COST OPTIMIZATION OF MICROGRID SYSTEM USING CUCKOO SEARCH ALGORITHM

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By

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This is to certify that the thesis entitled "COST OPTIMIZATION OF MICROGRID SYSTEM USING CUCKOO SEARCH ALGORITHM" submitted by Ms. **KEYA MAITRA** of **Registration No-129428 of 2014-2015** in partial fulfillment of the requirements for the award of degree in **Master of Engineering in Power Engineering** of **Jadavpur University**.

This is an authentic work carried by her under my 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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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis entitled "COST OPTIMIZATION OF MICROGRID SYSTEM USING CUCKOO SEARCH ALGORITHM" contains various literature survey and original work that have been carried out by the undersigned candidate, as a part of Degree of **Master of Engineering in Power Engineering** studies.

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ABSTRACT

Presently conventional energy resources are not always suitable or sufficient to cope with ever increasing energy demand in this world. Hence renewable energy sources have come up as an alternative in distributed energy system. In this work, microgrid system is introduced using distributed renewable energy sources and the economic perspectives are studied for different combinations.

A comparative study has been done to find the optimal power generation from distributed energy resources (DERs) for minimum generation cost. Two types of power delivery models have been considered; the first one consisting of Solar, Biomass and Battery whereas the second one is made out of four renewable energy sources namely biomass gassifier unit, solar module, and wind energy system along with battery storage system. The microgrid deals with power generation and supply demand in a small community and consumer based load data is considered on the basis of 24 hrs use. Here the microgrid is connected with a conventional power grid to purchase /sell excess power from / to the main grid.

This work explores the application of a new meta-heuristic algorithm namely Cuckoo Search (CS) in the area of cost optimization problem. The effectiveness of the proposed algorithm is developed in specific two cases to minimise the system generation cost and its performance is compared with other well established heuristic algorithms like Genetic Algorithm (GA) etc.

MATLAB codes are developed in house to evaluate the fitness function of this problem using cuckoo search algorithm. The result reveals that, combination of biomass gasifier unit and solar photovoltaic system is cost effective with respect to the other combination consisting of biomass gasifier unit, solar photovoltaic system and wind turbine generator. In addition, the obtained result is also compared with that generated by genetic algorithm (GA) and cuckoo search algorithm is proved better for the same input data.

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CHAPTER 1

INTRODUCTION TO ENERGY SYSTEM

1.1. Current Energy Scenario in India

Energy is one of the essential elements for the economic development of any country. The economics of the country is highly affected by the ever increasing energy demands leading to huge investments. In case of developing countries like India, energy demand is increasing day by day. Energy consumption rate in India is very high so it is the 6th largest energy consumer country in the world with 3.5% consumption rate. In recent years the energy consumption of India has been increasing at a very fast rate due to increase in population and economic development. All over the world India has ranked fourth in energy demand after USA, China and Russia. In the year 2020 it is estimated that demand will be 2.5 times of the present time [1].

The energy scenario of India shows that, primary energy production depends on coal based plants, followed by hydro, nuclear and other renewable energy resources. The modern trends show that the installed electricity generating capacity based on thermal power increased from about 80GW to around 200GW from 2005-06 to 2013-15 [2]. Hydro power based electricity generation has been maintained constantly around 40GW in this same period. Nuclear power generation is still in its budding stage and can prove to be more useful in the near future. Contribution from other utilities has shown a gradual increase of about 10% in this period [2].

In India total installed capacity is 228,665 Mw as on 29.02.2016, thermal power plants contribute 69.76% with the capacity of 201,360 Mw. The contribution of the hydro-thermal plants come next with an installed capacity of 42,703 Mw (14.79%).Nuclear plants give 2% (57800 Mw) of the total installed capacity. To meet the excess energy demand renewable energy sources like solar, wind, biomass, small hydro plants are used which gives 13.45% with an installed capacity of 38,822 Mw [3].

