2.400	0.900		1.0736	0.1000
30	100	0.65	0.85	10.6	1.9		1.0768	0.2116

In table XXVIII IEEE 30 busdata with high load values have been optimized using a capacitor of range between (0.1 – 1 MVar) with the help of differential evolution technique. Capacitor injects reactive power to the system to minimize voltage deviation. After through observation of the results it can be shown after iteration of each buses, bus no. 11 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 0.6471 p.u to 1.0708 p.u for device size 0.1183 MVar. Thus it can be stated that bus no. 11 is the best bus to place capacitor device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are kept fixed for this optimization.

Table XXIX: RESULT AFTER PLACING CAPACITOR (0.1 - 1 MVar) IN LOW LOAD WITH FIXED MF, CR, IN (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	0.65	0.85	0	0	**1.1162**	0	0
2	100	0.65	0.85	21.70	12.70		1.1161	0.2544
3	100	0.65	0.85	0.600	0.200		1.1144	0.6195
4	100	0.65	0.85	4.600	0.600		1.1158	0.1047
5	100	0.65	0.85	94.20	19		1.1161	0.6127
6	100	0.65	0.85	0	0		1.1140	0.8102
7	100	0.65	0.85	12.80	5.900		1.1151	0.4696
8	100	0.65	0.85	30	30		1.1161	0.1171
9	100	0.65	0.85	0	0		1.1092	0.9989
10	100	0.65	0.85	2.800	1		1.1043	0.9985
11	100	0.65	0.85	0	0		1.1161	0.7488
12	100	0.65	0.85	8.200	3.500		1.1098	0.8535
13	100	0.65	0.85	0	0		1.1161	0.3253
14	100	0.65	0.85	2.200	0.600		1.1068	0.8733
15	100	0.65	0.85	4.200	0.500		1.1079	0.7109
16	100	0.65	0.85	2.500	0.800		1.1129	0.2884
17	100	0.65	0.85	5	2.800		1.1040	1
18	100	0.65	0.85	3.200	0.900		1.1034	0.8582
19	100	0.65	0.85	9.500	3.400		1.1010	0.9779
20	100	0.65	0.85	2.200	0.700		1.1011	0.9947
21	100	0.65	0.85	17.50	11.20		1.1028	0.9932
22	100	0.65	0.85	0	0		1.1060	0.6999
23	100	0.65	0.85	3.200	1.600		1.1026	0.9944
24	100	0.65	0.85	8.700	6.700		1.1105	0.3537
25	100	0.65	0.85	0	0		1.1109	0.2916
26	**100**	0.65	0.85	**3.500**	**2.300**		1.0944	0.9961
27	100	0.65	0.85	0	0		1.1083	0.5437
28	100	0.65	0.85	0	0		1.1139	0.5787
29	100	0.65	0.85	2.400	0.900		1.1004	0.9987
30	100	0.65	0.85	10.60	1.900		1.1034	0.9976

IEEE 30 busdata with low load value modification has been optimized with a capacitor of range between (0.1 – 1 MVar) by differential evolution technique in the table XXIX. Capacitor device injects extra reactive power to the system. After optimization the results have been presented in the table. After through observation it can be shown that bus no. 26 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 1.1162 p.u to 1.0994 p.u for device size 0.9961 MVar. So bus no. 26 is the best bus to place capacitor device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are kept fixed for this optimization.

Table XXX: RESULT AFTER PLACING CAPACITOR (0.1-1 MVar) IN HIGH LOAD WITH CHANGED MF, CR, IN (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	0.7	0.9	0	0	**0.6471**	0	0
2	50	0.7	0.9	21.70	12.70		1.070	0.7808
3	50	0.7	0.9	4.600	2.200		1.0712	0.1216
4	50	0.7	0.9	14.60	2.600		1.0712	0.1007
5	50	0.7	0.9	94.20	19		1.0708	0.7256
6	50	0.7	0.9	3	1		1.0712	0.1255
7	50	0.7	0.9	42.80	20.90		1.0713	0.1896
8	50	0.7	0.9	30	30		1.0708	0.1000
9	50	0.7	0.9	4	1		1.2060	0.6379
10	50	0.7	0.9	10.80	4		1.0722	0.1014
11	**50**	**0.7**	**0.9**	**0**	**0**		**1.0708**	**0.1148**
12	50	0.7	0.9	22.20	14.50		1.0722	0.1632
13	50	0.7	0.9	0	0		1.0708	0.3342
14	50	0.7	0.9	12.20	2.600		1.0721	0.1068
15	50	0.7	0.9	16.20	4.500		1.0722	0.1043
16	50	0.7	0.9	3.500	2.800		1.0721	0.1000
17	50	0.7	0.9	9	10.80		1.0724	0.1111
18	50	0.7	0.9	3.200	0.900		1.0725	0.1000
19	50	0.7	0.9	9.500	3.400		1.0729	0.1173
20	50	0.7	0.9	2.200	0.700		1.0726	0.1000
21	50	0.7	0.9	17.50	11.20		1.0745	0.2328
22	50	0.7	0.9	0	0		1.0751	0.2467
23	50	0.7	0.9	3.200	1.600		1.0724	0.1000
24	50	0.7	0.9	8.700	6.700		1.0728	0.1000
25	50	0.7	0.9	0	0		1.0735	0.1111
26	50	0.7	0.9	3.500	2.300		1.0744	0.1262
27	50	0.7	0.9	0	0		1.0731	0.1023
28	50	0.7	0.9	0	0		1.0714	0.1138
29	50	0.7	0.9	2.400	0.900		1.0736	0.1000
30	50	0.7	0.9	10.6	1.9		1.0767	0.2071

In table XXXI the 30 busdata with high load values have been optimized using a capacitor of range between (0.1 – 1 MVar) with differential evolution technique. After through observation of the results of each buses, bus no. 11 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 0.6471 p.u to 1.0708 p.u for device size 0.1148 MVar. Thus it can be stated that bus no. 11 is the best bus to connect capacitor device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are changed for this optimization.

Table XXXI: RESULT AFTER PLACING CAPACITOR (0.1-1 MVar) IN LOW LOAD WITH CHANGED MF, CR, IN (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	0.7	0.9	0	0	**1.1162**	0	0
2	50	0.7	0.9	21.70	12.70		1.1161	0.2339
3	50	0.7	0.9	0.600	0.200		1.1154	0.2715
4	50	0.7	0.9	4.600	0.600		1.1153	0.2613
5	50	0.7	0.9	94.20	19		1.1161	0.1000
6	50	0.7	0.9	0	0		1.1138	0.8812
7	50	0.7	0.9	12.80	5.900		1.1145	0.7640
8	50	0.7	0.9	30	30		1.1161	0.2399
9	50	0.7	0.9	0	0		1.1094	0.9664
10	50	0.7	0.9	2.800	1		1.1043	0.9980
11	50	0.7	0.9	0	0		1.1161	0.9051
12	50	0.7	0.9	8.200	3.500		1.1120	0.5513
13	50	0.7	0.9	0	0		1.1161	1
14	50	0.7	0.9	2.200	0.600		1.1099	0.5782
15	50	0.7	0.9	4.200	0.500		1.1131	0.2504
16	50	0.7	0.9	2.500	0.800		1.1107	0.5018
17	50	0.7	0.9	5	2.800		1.1116	0.3646
18	50	0.7	0.9	3.200	0.900		1.1109	0.3484
19	50	0.7	0.9	9.500	3.400		1.1106	0.3544
20	50	0.7	0.9	2.200	0.700		1.1013	0.9815
21	50	0.7	0.9	17.50	11.20		1.1028	0.9911
22	50	0.7	0.9	0	0		1.1096	0.4488
23	50	0.7	0.9	3.200	1.600		1.1026	0.9972
24	50	0.7	0.9	8.700	6.700		1.1133	0.1739
25	**50**	0.7	0.9	**0**	**0**		1.1060	0.5770
26	**50**	**0.7**	**0.9**	**3.500**	**2.300**		**1.0943**	**0.9999**
27	50	0.7	0.9	0	0		1.1074	0.6054
28	50	0.7	0.9	0	0		1.1136	0.6623
29	50	0.7	0.9	2.400	0.900		1.1003	0.9995
30	50	0.7	0.9	10.60	1.900		1.1095	0.5123

In table XXX the 30 busdata with low load values have been optimized using a capacitor of range between (0.1 – 1 MVar) with differential evolution technique. Capacitor injects reactive power of its device range to the system. After through observation of the results it can be shown after 100th iteration of each buses, bus no. 26 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 1.1162 p.u to 1.0943 p.u for device size 0.9999 MVar. Thus it can be stated that bus no. 26 is the best bus to connect capacitor device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are changed for this optimization from their fixed values of previous tables.