The geographical distribution of installed power generation capacity as on 31.03.15 is shown in Fig. 1.1. The total installed capacity all over India is 245.25GW. Out of this, the western region has the highest sharing capacity (36.19%) and north eastern region has the lowest sharing capacity (1.19%).Northern region and southern region accounted for 26.28% and

24.06% share respectively. Sikkim, among all the states registered highest annual growth in installed capacity followed by Chhattisgarh and Madhya Pradesh.

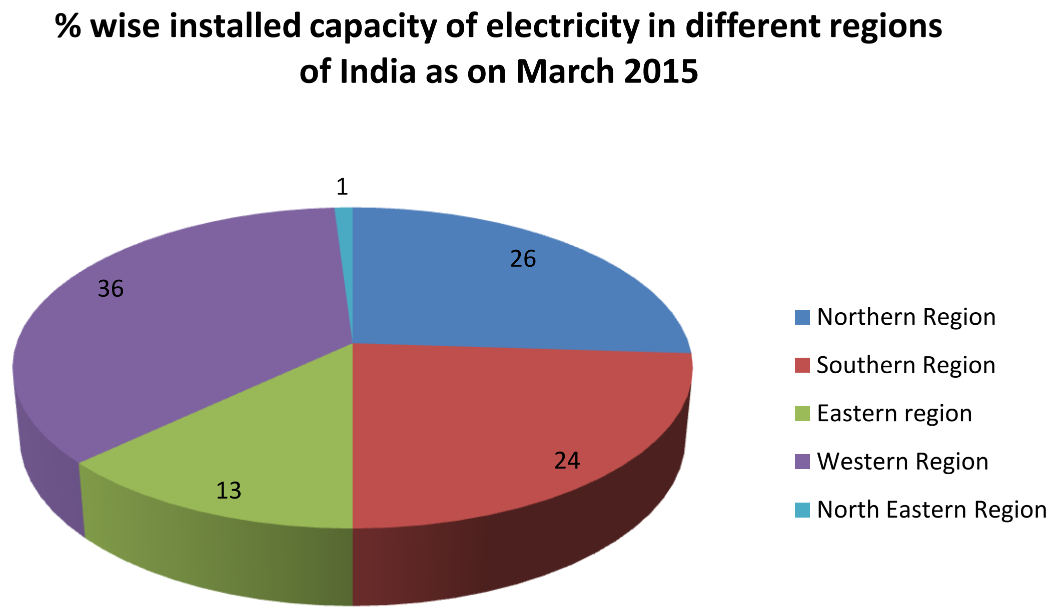


FIG 1.1: Region wise installed capacities in India as on 31.03.2015 [2].

It has been observed that India posses a huge potential for installation of renewable sources like solar and wind. According to the Ministry of New and Renewable Energy (MNRE), India sets target of 1400 MW solar power, 2400 MW wind power, 250 MW small hydro powers, 400 MW bio power by March 2019.

1.2. Installed renewable energy sources in INDIA

In India renewable energy source is the most important application for generation of power such as solar, biomass, wind tide etc. It is estimated that the total potential in power generation from renewable sources is 147615 Mw as on 31.03.15. This includes wind power energy of 102772 Mw (69.6%) followed by small hydro power energy of 17,538(11.88%) and 500 Mw (3.39%) from biogases. Total 1221.26 MW Solar Cookers are installed as on 31.03.2015, 825.09 MW were installed in Gujarat and 223.9 MW in Rajasthan.

Table 1.1 shows that the position of Gujrat is first among all the states with 25.04% (36,956 Mw) installed capacity followed by Karnataka with sharing capacity of 13.08% (19,315 Mw) and Tamilnadu with 11.7% share (16,483 Mw) due to their wind resources. Gujarat and Rajasthan enhance their installed capacity in solar power. To produce renewable power from biogas plants Maharashtra tops in the list followed by Andhra Pradesh, Karnataka, Uttar Pradesh, Gujarat etc. [2]

Table 1.1: Installed renewable power in India as on 31.04.15

State wise Distribution of Renewable Power in India as on 31.03.2015 (Total Reserves = 147615 Mega Watt)	
State	**% Reserve of Renewable Power**
Gujarat	25%
Karnataka	13%
Andhra Pradesh	11%
Tamil Nadu	11%
Maharashtra	7%
Jammu & Kashmir	5%
Madhya Pradesh	4%
Rajasthan	4%
Punjab	3%
Uttar Pradesh	3%
Other states and Union Territories	14%

The installed renewable systems and their efficient performance have promoted the idea of designing hybrid energy systems where the renewable sources and the non renewable sources are being installed together. This helps in meeting the high energy demands resulting in better economics of the system. From the table 1.2 it is found that solar power is utilised more in 2015 comparison to 2014 and utilization of the other renewable sources is growing rapidly.