5.8. TABULATED RESULT OF DIFFERENTIAL EVOLUTION (DE) WITH CAPACITOR DEVICE PARAMETER (0 – 1.5) MVar BY CHANGING CROSSOVER RATIO (CA), MUTATION FACTOR (MF)

Table XXXII: RESULT AFTER PLACING CAPACITOR (0 – 1.5 MVar) IN HIGH LOAD WITH FIXED MF, CR (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		CONGESTION BEFORE CAPACITOR PLACEMENT	CONGESTION OBSERVED AFTER CAPACITOR PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	0.65	0.85	21.70	12.70	**0.6471**	0	0
2	100	0.65	0.85	4.600	2.200		1.0708	1.2220
3	100	0.65	0.85	14.60	2.600		1.0708	0
4	100	0.65	0.85	94.20	19		1.0708	0.9653
5	100	0.65	0.85	3	1		1.0708	1.4872
6	100	0.65	0.85	42.80	20.90		1.0708	0.1357
7	**100**	0.65	0.85	30	30		1.0712	0.1738
8	100	0.65	0.85	4	1		1.0708	1.3983
9	100	0.65	0.85	10.80	4		1.0747	0.4846
10	**100**	0.65	0.85	**0**	**0**		1.0708	0.0964
11	**100**	**0.65**	**0.85**	**22.20**	**14.50**		**1.0608**	**0.2531**
12	100	0.65	0.85	0	0		1.0718	0.1121
13	100	0.65	0.85	12.20	2.600		1.0708	1.0198
14	100	0.65	0.85	16.20	4.500		1.0708	0.6543
15	100	0.65	0.85	3.500	2.800		1.0708	0.4213
16	100	0.65	0.85	9	10.80		1.0710	0.0153
17	100	0.65	0.85	3.200	0.900		1.0708	0.3794
18	100	0.65	0.85	9.500	3.400		1.0720	0.0712
19	100	0.65	0.85	2.200	0.700		1.0731	0.1278
20	100	0.65	0.85	17.50	11.20		1.0708	0.1568
21	100	0.65	0.85	0	0		1.0718	0.0652
22	100	0.65	0.85	3.200	1.600		1.0850	0.8214
23	100	0.65	0.85	8.700	6.700		1.0833	0.7781
24	100	0.65	0.85	0	0		1.0708	0.3579
25	100	0.65	0.85	3.500	2.300		1.0708	0.9754
26	100	0.65	0.85	0	0		1.0708	0.9664
27	100	0.65	0.85	0	0		1.0708	0.4867
28	100	0.65	0.85	2.400	0.900		1.0708	0.1176
29	100	0.65	0.85	10.6	1.9		1.0708	0.0421
30	100	0.65	0.85	21.70	12.70		1.0736	0.0976

In table XXXI the 30 busdata with high load values have been optimized using a capacitor of range between (0 – 1.5 MVar) with differential evolution technique. Observation of the results of each buses, bus no. 11 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 0.6471 p.u to 1.0608 p.u for device size 0.2531 MVar. Thus it can be stated that bus no. 11 is the best bus to connect capacitor device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are changed for this optimization.

Table XXXIII: RESULT AFTER PLACING CAPACITOR (0 – 1.5 MVar) IN LOW LOAD WITH FIXED MF, CR (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	0.65	0.85	0	0	**1.1162**	0	0
2	100	0.65	0.85	21.70	12.70		1.1161	0.2544
3	100	0.65	0.85	0.600	0.200		1.1144	0.6195
4	100	0.65	0.85	4.600	0.600		1.1158	0.1047
5	100	0.65	0.85	94.20	19		1.1161	0.6127
6	100	0.65	0.85	0	0		1.1140	0.8102
7	**100**	0.65	0.85	12.80	5.900		1.1151	0.4696
8	100	0.65	0.85	30	30		1.1161	0.1171
9	100	0.65	0.85	0	0		1.1092	0.9989
10	100	0.65	0.85	2.800	1		1.1043	0.9985
11	100	0.65	0.85	0	0		1.1161	0.7488
12	100	0.65	0.85	8.200	3.500		1.1098	0.8535
13	100	0.65	0.85	0	0		1.1161	0.3253
14	100	0.65	0.85	2.200	0.600		1.1068	0.8733
15	100	0.65	0.85	4.200	0.500		1.1079	0.7109
16	100	0.65	0.85	2.500	0.800		1.1129	0.2884
17	100	0.65	0.85	5	2.800		1.1040	1
18	100	0.65	0.85	3.200	0.900		1.1034	0.8582
19	100	0.65	0.85	9.500	3.400		1.1010	0.9779
20	100	0.65	0.85	2.200	0.700		1.1011	0.9947
21	100	0.65	0.85	17.50	11.20		1.1028	0.9932
22	100	0.65	0.85	0	0		1.1060	0.6999
23	100	0.65	0.85	3.200	1.600		1.1026	0.9944
24	100	0.65	0.85	8.700	6.700		1.1105	0.3537
25	100	0.65	0.85	0	0		1.1109	0.2916
26	**100**	**0.65**	**0.85**	**3.500**	**2.300**		**1.0944**	**0.3453**
27	100	0.65	0.85	0	0		1.1083	0.5437
28	100	0.65	0.85	0	0		1.1139	0.5787
29	100	0.65	0.85	2.400	0.900		1.1004	0.9987
30	100	0.65	0.85	10.60	1.900		1.1034	0.9976

IEEE 30 bus radial system data with low load value modification has been optimized with a capacitor of range between (0 – 1.5 MVar) by differential evolution technique in the table XIII. After optimization the results and through observation it can be shown that bus no. 26 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 1.1162 p.u to 1.0944 p.u with capacitor device size 0.3453 MVar. So bus no. 26 is the best bus to place capacitor device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are fixed.

Table XXXIV: RESULT AFTER PLACING CAPACITOR (0 – 1.5 MVar) IN HIGH LOAD WITH CHANGED MF, CR (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	0.7	0.9	0	0	0.6471	0	0
2	50	0.7	0.9	21.70	12.70		1.0708	1.3958
3	50	0.7	0.9	4.600	2.200		1.0708	0.1007
4	50	0.7	0.9	14.60	2.600		1.0708	0.1111
5	50	0.7	0.9	94.20	19		1.0708	0.4759
6	50	0.7	0.9	3	1		1.0708	0.1367
7	50	0.7	0.9	42.80	20.90		1.0712	0.1757
8	50	0.7	0.9	30	30		1.0708	0.1002
9	50	0.7	0.9	4	1		1.2130	1.5000
10	50	0.7	0.9	10.80	4		1.0708	0.3210
11	**50**	**0.7**	**0.9**	**0**	**0**		**1.0708**	**0.2470**
12	50	0.7	0.9	22.20	14.50		1.0708	0.2231
13	50	**0.7**	**0.9**	**0**	**0**		**1.0708**	**0.9307**
14	50	0.7	0.9	12.20	2.600		1.0708	0.0015
15	50	0.7	0.9	16.20	4.500		1.0708	0.1243
16	50	0.7	0.9	3.500	2.800		1.0712	0.0313
17	50	0.7	0.9	9	10.80		1.0708	0.1182
18	50	0.7	0.9	3.200	0.900		1.0724	0.0942
19	50	0.7	0.9	9.500	3.400		1.0727	0.1079
20	50	0.7	0.9	2.200	0.700		1.0708	0.3821
21	50	0.7	0.9	17.50	11.20		1.0744	0.2280
22	50	0.7	0.9	0	0		1.0850	0.8215
23	50	0.7	0.9	3.200	1.600		1.0717	0.0546
24	50	0.7	0.9	8.700	6.700		1.0708	0.0591
25	50	0.7	0.9	0	0		1.0708	0.6521
26	50	0.7	0.9	3.500	2.300		1.0708	0.0012
27	50	0.7	0.9	0	0		1.0708	0.4578
28	50	0.7	0.9	0	0		1.0708	0.1143
29	50	0.7	0.9	2.400	0.900		1.0708	0.0023
30	50	0.7	0.9	10.6	1.9		1.0724	0.0563

IEEE 30 bus radial system data with high load value modification has been optimized with a capacitor of range between (0 – 1.5 MVar) by differential evolution technique in the table XV. Capacitor device injects extra reactive power to the system. After optimization the results have been presented in the table. After through observation it can be shown that bus no. 11 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 0.6471 p.u to 1.0708 p.u for device size 0.2470 MVar. So it can be stated that bus no. 11 is the best bus to place capacitor device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are changed from their normal values for this optimization.