Table 1.2: Installed renewable power in India as on 31.04.15		
Source wise Installed Capacity of Grid Interactive Renewable Power in India		
Types of Renewable Sources of Energy	**Capacity as on March 2014 (in Mega Watt)**	**Capacity as on March 2015 (in Mega Watt)**
Biomass Power	3601.03	4013.55
Waste to Energy	96.08	106.58
Wind Power	19051.46	21136.40
Small Hydro Power	3632.25	3803.70
Solar Power	1686.44	2631.96

1.3. Necessity of hybrid system

In our global society, fossil fuel such as coal, oil and natural gas are the three types of fossil fuels that we mostly used to meet our energy needs. But fossil fuel is the non renewable sources. They are limited and depleted in nature. There is clear evidence that climate change depends on human activities which is related to production and consumption of energy.

Coal which is the major fuel in the thermal power plants, considered as a heavily polluting elements. Burning coal in the thermal plants creates black carbon, sulphates and other gaseous pollutants due to incomplete combustion which causes emission of green house gases such as CO2, NO2, and SO2 etc. One of the biggest disadvantages of burning crude oil is that it also releases CO2 [4]. Natural gas is composed mainly of methane (CH4) and a small percentage of other hydrocarbons. Burning of natural gas also releases CO2, carbon monoxide and other compounds which cause green house effect. The effect of green house gases contributes to global warming. This in turn results in climate changes randomly like monsoon rainfall patterns changes, abnormal heating, and sea level increases. SO2 and NO2 cause acid rain that harms aquatic life and human health.

Here one very important factor is population growth. Energy demand has the linear relationship with population growth. This would lead to extinction of fossil fuels and natural gases leading to shortage in energy resources for the human society. Hence, renewable energy sources are the good substitute to meet our future energy demands. Sun, wind, water are the perfect non- polluting, efficient energy sources. Use of renewable energy enables us to protect the environment from toxic pollutants and keep people healthier. Future energy demands have to be managed in such a way that renewable energy resources is developed and used properly to meet in times of excess demands. The installation, maintenance and operation cost of involving these systems needs a detailed study for efficient use of the hybrid systems.

1.4. Objective of the work

The purpose of the work is to provide an optimal solution to an autonomous power delivery system incorporating renewable energy. Different types of resources can form micro grid to supply load demand though a proper combination of renewable energy sources with an effective optimization technique which can satisfy the energy needs with minimum cost. For analysis purposes, in this work different sets of combination of renewable sources have been made using solar, wind, biomass, and battery system to form the micro grid. The optimal solution aims to minimise the total annual cost of the system which includes running cost, installation cost, micro grid cost and utility cost. Mathematical analysis is based on a modern meta-heuristic technique namely cuckoo search algorithm. The optimal solutions obtained by Cuckoo Search algorithm are very efficient and best solutions are obtained in a short period of time. The cuckoo search algorithm evaluated total annual cost for the autonomous power delivery system with biomass gasifier unit, solar cell and battery system for case 1 and biomass, solar, wind and battery for case 2. Finally, an economic comparison has been carried out for these two cases. The optimization programs have been designed in MATLAB software. The entire model prototype of the work has been designed based on previous experimental works.

1.5. Contribution of the work

Some literature reviews have been done from the previous works on microgrid. Operation and involved cost in micro grid, different cost optimization techniques and load and demand side management of the system have been made in these works. This thesis work contributes a modern and effective method for a generating load scheduling problem in power system by involving Cuckoo Search Algorithm. Here, MATLAB codes are developed for calculating fitness function of the load scheduling problem with a well established optimization technique called cuckoo search algorithm. Cuckoo search algorithm is very robust and reliable process to solve complex optimization problems using various constrains. It can also be abundantly combined with other optimization techniques.