Table XXXV: RESULT AFTER PLACING CAPACITOR (0 – 1.5 MVar) IN LOW LOAD WITH CHANGED MF, CR (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE CAPACITOR PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER CAPACITOR PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	0.7	0.9	0	0		0	0
2	50	0.7	0.9	21.70	12.70	**1.1162**	1.1161	1.3291
3	50	0.7	0.9	0.600	0.200		1.1145	0.5720
4	50	0.7	0.9	4.600	0.600		1.1123	1.2972
5	50	0.7	0.9	94.20	19		1.1161	0.1264
6	50	0.7	0.9	0	0		1.1144	0.6337
7	50	0.7	0.9	12.80	5.900		1.1143	0.8701
8	50	0.7	0.9	30	30		1.1161	0.2836
9	50	0.7	0.9	0	0		1.1058	1.4892
10	50	0.7	0.9	2.800	1		1.0986	1.4822
11	50	0.7	0.9	0	0		1.1161	1.1155
12	50	0.7	0.9	8.200	3.500		1.1057	1.4344
13	50	0.7	0.9	0	0		1.1161	0.0337
14	50	0.7	0.9	2.200	0.600		1.1071	0.8485
15	50	0.7	0.9	4.200	0.500		1.1095	0.5705
16	50	0.7	0.9	2.500	0.800		1.1116	0.4177
17	50	0.7	0.9	5	2.800		1.0993	1.3867
18	50	0.7	0.9	3.200	0.900		1.1041	0.8097
19	50	0.7	0.9	9.500	3.400		1.1000	1.0438
20	50	0.7	0.9	2.200	0.700		1.0936	1.4957
21	50	0.7	0.9	17.50	11.20		1.0962	1.4882
22	50	0.7	0.9	0	0		1.1147	0.0882
23	50	0.7	0.9	3.200	1.600		1.0958	1.4983
24	50	0.7	0.9	8.700	6.700		1.1002	1.0073
25	50	0.7	0.9	0	0		1.1014	0.8428
26	**50**	**0.7**	**0.9**	**3.500**	**2.300**		**1.0872**	**1.4713**
27	50	0.7	0.9	0	0		1.1064	0.6810
28	50	0.7	0.9	0	0		1.1128	0.8840
29	50	0.7	0.9	2.400	0.900		1.0928	1.4740
30	50	0.7	0.9	10.60	1.900		1.1150	0.0771

In table XIV the 30 busdata with low load values have been optimized using a capacitor of range between (0 – 1.5 MVar) with differential evolution technique. Capacitor device injects extra reactive power to the system. After through observation of the results of each buses, bus no. 26 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 1.1162 p.u to 1.0872 p.u for device size 1.4713 MVar. Thus it can be stated that bus no. 26 is the best bus to place capacitor device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are changed for this optimization.

A comparison study is made between Table (XXVIII - XXXI) and Table (XXXII – XXXVI). It can be stated that with the increase in capacitor device parameter the percentage of total voltage deviation did not increase for each case but an increase in device var rating can be observed which is keeping the voltage deviation values almost the same for each cases. As seen in Table XXVIII and XXXII, the voltage deviation in bus number 11 with increased capacitor parameter the var rating of the device changes. Again, in Table XXIX and XXXIII, the voltage deviation in bus number 26 with increased capacitor parameter remains almost same but var rating varies. In Table XXXI and XXXIV, the voltage deviation in bus number 26 with increased capacitor parameter remains same with device size again increases. Similarly, in Table XXXI and XXXVI, the voltage deviation in bus number 11 with increased capacitor parameter improves with increased capacitor var values. As the results shows increase in reactive compensation limit decreases percentage of voltage deviation so another case study has been made with STATCOM devices, for which reactive power compensation limit is more than that of the CAPACITOR device.

5.9. TABULATED RESULT OF DIFFERENTIAL EVOLUTION (DE) WITH STATCOM DEVICES PARAMETER (-100 – 100) MVar BY CHANGING CROSSOVER RATIO (CA), MUTATION FACTOR (MF)

Table XXXVI: RESULT AFTER PLACING STATCOM (-100 - 100 MVar) IN HIGH LOAD WITH FIXED MF, CR, IN AND BS (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	0.65	0.85	0	0	0.6471	0	0
2	100	0.65	0.85	21.70	12.70		0.5889	-63.2524
3	100	0.65	0.85	4.600	2.200		0.5102	-7.3245
4	100	0.65	0.85	14.60	2.600		3.1029	100
5	100	0.65	0.85	94.20	19		1.6930	-95.8245
6	**100**	**0.65**	**0.85**	**3**	**1**		**0.4670**	**-90.8959**
7	100	0.65	0.85	42.80	20.90		0.4702	3.7231
8	100	0.65	0.85	30	30		0.7551	32.8129
9	100	0.65	0.85	4	1		5.6908	100
10	100	0.65	0.85	10.80	4		0.5721	-95.4562
11	100	0.65	0.85	0	0		1.4013	-100
12	100	0.65	0.85	22.20	14.50		0.7813	43.8879
13	100	0.65	0.85	0	0		0.7813	1.8475
14	100	0.65	0.85	12.20	2.600		0.7781	-1.4759
15	100	0.65	0.85	16.20	4.500		0.7779	0.40307
16	100	0.65	0.85	3.500	2.800		0.7779	-0.04390
17	100	0.65	0.85	9	10.80		2.4455	-100
18	100	0.65	0.85	3.200	0.900		1.2448	61.42193
19	100	0.65	0.85	9.500	3.400		1.9751	-43.7468
20	100	0.65	0.85	2.200	0.700		1.2129	46.7518
21	100	0.65	0.85	17.50	11.20		1.1870	17.6725
22	100	0.65	0.85	0	0		1.1431	100
23	100	0.65	0.85	3.200	1.600		1.5433	-97.9540
24	100	0.65	0.85	8.700	6.700		1.1857	-31.5795
25	100	0.65	0.85	0	0		1.5824	-26.0214
26	100	0.65	0.85	3.500	2.300		1.2740	20.2781
27	100	0.65	0.85	0	0		1.1232	62.7930
28	100	0.65	0.85	0	0		2.0162	-98.3483
29	100	0.65	0.85	2.400	0.900		1.3431	-31.0209
30	100	0.65	0.85	10.6	1.9		1.8962	-28.5142

In table XXXVI the 30 busdata with high load values have been optimized using a STATCOM device of range between (-100 – 100 MVar) with differential evolution technique. STATCOM injects extra reactive power to the system. After through observation of the results it can be shown after 100th iteration of each buses, bus no. 6 provides the lowest total voltage deviation values than other buses in the system. It improves voltage deviation from 0.6471 p.u to 0.4670 p.u for device size -90.8959 MVar. The negative value indicates drawl of var from the line. Thus it can be stated that bus no. 6 is the best bus to place STATCOM device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are fixed for this case study.

Table XXXVII: RESULT AFTER PLACING STATCOM (-100 - 100 MVar) IN LOW LOAD WITH FIXED MF, CR, IN AND BS (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	0.65	0.85	0	0	1.1162	0	0
2	100	0.65	0.85	21.70	12.70		0.9649	76.5923
3	100	0.65	0.85	0.600	0.200		0.8208	52.5886
4	100	0.65	0.85	4.600	0.600		1.6691	91.8530
5	100	0.65	0.85	94.20	19		0.7804	-98.3679
6	100	0.65	0.85	0	0		0.7281	-14.1396
7	**100**	0.65	0.85	12.80	5.900		1.0561	50.5839
8	100	0.65	0.85	30	30		0.7253	-45.5097
9	**100**	**0.65**	**0.85**	**0**	**0**		**0.6782**	**9.6744**
10	100	0.65	0.85	2.800	1		1.4015	-68.5930
11	100	0.65	0.85	0	0		0.9139	65.64736
12	100	0.65	0.85	8.200	3.500		2.4426	54.15243
13	100	0.65	0.85	0	0		0.9685	-57.8074
14	100	0.65	0.85	2.200	0.600		0.9681	-3.1096
15	100	0.65	0.85	4.200	0.500		4.8298	75.5824
16	100	0.65	0.85	2.500	0.800		1.0910	-96.8606
17	100	0.65	0.85	5	2.800		1.0909	-1.11017
18	100	0.65	0.85	3.200	0.900		2.4846	-85.4167
19	100	0.65	0.85	9.500	3.400		1.1317	66.6735
20	100	0.65	0.85	2.200	0.700		1.1145	100
21	100	0.65	0.85	17.50	11.20		0.9986	-54.1899
22	100	0.65	0.85	0	0		1.7434	-89.0099
23	100	0.65	0.85	3.200	1.600		1.7389	2.3497
24	100	0.65	0.85	8.700	6.700		2.3795	-52.9454
25	100	0.65	0.85	0	0		1.7833	30.9542
26	100	0.65	0.85	3.500	2.300		1.1342	26.00786
27	100	0.65	0.85	0	0		1.9538	-39.0384
28	100	0.65	0.85	0	0		2.0402	26.3934
29	100	0.65	0.85	2.400	0.900		2.1412	3.63333
30	100	0.65	0.85	10.60	1.900		2.0382	-2.7803

IEEE 30 bus radial system data with low load value modification has been optimized with a STATCOM device of range between (-100 – 100 MVar) by differential evolution technique in the table XXXVII. After optimization the results and through observation it can be shown that bus no. 9 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 1.1162 p.u to 0.6782 p.u with capacitor device size 9.67442 MVar. So bus no. 9 is the best bus to place STATCOM device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are fixed.