1.6. Structure of the Thesis

This thesis is organized in eight chapters as follows:

Chapter one provides the overview of the current energy scenario of India and gives an idea about necessity of renewable energy sources along with total installation capacity of renewable sources in India. The chapter also highlights the basic importance of this specific research works.

Chapter Two introduces to the recent trends and concepts of microgrid and briefly discussed about its operation and control strategies. This chapter also includes the economic aspects of microgrid and some reviews on soft computing techniques for optimization purposes.

Chapter Three deals with increasing energy demands considering of demand side management programs.

Chapter four introduces the objective function of this optimum cost calculation problem.

Chapter five focuses on solution techniques of the proposed problem. This chapter also provides a summary of recently developed meta-heuristic algorithms; cuckoo search and application of this algorithm in this specific work.

Chapter six presents a brief discussion on biomass gasifier model, solar photovoltaic system, wind energy system and battery storage system with basic configuration and mathematical formulation of these renewable energy systems.

In Chapter seven represents the input parameters for the proposed problem and a comparison result between two specified test cases. The obtained results are carefully explained in the discussions.

In Chapter eight future possibilities of this proposed work is discussed well and an overall conclusion has drawn respective.

CHAPTER 2
TRENDS IN MICROGRID RESEARCH

2.1. Introduction to Microgrids

Micro grid is a power supply network which provides small scale power to a small community. The combination of distributed generators based on renewable energy resources (RERs) like photovoltaic system, wind turbine, fuel cells, micro-turbine and batteries has introduced a recent concept of Microgrid [MG]. It is connected to both local generating units and utility grid which enables continuous power supply in a small community. Transmissions losses are highly reduced due to the presence of power generating sources remaining at the load side and it also increases the reliability and stability of the system [5][6]. For larger load demand, small units of micro grids are interconnected to each other to form a large network which is called power parks. Some literature reviews are discussed below on operating modes of micro grid.

2.1.1. DC VS AC Microgrid

According to power generation, micro grids are two types; AC and DC micro grids [7] [8]. For a Low voltage AC(LVAC) network Distributed energy resources such as wind turbines, biogas etc that produce AC output are connected directly to an AC bus line or may need AC/DC/AC power converts to enable their stability. Similarly DG unit which produces DC output such as solar cell, fuel cell and energy storage devices can be connected to AC bus line of the LVAC networks using DC/AC inverters.

In another work, the authors gives an overview of LVAC and LVDC network consists with various renewable energy resources (RES), energy storage systems (ESS) and loads [9]. A good comparison is carried out of DC Microgrid system with AC MG system by discussing their feasibility, structural configurations and control strategies [10]. The comparison result reveals that DC microgrid systems will soon be the right potential for the future energy demands. On the other side, inrush currents caused by transformers, synchronization with DG units, voltage level control and system stability are still the most important challenges to consider in the AC microgrid systems contrary to the DC microgrid systems [10].

There are a number of advantages discussed of DC micro grid over AC micro grid [11]. AC power is most preferable for domestic and commercial purpose due to its transformation in different level and easily transmits to a long distance which is essential for different AC equipments. But DC power is required in industrial power distribution, telecommunication and point to point transmission for long distance. Many small scale micro sources natively generate low voltage DC power. Most of these generated powers is delivered to LVAC networks and require inefficient and costly power invertors, where the generated power may ultimately be supplied to DC devices. DC micro grid has better protection, simple control strategies and it does not affected by skin effect which is another advantage over ac micro grid. Both the AC and DC Microgrid can operate in the two modes in the power system network.

2.1.2. Operating modes of Microgrid

2.1.2.1. Grid connected and islanded mode

Microgrid operates in two modes; grid connected and grid disconnected mode. Grid connected microgrids are able to provide uninterrupted power supply where island operated microgrids run by braking away from the grid, depending on the power generation and load demand with suitable market policies. Generally microgrid operates in interconnected mode. In a research work, the author has analysed the control strategies for an island operated microgrid system [12]. In such conditions, the microgrid must have the capability to operate autonomously and stably. The design, control, and optimization of island microgrid systems are usually very complex tasks in remote areas. Review results of [12] shows that systems are those consisting of a PV Generator and/or Wind Turbines and/or Diesel Generator, with energy storage system are most frequent system. In addition, load shedding strategies are analysed properly.

In any abnormal condition microgrid should disconnect itself from main grid and to be shifted to islanded operating mode [13]. The deviation in voltage and frequency becomes more prominent when microgrid is shifted to islanded mode from grid connected mode. In grid connected mode of microgrid, the voltage and frequency are controlled by the grid. When the microgrid operates in island mode [14], one or more primary or intermediate energy sources should be controlled by adjusting its voltage and frequency. If the frequency reaches to a poor value, the load may be momentarily shaded. To maintain the system frequency some control methods are used. Some existing microgrid frequency control methods are classified as primary and secondary frequency regulation in traditional power system. These methods give very fast response when load fluctuates with large amplitude. To overcome the drawbacks of existing frequency control method, an improved frequency control method is proposed. This makes the system steady when load fluctuates rapidly. Simulation results prove that this effective control strategy repress the drawbacks and improve frequency stability of microgrid system in some extent [15]

A new approach in microgrid mechanization is modelling an intelligent and self controllable microgrid system which can automatically manages the load demand. In this type of control, central controller of microgrid can communicate with the loads and give direction to isolate from the grid in any unnecessary condition. This feature reduces the overall load demand from the system in peak-load hours [16]. In this type of hybrid system, frequency fluctuation may happen due to random load fluctuation. Thus Computer based Monitoring system may be provided for power quality control to oppose frequency fluctuation. Different control techniques have been implemented for efficient operation of AC and DC microgrids.

2.1.3. Different control strategies for AC Microgrid

Different control techniques have been designed for controlling the operation of Microgrid based on some characteristics. There are two basic control techniques are used in microgrid operation; 1) droop control 2) active load sharing [17].

In an island operated AC microgrid, two important tasks are considered. The first one is to maintain the voltage and frequency stabilities and the second one is share the load demand among various parallel connected Inverters. Different control schemes have been discussed for AC microgrid. Some control methods like master/slave control, communication based control methods and distributed control methods perform a good current sharing, however these methods are not productive due to their low reliability and redundancy. On the other hand, the droop control method avoids communication lines/cables which increase system reliability and flexibility. For further improvement, virtual structure-based method, common variable based methods, signal injection method are able to overcome the inherent drawbacks of droop control method [17].

A brief description is for grid interactive ac microgrids structures, controls and power management strategies are presented. Control methods for power electronics interfaced distributed energy units in grid connected ac microgrids are discussed well. Finally future challenges and opportunities are analysed in [18] to achieve a more intelligent and flexible AC grid.

2.1.4. Different control aspects of DC Microgrid

In case of multiple DC micogrids, Hierarchical control method is a universal move towards standardization of Microgrid. In this method, the levels are considered as primary level, secondary level, and tertiary level. The power balancing strategies are categorized as: 1) centralized 2) decentralized 3) distributed. Master slave Method, average current control method is referred as current sharing method.

2.1.4.1. Basic Control Techniques

Two basic control techniques of microgrid viz. active load sharing and droop control [19].

2.1.4.1.1. Active load sharing

Active load sharing controls voltage level by communicating with converters of energy sources and maintain the constant voltage of DC link. In this type of control, high speed communication links transmit signal of power generation. Central controller communicates with load and storage devices and directs them as per load demand requirement. The operation gets fast if there is no problem in communication channel [20]. Active load sharing is classified as centralized controller, master-slave controller, and circular chain controller. Centralized controller requires high-speed communication and reliability deteriorates due to single point of failure. In master slave mode one converter acts as a master and operates as voltage source converter the other one acts as slave and operates as a current source converter to regulate DC microgrid voltage.