Table XXXVIII: RESULT AFTER PLACING STATCOM (-100 - 100 MVar) IN HIGH LOAD WITH CHANGED MF, CR, IN AND BS (CA)

BUS No.	No. OF INDIVIDUAL	No.OF BELIEF SPACE	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
					P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	5	0.75	0.95	0	0	**0.6471**	0	0
2	50	5	0.75	0.95	21.70	12.70		0.5889	-54.2791
3	50	5	0.75	0.95	4.600	2.200		2.8750	100
4	50	5	0.75	0.95	14.60	2.600		0.5347	-99.9973
5	50	5	0.75	0.95	94.20	19		0.5158	-8.2109
6	50	5	0.75	0.95	3	1		0.5420	16.2282
7	50	5	0.75	0.95	42.80	20.90		0.5150	-16.1460
8	50	5	0.75	0.95	30	30		0.4894	-10.2865
9	50	5	0.75	0.95	4	1		0.4682	9.2345
10	50	5	0.75	0.95	10.80	4		0.4657	-1.4668
11	50	5	0.75	0.95	0	0		0.4657	-0.1010
12	50	5	**0.75**	**0.95**	**22.20**	**14.50**		**0.4560**	**1.9648**
13	50	5	0.75	0.95	0	0		0.4560	1.5819
14	50	5	0.75	0.95	12.20	2.600		0.4600	0.7407
15	50	5	0.75	0.95	16.20	4.500		0.7521	100
16	50	5	0.75	0.95	3.500	2.800		1.7049	-99.4518
17	50	5	0.75	0.95	9	10.80		0.8620	-37.8872
18	50	5	0.75	0.95	3.200	0.900		0.9311	8.6672
19	50	5	0.75	0.95	9.500	3.400		1.1410	-35.2701
20	50	5	0.75	0.95	2.200	0.700		0.8433	26.0026
21	50	5	0.75	0.95	17.50	11.20		0.8432	2.0153
22	50	5	0.75	0.95	0	0		5.1950	57.6967
23	50	5	0.75	0.95	3.200	1.600		0.9171	-61.8861
24	50	5	0.75	0.95	8.700	6.700		0.9046	-9.91280
25	50	5	0.75	0.95	0	0		0.9047	-0.1562
26	50	5	0.75	0.95	3.500	2.300		0.9098	1.5010
27	50	5	0.75	0.95	0	0		2.4006	-100
28	50	5	0.75	0.95	0	0		1.9487	99.9179
29	50	5	0.75	0.95	2.400	0.900		1.2211	35.1962
30	50	5	0.75	0.95	10.6	1.9		1.3324	9.7218

For table XXXIX differential evolution technique has been implemented with STATCOM of reactive power compensation between (-100 – 100 MVar). The algorithm technique has been implemented for high load condition with the variation of optimization techniques parameters as well to achieve various improvement conditions. Bus no. 12 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 0.6471 p.u to 0.4560 p.u for device size 1.9648 MVar. Thus it can be stated that bus no. 12 is the best bus to place STATCOM device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are changed for this optimization from their fixed values.

Table XXXIX: RESULT AFTER PLACING STATCOM (-100 - 100 MVar) IN LOW LOAD WITH CHANGED MF, CR, IN AND BS (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	0.75	0.9	0	0	**1.1162**	0	0
2	50	0.75	0.9	21.70	12.70		1.1161	-66.9848
3	50	0.75	0.9	0.600	0.200		0.8708	91.6521
4	50	**0.75**	**0.9**	**4.600**	**0.600**		**0.8073**	**60.4286**
5	50	0.75	0.9	94.20	19		1.1490	43.81315
6	50	0.75	0.9	0	0		0.8397	-25.2853
7	50	0.75	0.9	12.80	5.900		3.0794	79.8785
8	50	0.75	0.9	30	30		0.9332	-81.6162
9	50	0.75	0.9	0	0		1.8658	35.8793
10	50	0.75	0.9	2.800	1		0.9097	-26.6293
11	50	0.75	0.9	0	0		11.2924	100
12	50	0.75	0.9	8.200	3.500		7.4024	-99.0827
13	50	0.75	0.9	0	0		2.3272	-95.3041
14	50	0.75	0.9	2.200	0.600		2.3545	-14.3147
15	50	0.75	0.9	4.200	0.500		2.3556	-0.1463
16	50	0.75	0.9	2.500	0.800		2.3761	-2.9218
17	50	0.75	0.9	5	2.800		5.7775	20.5010
18	50	0.75	0.9	3.200	0.900		2.4103	-16.9975
19	50	0.75	0.9	9.500	3.400		2.4246	-1.3019
20	50	0.75	0.9	2.200	0.700		3.2575	91.5658
21	50	0.75	0.9	17.50	11.20		4.8753	88.4306
22	50	0.75	0.9	0	0		5.8765	-80.5640
23	50	0.75	0.9	3.200	1.600		1.0867	21.9317
24	50	0.75	0.9	8.700	6.700		3.6832	95.9815
25	50	0.75	0.9	0	0		2.3416.	64.2585
26	50	0.75	0.9	3.500	2.300		1.9865	63.8306
27	50	0.75	0.9	0	0		2.6543	20.8663
28	50	0.75	0.9	0	0		6.1453	74.3139
29	50	0.75	0.9	2.400	0.900		2.3578	-53.6106
30	50	0.75	0.9	10.60	1.900		2.6890	-31.3147

In table XXXVIII the 30 busdata with low load values have been optimized using a STATCOM device of range between (-100 – 100 MVar) with differential evolution technique. STATCOM injects extra reactive power to the system. After through observation of the results it can be shown after 100th iteration of each buses, bus no. 4 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 1.1162 p.u to 0.8073 p.u for device size 60.4286 MVar. Thus it can be stated that bus no. 4 is the best bus to connect STATCOM device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are changed for this optimization from their fixed values.

5.10. TABULATED RESULT OF DIFFERENTIAL EVOLUTION (DE) WITH STATCOM DEVICES PARAMETER (-160 – 160 MVar) BY CHANGING CROSSOVER RATIO (CA), MUTATION FACTOR (MF) NO. OF INDIVIDUAL (IN)

Table XL: RESULT AFTER PLACING STATCOM (-160 - 160 MVar) IN HIGH LOAD WITH FIXED MF, CR, IN AND BS (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	0.65	0.85	0	0	**0.6471**	0	0
2	100	0.65	0.85	21.70	12.70		0.5074	-119.7523
3	100	0.65	0.85	4.600	2.200		0.8085	-82.0401
4	100	0.65	0.85	14.60	2.600		0.5236	73.2792
5	100	0.65	0.85	94.20	19		0.5236	0.03637
6	100	0.65	0.85	3	1		0.5231	-0.4987
7	100	0.65	0.85	42.80	20.90		0.5199	-16.5900
8	100	0.65	0.85	30	30		0.5004	-11.5794
9	100	0.65	0.85	4	1		0.4735	12.0933
10	**100**	**0.65**	**0.85**	**10.80**	**4**		**0.4696**	**-0.6986**
11	100	0.65	0.85	0	0		0.4696	0.5739
12	100	0.65	0.85	22.20	14.50		1.5789	160
13	100	0.65	0.85	0	0		2.2557	-152.1291
14	100	0.65	0.85	12.20	2.600		0.7419	-72.5675
15	100	0.65	0.85	16.20	4.500		4.1757	-160
16	100	0.65	0.85	3.500	2.800		1.1853	113.9892
17	100	0.65	0.85	9	10.80		1.5846	19.4703
18	100	0.65	0.85	3.200	0.900		1.3787	-23.2446
19	100	0.65	0.85	9.500	3.400		1.3632	-10.1194
20	100	0.65	0.85	2.200	0.700		1.7890	88.1714
21	100	0.65	0.85	17.50	11.20		1.3622	-98.3222
22	100	0.65	0.85	0	0		2.6451	-71.8865
23	100	0.65	0.85	3.200	1.600		1.3211	81.7378
24	100	0.65	0.85	8.700	6.700		3.2401	-106.7199
25	100	0.65	0.85	0	0		1.8410	50.3007
26	100	0.65	0.85	3.500	2.300		1.8206	-2.9250
27	100	0.65	0.85	0	0		1.8992	-4.1268
28	100	0.65	0.85	0	0		1.7940	29.3263
29	100	0.65	0.85	2.400	0.900		2.6784	160
30	100	0.65	0.85	10.6	1.9		1.9870	132.3703

In table XL the 30 busdata with high load values have been optimized using a STATCOM device of range between (-160 – 160 MVar) with differential evolution technique. STATCOM injects reactive power to the system. After through observation of the results it can be shown after 100th iteration of each buses, bus no. 10 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 0.6471 p.u to 0.4696 p.u for device size -0.6986 MVar. Thus it can be stated that bus no. 10 is the best bus to connect STATCOM device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are fixed.