2.1.4.1.2. Droop control

Droop control is mainly used in parallel operation of DC-DC, AC-DC and DC-AC converter. When two or more converter is operated in parallel, that converters are acts as a voltage source. In this condition a circular current is generated due to existence of impendence in distribution cable. These methods require interconnection between converters which increase complexity in system [21].

Various control techniques are proposed for DC microgrid. Droop control, muster slave control, average current control technique, centre limit control methods and these are widely used for load sharing in DC microgrid. Most of these methods involve some forms of drawbacks. These methods not only restrict the location of DG units but also the reason of system failure thus increases the cable line noises [22]. DC bus signalling is used to control the DC microgrid. But this control method is preferable for small DC microgrid where line resistances are negligible [23].

2.1.4.2. Centralized and decentralized control

DC microgrids have become efficient model due to high efficiency, reliability, and easily get interconnected to renewable energy sources comparison to the ac system. Power management strategies of dc microgrid are: 1) to make sure equal load sharing (in per unit) among all micro sources; and 2) to keep low-voltage regulation of the system. According to power balancing strategies there are two types of control methods in DC micro grid; centralized and decentralized control. In centralized control a central controller uses communication links to communicate with all Distributed generating (DG) units. This proposed method increases the system complexity and sometimes communication link failure occurs thus system reliability deteriorates. For decentralized control the DG unit uses local variables. This method does not require any communication link [24]. Decentralized controller for dc microgrid is introduced to ensure proportional load sharing and improve voltage regulation. The advantages of de centralized method are low-voltage regulation; high reliability, stability, and equal load sharing**,** to confirm the feasibility of the system [25].

2.1.4.3. Hierarchical control method

Hierarchical control of DC microgrid includes primary, secondary and tertiary control [26] [27].

1. Primary Control

Primary control method is based on voltage droop, and current. The droop magnitude is obtained from error signal of converter output. This method communicates less in power sharing among the distribution energy resource system [28].

2. Secondary control

Secondary control method maintains the voltage regulation with the microgrid central controller. It helps to re-establish the system from voltage deviation caused by droop control and controls the power flow with other DC microgrid or distribution system [29].

3. Tertiary Controls

This control approach works on energy management which aims to control DC microgrid in optimal mode. This method also includes energy efficiency, stability and economic issues related with the system [28].The hierarchical control method is applied for both grid connected, island mode[30] and the control technique makes the system flexible.

2.1.4.4. Current Sharing Methods

Many control techniques have been established in the past decades to solve the problem of load sharing in parallel operation. A well-established control method is frequency and voltage Droop or droop control method which significantly improves the load-sharing capability. However, this method can only applied for a specified range of operation. To achieve this appropriate current sharing and voltage regulation in parallel system a generalized model using IACS (Instantaneous Average Current-Sharing Control Scheme) has been developed. This technique requires interconnections among inverters for information sharing which is based on instantaneous average current-sharing control. A general model of a single-phase parallel-connected inverter system is considered in this work [31]. This model consist the detail of the control loops that employ a proportional-resonant controller, but not the switching action. A new gain scheduling technique has been invented for the controller to improve the current and power sharing strategies, where different line impedance is considered among all the inverters. The results of the simulation show that the adaptive gain-scheduling approaches improve conventional controller performance in terms of current and power sharing among inverters under various line impedance conditions.

2.1.4.5. Gain scheduling technique with soft computation

In the area of optimization, many researchers have indicates that fast computation techniques are better compare to the slower conventional methods. So the recent focus has shifted towards soft computation techniques due to the needs of optimum results in short interval. A new voltage control method has been developed that combines fuzzy control with Gain scheduling techniques to achieve the proper power generation and energy management strategies of standalone and grid connected DC microgrid system. The method is used to control the DGs under normal and fault condition under load variation. In DC microgrid a control strategies for three phase VSI combined with three phase load, utility grid has also been suggested under various working condition [32].

2.1.4.6. Active and reactive power control using FACTS device

The potential benefits from renewable energy sources are extend gradually over past two decades and development of microgrid consisting with renewable energy sources are becoming an important research area in modern power system. Microgrid consists of renewable sources which are placed close to the load side. In order to control active and reactive power each single DG and it's smooth Operation and control voltage frequency of AC, DC and hybrid AC/DC microgrid system, various methods like FACTS (flexible alternating current transmission system) and storage devices, multiagents, optimization techniques have been focused in [33].