Table XLI: RESULT AFTER PLACING STATCOM (-160 - 160 MVar) IN LOW LOAD WITH FIXED MF, CR, IN AND BS (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	100	0.65	0.85	0	0	**1.1162**	0	0
2	100	0.65	0.85	21.70	12.70		1.0746	28.8263
3	100	0.65	0.85	0.600	0.200		0.8120	99.7592
4	100	0.65	0.85	4.600	0.600		0.8119	1.5455
5	100	0.65	0.85	94.20	19		0.8119	2.03969
6	**100**	**0.65**	**0.85**	**0**	**0**		**0.8117**	**-3.8228**
7	**100**	0.65	0.85	12.80	5.900		1.1392	-160
8	100	0.65	0.85	30	30		0.9153	127.8147
9	100	0.65	0.85	0	0		0.9942	160
10	100	0.65	0.85	2.800	1		1.2081	-147.10730
11	100	0.65	0.85	0	0		1.2034	-6.8502
12	100	0.65	0.85	8.200	3.500		1.1396	8.9032
13	100	0.65	0.85	0	0		1.1268	0.4532
14	100	0.65	0.85	2.200	0.600		3.0702	-160
15	100	0.65	0.85	4.200	0.500		1.3893	115.8089
16	100	0.65	0.85	2.500	0.800		3.2006	-143.2680
17	100	0.65	0.85	5	2.800		1.6509	106.4362
18	100	0.65	0.85	3.200	0.900		1.6546	2.5211
19	100	0.65	0.85	9.500	3.400		4.1876	-160
20	100	0.65	0.85	2.200	0.700		1.8400	135.0055
21	100	0.65	0.85	17.50	11.20		1.8364	0.5003
22	100	0.65	0.85	0	0		2.6810	32.8233
23	100	0.65	0.85	3.20	1.600		1.9476	-45.9744

				0				
24	100	0.65	0.85	8.700	6.700		1.9486	-0.7574
25	100	0.65	0.85	0	0		1.6543	108.2576
26	100	0.65	0.85	3.500	2.300		2.8641	-90.1198
27	100	0.65	0.85	0	0		2.0138	-50.4768
28	100	0.65	0.85	0	0		2.0112	4.8865
29	100	0.65	0.85	2.400	0.900		2.0455	-3.5078
30	100	0.65	0.85	10.60	1.900		2.0148	3.6206

For table XLI differential evolution technique has been implemented with STATCOM of reactive power compensation between (-160 – 160 MVar). The algorithm technique has been implemented for low load condition with the variation of optimization techniques parameters as well to achieve various improvement conditions. Bus no. 6 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 1.1162 p.u to 0.8117 p.u for device size -3.8228 MVar. Thus it can be stated that bus no. 6 is the best bus to connect STATCOM device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are fixed.

Table XLII: RESULT AFTER PLACING STATCOM (-160 - 160 MVar) IN HIGH LOAD WITH CHANGED MF, CR AND IN (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	0.75	0.95	0	0	**0.6471**	0	0
2	50	**0.75**	**0.95**	**21.70**	**12.70**		**0.5074**	**-146.6010**
3	50	0.75	0.95	4.600	2.200		1.0965	-160
4	50	0.75	0.95	14.60	2.600		0.5522	138.2657
5	50	0.75	0.95	94.20	19		0.5520	-77.4102
6	50	0.75	0.95	3	1		0.5464	-5.03516
7	50	0.75	0.95	42.80	20.90		3.1663	151.5205
8	50	0.75	0.95	30	30		0.6135	-140.6805
9	50	0.75	0.95	4	1		0.6135	-5.6540
10	50	0.75	0.95	10.80	4		3.8991	-160
11	50	0.75	0.95	0	0		2.0199	114.9474
12	50	0.75	0.95	22.20	14.50		1.1150	43.5320
13	50	0.75	0.95	0	0		1.0647	-3.0762
14	50	0.75	0.95	12.20	2.600		1.0971	2.5418
15	50	0.75	0.95	16.20	4.500		1.0676	-1.8967
16	50	0.75	0.95	3.500	2.800		1.0653	0.5689
17	50	0.75	0.95	9	10.80		4.3014	-160
18	50	0.75	0.95	3.200	0.900		1.8924	89.8148
19	50	0.75	0.95	9.500	3.400		1.7614	9.4010
20	50	0.75	0.95	2.200	0.700		1.6891	160
21	50	0.75	0.95	17.50	11.20		1.1245	151.1614
22	50	0.75	0.95	0	0		1.6543	69.6134
23	50	0.75	0.95	3.200	1.600		1.7234	66.0566
24	50	0.75	0.95	8.700	6.700		1.4589	130.9751
25	50	0.75	0.95	0	0		1.7543	-155.7199
26	50	0.75	0.95	3.500	2.300		1.8934	128.4091
27	50	0.75	0.95	0	0		1.2568	-118.8935
28	50	0.75	0.95	0	0		2.3696	118.2164
29	50	0.75	0.95	2.400	0.900		0.9975	12.1938
30	50	0.75	0.95	10.6	1.9		1.2457	129.1438

For table XLIII differential evolution technique has been implemented with STATCOM device of reactive power compensation between (-160 – 160 MVar). The algorithm technique has been implemented for high load condition with the variation of optimization techniques parameters as well to achieve various improvement conditions. For each cases the total system voltage deviation has been minimized but for the best cases it reduced from 0.6471 p.u to 0.5074 p.u with STATCOM device size -146.6010 MVar.

Table XLIII: RESULT AFTER PLACING STATCOM (-160 - 160 MVar) IN LOW LOAD WITH CHANGED MF, CR AND IN (DE)

BUS No.	No. OF INDIVIDUAL	CROSS OVER RATIO	MUTATION FACTOR	LOAD		VOLTAGE DEVIATION BEFORE STATCOM PLACEMENT	VOLTAGE DEVIATION OBSERVED AFTER STATCOM PLACEMENT	
				P	Q	VOLTAGE DEVIATION (p.u)	VOLTAGE DEVIATION (p.u)	DEVICE SIZE (MVar)
1	50	0.75	0.9	0	0	**1.1162**	0	0
2	50	0.75	0.9	21.70	12.70		0.8418	133.3188
3	50	0.75	0.9	0.600	0.200		0.8230	18.0639
4	50	0.75	0.9	4.600	0.600		0.8211	3.7307
5	50	0.75	0.9	94.20	19		0.7979	-28.0473
6	50	0.75	0.9	0	0		0.9360	-18.0573
7	50	0.75	0.9	12.80	5.900		0.8170	13.2074
8	50	0.75	0.9	30	30		0.8095	13.9083
9	50	0.75	0.9	0	0		0.6706	18.0553
10	50	0.75	0.9	2.800	1		0.6544	2.3170
11	50	0.75	0.9	0	0		0.8005	-36.1221
12	50	**0.75**	**0.9**	**8.200**	**3.500**		**0.6276**	**20.5014**
13	50	0.75	0.9	0	0		0.6579	-15.7501
14	50	0.75	0.9	2.200	0.600		3.4881	-160
15	50	0.75	0.9	4.200	0.500		0.9271	121.4333
16	50	0.75	0.9	2.500	0.800		0.8838	-9.0004
17	50	0.75	0.9	5	2.800		2.8041	-86.8005
18	50	0.75	0.9	3.200	0.900		1.2458	66.03164
19	50	0.75	0.9	9.500	3.400		1.5780	140.4211
20	50	0.75	0.9	2.200	0.700		1.9026	-157.9736
21	50	0.75	0.9	17.50	11.20		1.5070	-18.9738
22	50	0.75	0.9	0	0		1.3245	67.8786
23	50	0.75	0.9	3.200	1.600		1.4779	-90.1452
24	50	0.75	0.9	8.700	6.700		1.4781	-0.3225
25	50	0.75	0.9	0	0		1.5082	-3.1979
26	50	0.75	0.9	3.500	2.300		4.3730	-138.2239
27	50	0.75	0.9	0	0		2.4064	72.6868
28	50	0.75	0.9	0	0		2.4029	-5.8498
29	50	0.75	0.9	2.400	0.900		3.0140	-20.9706
30	50	0.75	0.9	10.60	1.900		2.5222	27.4143

IEEE 30 bus radial system data with low load value modification has been optimized with a STATCOM device of range between (-160 – 160 MVar) by differential evolution technique in the table XLII. After optimization the results and through observation it can be shown that bus no. 12 provides the lowest total voltage deviation values than other buses in the system, as it improves voltage deviation from 1.1162 p.u to 0.6276 p.u with capacitor device size 20.5014 MVar. So bus no. 12 is the best bus to place STATCOM device to minimize total voltage deviation of the system. Optimization parameters like CR, IN BS and MF are changed for this optimization.

If a comparison study is made between Table (XXXVI - XXXIX) and Table (XL - XXXIII), it can be stated that with the increase in STATCOM device parameter the percentage of total voltage deviation has slightly differentiated for each cases but the size of the device has been increased for compensation. As seen in Table XXXVI and XL, the voltage deviation of bus number 6 and 10 respectively improved with increased capacitor parameter but size of the devices i.e. var rating has been increased. Again, in Table XXXVII and XLI, the voltage deviation of bus number 9 and 6 respectively improved with increased STATCOM parameter var rating of the device has increased as well. Table XXXVIII and XLII, the voltage deviation compared between bus number 4 and 12 with increased STATCOM var rating increases. Similarly, in Table XXXIX and XXXIII, the voltage deviation comparison between in bus number 12 and 2 respectively improved with the increase in device var rating. As the results shows increase in reactive compensation limit decreases percentage of voltage deviation so another case study has been made with UPFC devices, which can inject both real and reactive power and changes the power angles of the buses, to improves voltage deviation and congestion of the system.

5.11. TABULATED RESULT OF DIFFERENTIAL EVOLUTION (DE) WITH UPFC DEVICES BY CHANGING CROSSOVER RATIO (CA), MUTATION FACTOR (MF) NO. OF INDIVIDUAL (IN)

Table XLIV: RESULT AFTER PLACING UPFC (0 to 1 MVA & -180 to 180 rad) IN HIGH LOAD WITH FIXED MF, CR AND IN (DE)

BUS No.	No. OF INDIVIDUAL	CROSSOVER RATIO	MUTATION FACTOR	LOAD		CONGESTION BEFORE UPFC PLACEMENT		CONGESTION OBSERVED AFTER UPFC PLACEMENT					
				P	Q	CURRENT (KA)	FITNESS	FITNESS	CURRENT (KA)	ACTIVE POWER (MW)	REACTIVE POWER (MVar)	DEVICE SIZE 1 (MVA)	DEVICE SIZE 2 (rad)
1	100	0.65	0.85	0	0	**29.1818**	**14.5295**	0	0	0	0	0	0
2	100	**0.65**	**0.85**	**21.70**	**12.70**			**-1.0896**	**25.2967**	**2.5587**	**8.0943**	**1.0000**	**-2.9333**
3	100	0.65	0.85	4.600	2.200			10.3914	26.3676	23.0053	13.0273	1.0000	-3.1416
4	100	0.65	0.85	14.60	2.600			11.8227	25.1355	13.0009	1.3985	0.9855	-0.5764
5	100	0.65	0.85	94.20	19			1.1457	26.0054	21.8986	12.2649	1.0000	-1.0580
6	100	0.65	0.85	3	1			6.8049	25.6928	20.5350	8.9508	1.0000	-3.1416
7	100	0.65	0.85	42.80	20.90			12.9089	26.7519	4.9006	9.5740	0.9729	-1.8832
8	100	0.65	0.85	30	30			14.9847	24.2163	96.9737	19.1344	0.9826	1.0820
9	100	0.65	0.85	4	1			13.7794	26.8891	1.5539	2.3416	0.9989	-0.8334
10	100	0.65	0.85	10.80	4			14.7624	25.0996	3.3036	0.4960	0.9778	-2.6577
11	100	0.65	0.85	0	0			12.3862	26.7550	3.6632	1.8444	0.9956	-1.9178
12	100	0.65	0.85	22.20	14.50			13.0826	25.7881	3.8280	0.2786	1.0000	-3.1416
13	100	0.65	0.85	0	0			15.0827	27.0296	3.5627	3.0482	0.9964	-2.2178
14	100	0.65	0.85	12.20	2.600			14.0339	25.4556	6.7691	0.8330	0.9983	-0.0159
15	100	0.65	0.85	16.20	4.500			7.8523	25.7093	12.0399	2.1391	1.0000	-3.1416
16	100	0.65	0.85	3.500	2.800			15.4734	26.5645	20.3563	14.192	0.9693	-3.0728
17	100	0.65	0.85	9	10.80			14.8212	27.5771	22.0243	15.132	0.9848	-2.3629
18	100	0.65	0.85	3.200	0.900			14.6031	24.6735	26.4030	14.089	0.9427	-1.7203
19	100	0.65	0.85	9.500	3.400			15.0496	26.3840	20.0187	13.763	0.9566	0.2523
20	100	0.65	0.85	2.200	0.700			15.0565	25.6028	12.6310	3.5884	0.9765	-2.6255
21	100	0.65	0.85	17.50	11.20			15.3203	26.4329	1.6554	3.3229	0.9656	0.3712
22	100	0.65	0.85	0	0			15.0839	24.4206	17.2144	4.8657	0.9912	-1.9592
23	100	0.65	0.85	3.200	1.600			15.1456	25.7374	3.7777	2.6738	0.9542	-0.5447
24	100	0.65	0.85	8.700	6.700			15.3335	26.5745	9.9975	7.7666	0.9965	0.9333
25	100	0.65	0.85	0	0			14.9411	24.5718	8.7688	3.3553	0.9970	-1.1894
26	100	0.65	0.85	3.500	2.300			15.0665	26.4880	10.5267	3.9712	0.9345	-0.3629
27	100	0.65	0.85	0	0			14.7727	27.4846	15.2423	0.0355	0.9903	-2.0051
28	100	0.65	0.85	0	0			15.0862	25.6507	14.3539	4.5060	0.9644	-0.3974
29	100	0.65	0.85	2.400	0.900			15.1513	24.5674	15.0327	14.2471	0.9918	0.0314
30	100	0.65	0.85	10.6	1.9			15.1720	24.7865	13.7256	1.37073	0.9863	1.52862

In table XLIV the 30 busdata with high load values have been optimized using a UPFC device of range between (0 – 1 MVA, -180 – 180 rad) with differential evolution technique. UPFC injects both real and reactive power to the system, changes power angle of buses to reduce congestion. After observation of the results it can be shown after 100th iteration of each buses, bus no. 2 provides the lowest total fitness value than other buses in the system, as it improves fitness from 14.5295 p.u to -1.0896 p.u for device range 0.9244 and phase angle -1.5280. Thus it can be stated that bus no. 2 is the best bus to connect UPFC device to minimize fitness of the system. A noticeable decrease in the current from 29.1818 KA to 25.2967 KA and the phase angle supplied by UPFC device is -2.9333 rad. in bus number 2 shows improved congestion condition. Optimization parameters like CR, IN BS and MF are fixed.

Table XLV: RESULT AFTER PLACING UPFC (0 to 1 MVA & -180 to 180 rad) IN LOW LOAD WITH FIXED MF, CR, IN AND BS (DE)

BUS No.	No. OF INDIVIDUAL	CROSSOVER RATIO	MUTATION FACTOR	LOAD			CONGESTION BEFORE UPFC PLACEMENT	CONGESTION OBSERVED AFTER UPFC PLACEMENT					
				P	Q	CURRENT (KA)	FITNESS p.u	FITNESS p.u	ACTIVE POWER (MW)	REACTIVE POWER (MVar)	CURRENT (KA)	DEVICE SIZE 1 (MVA)	DEVICE SIZE 2 (rad)
1	100	0.65	0.85	0	0	**19.4748**	**7.3081**	0	0	0		0	0
2	**100**	**0.65**	**0.85**	**21.70**	**12.70**			**0.9773**	**0.2504**	**13.0929**	**18.6685**	**1.0000**	**3.1416**
3	100	0.65	0.85	0.600	0.200			5.6631	23.2860	11.4149	18.0933	1.0000	3.1416
4	100	0.65	0.85	4.600	0.600			6.0074	2.4456	5.60563	18.6031	0.9855	-0.5764
5	100	0.65	0.85	**94.20**	**19**			-0.8465	24.9485	4.4645	18.7129	1.0000	0.4662
6	100	0.65	0.85	0	0			3.9599	23.9582	11.0291	18.3205	1.0000	3.1416
7	100	0.65	0.85	12.80	5.900			5.8906	9.3441	2.1469	18.5035	0.9729	-1.8832
8	100	0.65	0.85	30	30			6.8739	94.4890	21.2016	17.8350	0.9826	1.0820
9	100	0.65	0.85	0	0			6.6248	0.0327	0.9512	18.0493	0.9989	-0.8334
10	100	0.65	0.85	2.800	1			7.0722	18.1758	16.1783	17.8750	0.9778	-1.4500
11	100	0.65	0.85	0	0			6.0095	2.2876	6.3151	17.9680	0.9956	-1.9178
12	100	0.65	0.85	8.200	3.500			6.4533	0.3132	0.2871	17.7538	1.0000	3.1416
13	100	0.65	0.85	0	0			7.0727	0.3124	0.0445	17.6799	0.9964	3.1416
14	100	0.65	0.85	2.200	0.600			6.9287	0.2164	0.3608	17.7501	0.9983	-1.8469
15	100	0.65	0.85	4.200	0.500			4.4474	2.4367	0.7399	18.1248	1.0000	-3.1416
16	100	0.65	0.85	2.500	0.800			7.2781	5.6898	2.2503	17.6236	0.9693	3.1416
17	100	0.65	0.85	5	2.800			7.2447	9.9236	2.5429	17.6606	0.9848	3.1416
18	100	0.65	0.85	3.200	0.900			7.0604	8.0940	2.4600	17.8395	0.9427	3.1416

19	100	0.65	0.85	9.500	3.400			7.2451	12.2156	1.5530	17.5653	0.9566	-0.4852
20	100	0.65	0.85	2.200	0.700			7.2898	1.6980	0.6939	17.5970	0.9765	2.9910
21	100	0.65	0.85	17.50	11.20			7.2882	0.9267	1.3857	17.6425	0.9656	3.1416
22	100	0.65	0.85	0	0			7.2331	2.9704	0.9132	17.5734	0.9912	-1.5019
23	100	0.65	0.85	3.200	1.600			7.2936	1.9740	5.5039	17.5355	0.9542	-0.7211
24	100	0.65	0.85	8.700	6.700			7.2878	14.3405	3.7782	17.6178	0.9965	0.9934
25	100	0.65	0.85	0	0			7.2154	3.4872	1.3508	17.6075	0.9970	-1.1894
26	100	0.65	0.85	3.500	2.30			7.3087	1.8229	2.1338	17.4941	0.9345	-1.1894
27	100	0.65	0.85	0	0			7.0875	5.4552	1.6844	17.7645	0.9903	-1.3037
28	100	0.65	0.85	0	0			7.2509	2.8496	2.1392	17.5741	0.9644	-1.6318
29	100	0.65	0.85	2.400	0.900			7.3080	16.896	23.275	17.4811	0.9918	-0.3974
30	100	0.65	0.85	10.60	1.900			7.2420	3.9343	0.9384	17.5728	0.9863	-0.9872

IEEE 30 bus radial system data with low load value modification has been optimized with a UPFC device of range between (0 – 1 MVA, -180 – 180 rad) by differential evolution technique in the table XLV. After optimization the results and through observation it can be shown that bus no. 2 provides the lowest fitness values than other buses in the system, as it improves fitness from 7.3081 p.u to 0.9773 p.u with UPFC device size . So bus no. 2 is the best bus to place UPFC device to minimize total voltage deviation of the system. Decrease in the current level from 19.4748 KA to 18.6685 KA and the phase angle supplied by UPFC device is 3.1416 rad and device size is 1 MVA marks decrease in the congestion. Optimization parameters like CR, IN BS and MF are fixed for this optimization.

Table XLVI: RESULT AFTER PLACING UPFC (0 to 1 MVA & -180 to 180 rad) IN HIGH LOAD WITH CHANGED MF AND CR (DE)

BUS No.	No. OF INDIVIDUAL	CROSSOVER RATIO	MUTATION FACTOR	LOAD		CONGESTION BEFORE UPFC PLACEMENT		CONGESTION OBSERVED AFTER UPFC PLACEMENT					
				P	Q	CURRENT (KA)	FITNESS	FITNESS	ACTIVE POWER (MW)	REACTIVE POWER (MVar)	CURRENT (KA)	DEVICE SIZE 1	DEVICE SIZE 2
1	50	0.75	0.9	0	0	**29.1818**	**14.5295**	0	0	0	0	0	0
2	**50**	**0.75**	**0.9**	**21.70**	**12.70**			**-1.0896**	**0.0652**	**0.0454**	**27.2967**	**1.0000**	**-3.1416**
3	50	0.75	0.9	4.600	2.200			10.391	21.9941	13.3359	26.3676	1.0000	-3.1416
4	50	0.75	0.9	14.60	2.600			12.1254	0.9695	6.9161	27.1253	0.9877	-2.2417
5	50	0.75	0.9	94.20	19			1.1457	20.2157	13.0941	26.9919	0.9975	-2.6529
6	50	0.75	0.9	3	1			6.7072	17.0200	10.5005	26.6888	0.9945	-1.4109
7	50	0.75	0.9	42.80	20.90			12.8154	14.2126	9.1557	26.8350	0.9850	-0.3831
8	50	0.75	0.9	30	30			15.0032	100.0288	15.2971	25.7925	0.9580	0.7438
9	50	0.75	0.9	4	1			13.6637	2.0081	2.4239	26.1891	0.9896	-0.9616
10	50	0.75	0.9	10.80	4			14.8115	12.8180	12.1835	26.1732	0.8686	3.1055
11	50	0.75	0.9	0	0			12.2565	0.5010	0.7052	26.1071	0.9987	-1.4204
12	50	0.75	0.9	22.20	14.50			13.0826	1.9885	0.7824	25.7550	1.0000	-3.1416
13	50	0.75	0.9	0	0			15.0757	4.3525	0.4160	25.7558	0.9860	1.7514
14	50	0.75	0.9	12.20	2.600			14.1833	1.8920	2.9231	25.9843	0.9802	-1.6059
15	50	0.75	0.9	16.20	4.500			7.3995	15.7004	2.3588	26.4646	1.0000	-3.1416
16	50	0.75	0.9	3.500	2.800			14.5368	24.8828	10.7096	26.0574	0.9759	1.7910
17	50	0.75	0.9	9	10.80			14.7413	22.2335	14.3943	25.5457	1.0000	-3.1416
18	50	0.75	0.9	3.200	0.900			14.6226	20.7273	16.0795	25.7923	0.9921	-0.1944
19	50	0.75	0.9	9.500	3.400			15.0372	21.5178	9.0211	25.4792	1.0000	-3.1416
20	50	0.75	0.9	2.200	0.700			15.9359	14.5836	0.6564	25.9059	0.9591	3.0861
21	50	0.75	0.9	17.50	11.20			15.1214	7.3261	1.2737	25.4428	0.9757	-0.7933
22	50	0.75	0.9	0	0			15.0949	16.4047	4.4692	25.4881	0.9925	-0.3228
23	50	0.7	0.9	3.2	1.6			15.3368	3.9318	1.2854	25.4473	0.9920	0.0549

		5		00	00								
24	50	0.75	0.9	8.700	6.700			15.3445	9.7453	4.7176	25.5250	0.9517	-0.8317
25	50	0.75	0.9	0	0			14.9192	11.6368	3.6586	25.5161	0.9282	-1.5917
26	50	0.75	0.9	3.500	2.300			15.0336	1.2865	2.1983	25.5559	0.9145	-0.4464
27	50	0.75	0.9	0	0			14.7934	19.0475	12.4403	25.6844	0.9246	-2.0704
28	50	0.75	0.9	0	0			15.0949	9.6365	5.2292	25.4861	0.9627	-0.4910
29	50	0.75	0.9	2.400	0.900			15.1324	27.3429	11.8223	25.4895	0.9297	0.5042
30	50	0.75	0.9	10.6	1.9			15.1725	14.0628	0.5091	25.4763	0.9760	0.2776

In table XLIV the 30 busdata with high load values have been optimized using a UPFC device of range between (0 – 1MVA, -180 – 180 rad) with differential evolution technique. UPFC injects both real and reactive power to the system, changes power angle of buses to reduce congestion. After observation of the results it can be shown after 100th iteration of each buses, bus no. 2 provides the lowest total fitness value than other buses in the system, as it improves fitness from 14.5295 p.u to -1.0896 p.u for device range and phase angle. Thus it can be stated that bus no. 2 is the best bus to connect UPFC device to minimize fitness of the system. Congestion is also improved by a marked change in the current level from 29.1818 KA to 27.2967 KA and the phase angle supplied by UPFC device is -3.1416 rad and device size is 1 MVA. Optimization parameters like CR, IN, BS and MF are fixed.

For each cases the total system voltage deviation has been minimized but the percentage of minimization is dependent on parameter of optimization technique. With the decrease in parameters the percentage improvement has also been decreased. As seen in Table XLIV and XLVII, the fitness in bus number 2 slightly increases with increased UPFC parameter. In Table XLV and XLVI, the fitness in bus number 2 slightly increases in bus no. 5 respectively with increased UPFC parameter. With increased operational parameters bus number 2 of Table XLVII shows better optimization. The fitness has been taken as the equal weightage of system loss and voltage deviation. Both loss and Voltage deviation has been taken with 0.5 weightage. Both weightage have been accepted as fitness and UPFC device minimizes the fitness function to show improvement. The results of the algorithm shows significant reduction in fitness, thus it can be stated with the use of UPFC device both losses and voltage deviation have been minimized.

Table XLVII: RESULT AFTER PLACING UPFC (0 to 1 MVA & -180 to 180 rad) IN LOW LOAD WITH CHANGED MF AND CR (DE)

BUS No.	No. OF INDIVIDUAL	CROSSOVER RATIO	MUTATION FACTOR	LOAD		CONGESTION BEFORE UPFC PLACEMENT		CONGESTION OBSERVED AFTER UPFC PLACEMENT					
				P	Q	CURRENT (KA)	FITNESS	FITNESS	ACTIVE POWER (MW)	REACTIVE POWER (MVar)	CURRENT (KA)	DEVICE SIZE 1	DEVICE SIZE 2 (rad)
1	50	0.75	0.9	0	0	**19.4748**	**7.3081**	0	0	0			
2	50	0.75	0.9	21.70	12.70			0.9773	3.9438	6.9510	18.5812	0.9775	-2.1448
3	50	0.75	0.9	0.600	0.200			5.6631	20.0647	11.5003	18.0933	1.0000	3.1416
4	50	0.75	0.9	4.600	0.600			5.9393	12.0360	1.5102	18.6023	0.9877	-2.2417
5	**50**	**0.75**	**0.9**	**94.20**	**19**			**-0.8663**	**20.2025**	**13.5591**	**18.7026**	**0.9975**	**-2.6529**
6	50	0.75	0.9	0	0			3.9677	22.3405	12.8486	18.2989	0.9945	-1.4109
7	50	0.75	0.9	12.80	5.900			6.0220	0.6861	3.4845	18.5489	0.9850	-0.3831
8	50	0.75	0.9	30	30			6.8729	91.9580	20.6443	17.8055	0.9580	0.7438
9	50	0.75	0.9	0	0			6.6434	6.1074	0.26328	18.0313	0.9896	-0.9616
10	50	0.75	0.9	2.800	1			7.0657	18.1808	7.8471	17.9141	0.9597	-0.8357
11	50	0.75	0.9	0	0			6.0384	1.5320	8.3882	17.9741	0.9987	-1.4204
12	50	0.75	0.9	8.200	3.500			6.4533	1.5213	1.9550	17.7538	1.0000	3.1416
13	50	0.75	0.9	0	0			7.0727	0.1586	0.1325	17.6799	1.0000	2.7067
14	50	0.75	0.9	2.200	0.600			7.0127	3.0358	0.6775	17.8102	0.9802	-1.6059
15	50	0.75	0.9	4.200	0.500			4.6458	4.3937	1.7639	18.1248	1.0000	-3.1416
16	50	0.75	0.9	2.500	0.800			7.2781	9.7223	4.7075	17.6236	1.0000	3.1416
17	50	0.75	0.9	5	2.800			7.2447	7.0272	4.0427	17.6606	1.0000	3.1416
18	50	0.75	0.9	3.200	0.900			7.0997	14.2298	4.3287	17.7396	0.9921	-0.1944
19	50	0.75	0.9	9.500	3.400			7.2444	7.6732	3.2070	17.6651	1.0000	1.9528
20	50	0.75	0.9	2.200	0.700			7.2898	0.3802	0.5142	17.5970	1.0000	2.9910
21	50	0.75	0.9	17.50	11.20			7.2842	1.0731	3.7637	17.5411	0.9757	-0.7933
22	50	0.75	0.9	0	0			7.2241	0.7000	1.0363	17.5993	0.9925	-0.3228
23	50	0.75	0.9	3.200	1.600			7.2951	3.7429	10.6379	17.5618	0.9920	0.0549
24	50	0.75	0.9	8.700	6.700			7.2878	6.0807	11.7925	17.6178	1.0000	0.9934

25	50	0.75	0.9	0	0			7.2109	2.5221	2.12475	17.5693	0.9282	-1.5917
26	50	0.75	0.9	3.500	2.300			7.3059	4.2892	0.6266	17.4941	1.0000	-1.3037
27	50	0.75	0.9	0	0			7.0730	7.8792	0.8989	17.7208	0.9011	-0.3652
28	50	0.75	0.9	0	0			7.2589	4.0931	2.2877	17.5737	0.9627	-0.4910
29	50	0.75	0.9	2.400	0.900			7.3080	19.790	14.1965	17.4811	1.0000	-0.9872
30	50	0.75	0.9	10.60	1.900			7.2501	3.8184	1.54355	17.6091	0.9760	0.2776

For table XLVI differential evolution technique has been implemented with UPFC of parameter limit between (0 – 1, -180 - 180). The algorithm technique has been implemented for low load condition with the variation of optimization techniques parameters as well to achieve various improvement conditions. Bus no. 5 provides the lowest fitness values than other buses in the system, as it improves voltage deviation from 7.3081 p.u to -0.8663 p.u for device size. Improved congestion is noticed by a marked decrease in the current from 19.4748 KA to 18.7026 KA and the phase angle supplied by UPFC device is -2.6529 rad and device size is 0.9975 MVA. Thus it can be stated that bus no. 5 is the best bus to connect UPFC device to minimize congestion of the system. Optimization parameters like CR, IN BS and MF are varied from fixed values.

CONCLUSION

After observing the results of both Cultural algorithm and Differential Evolution algorithm it is clear that voltage profile improves with the increase of the range of reactive power compensation devices. So far we have seen that with the increase in capacitor limit voltage deviation increases moderately. But with the increase of var rating of STATCOM device the voltage deviation improvement percentage is better than the capacitor device. Thus it can be concluded that STATCOM device is better suited for the system with high or low load condition than capacitor device as STATCOM can inject and take away reactive power whenever necessary from the buses. On the other hand UPFC device can inject and take away both active and reactive power from the buses, so UPFC device is better suited for the system which consists of both congestion and voltage deviation. UPFC also minimises line current values to reduce current flow of the congested lines and changes phase angle to reduce congestion of the congested lines. As UPFC device has both shunt and series operation condition control of this device is complex, so there is scope for improvement of UPFC model in near future. From the results of both algorithm techniques in this work it can be observed that DE technique provides better voltage deviation improvement result than CA algorithm although CA algorithm technique is advantageous as it consumes lesser computational time than DE algorithm. The convergence of CA algorithm is also better than DE technique. But from the precision of optimization point of view DE technique is superior to CA technique.

Chapter 6: *Conclusion and Future Scope*

6.1. CONCLUSION

Maintaining of the system voltage profile within permissible limit is necessary to fulfil certain contracted conditions to deliver desirable power. Instability in voltage profile may lead to damage in equipment of the system or of the consumers' side. As the buses are connected with each other total voltage profile improvement of the system would affect every bus of the system and reduce their own voltage deviation. Through Newton-Raphson programming the load flow solutions are done and the loads of the system is increased or decreased as necessary to study the change of voltage deviation of the system. Voltage profile within 0.95-1.05 value has been accepted as normal voltage value, in this thesis. Due to the increase or decrease of load the total system voltage deviation either decrease or increase respectively. For UPFC device the losses also minimized along with total system voltage deviation which may show significant improvement in system contingent condition. According to the devices the voltage deviation has been minimized differently, this happens due to the difference in range of the devices. As example STATCOM devices can inject more reactive power to the buses than capacitor bank. The fast convergence simplicity of evolutionary algorithm technique DE makes itself very appropriate for this work. CA algorithm also has fast convergence, it consumes less computational time, so this optimization technique also has been very useful for the optimization work. CA technique has the ability to overcome global minima problem effectively. Though from the results of the work DE algorithm provides lowest minimum voltage deviation and losses than CA. At the end it can be stated very specifically that for Voltage Profile improvement and minimizing total voltage deviation of the system STATCOM device is more useful than CAPACITOR bank due to its enlarged range and control parameter. If system congestion is desired to be minimize then UPFC device is the perfect solution.

6.2. FUTURE SCOPE

This work is limited to only two FACTS devices UPFC and STATCOM and their performances. Only one FACTS or capacitor devices have been considered to be connected with the bus, in this work. In future more advanced modelling of the used FACTS devices can be considered or other FACTS devices that have not been considered in this work can be used to achieve desired result. More series-shunt FACTS devices through which multi objective goals can be achieved can be considered as 2nd or 3rd generation of FACTS devices which are already available in the market of the developed countries. Total system voltage deviation has been calculated and minimized here, which does not clearly indicate definite voltage profile improvement of each buses. Same can be stated for system losses. With UPFC device advance modelling, there is a huge scope in future to achieve better congestion management. Although the total voltage deviation and losses have been significantly minimized, so voltage deviation and system congestion is reduced, so it serves the objective of the work well but in near future for further through research purpose can be quested on this topic to specifically show voltage profile improvement of each buses in the system. As this is the age of Smart Grid technologies, so this work can also be implemented on Smart Grid, to make its outcome even more stable and reliable. Smart Grid profile improvement would be a significant advancement of this work.

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