The technical and economic benefits obtained from Microgrids are generally classified as reduced emissions, improved efficiency, Power Quality and Reliability. Development of microgrid is rising day by day with advanced power electronics and control strategies. Still the biggest concern is high installation cost of these renewable energy systems to our general customer.

2.2. Economic aspects of Microgrid

In rural areas where transmission lines are not possible to be provided, hybrid renewable energy sources (HERS) can be a good substitute of this problem to ensure cost effective and reliable delivery of power. Renewable sources like solar and wind energies are depended on climate condition. However to get an uninterrupted power supply, microgrid has found as a solution to overcome the drawbacks of one another.

2.2.1. Involved cost and cost components-

Total annual cost parameters of a microgrid consist of operation or generation cost, installation cost, maintenance cost and utility cost [34]. Installation cost is different for different types of generating units. Installation cost for microgrid forming equipments, switching equipments, transformer, and controller, underground and overhead cables includes a huge amount. Generation cost includes fuel cost. Minimization of fuel cost is the main objective function in generation scheduling problem. Cost of these microgrid forming equipments and running cost of different renewable energy sources are analyzed in [35][36].To keep the generating units in a good working condition, maintenance cost is associated with the total annual cost. In grid connected mode, utility cost has to be considered. The microgrid could sell excess energy to main grid and also purchase essential power from utility providers [37]. Different energy storage technologies include super capacitor, flow batteries, and pumped hydro etc in distributed energy system [38]. Large energy storage system may increase total cost of the system so a proper analysis is required to get a cost effective system.

2.2.2. Involved cost with storage units

For ensuring continuous power supply to the demand side, storage system is very important for hybrid renewable energy system. Different types of storage units and their cost, related with their characteristics are brilliantly discussed in [34]. When cost is compared between stand alone system and grid connected system, such comparison should include issues like power quality and reliability, protection of the system.

A typical solar home system has been presented for cost assessment. Here considering the main cost components such as cost of a solar panel, total energy cost and cost of the storage battery. It has been identified that the four features, cost of solar PV panels, cost of battery and its longevity, bank interest rate plays the most significant role in determining the total energy cost. Solar installation cost is also taken into concern and the results proved that the total cost of energy is significantly higher for storage battery unit than that of the solar PV panel [39].

A new photovoltaic converter system is proposed to execute an innovative maximum power point tracking technique at a minimum use of cost. Here three Functions, maximum-power-point tracking, inverting and battery regulation are needed a photovoltaic system with battery back-up system. They are incorporated in a single converter which is cost effective. This converter operates maximum amount of photovoltaic cell, charges the battery and forms a DC to AC inverter to supply a complex power load. This charger allows the arrangement of low-voltage batteries with high-voltage PV arrays [40].

Optimization techniques are the most important tool in real world applications. Our valuable resources like time, money, fuel are always limited. These valuable resources are tried to use optimally by using some optimization techniques under various constraints. Different optimization algorithms are applied to achieve the optimum power generation. The optimal use of fuel cost generation is calculated by the application of the optimization techniques.

2.3. Optimization techniques for cost calculation

The reliability and economy of the system depends on unit sizing and optimization of the hybrid system, so it is a method to determine the size of hybrid system components by maintaining system reliability and system cost. System cost varies with the size of the system components. Over sizing of the system components will intensify the cost whether under sizing components can make inadequate power supply, so proper optimization techniques should be applied to get proper configuration.

Optimization techniques can be carried out in different ways. Considering the nature inspired algorithm and they are divided into two categories. One is deterministic technique, and other is stochastic technique**.** Again stochastic techniques are divided into two categories: Heuristic and Meta–Heuristic techniques. Meta–Heuristic techniques are also updated as Morden Meta Heuristic techniques which use different nature inspired algorithms such as genetic algorithm (GA), Differential evolution (DE), Particle swarm optimization (PSO) and Ant colony optimization (ACO), Bee Colony Algorithm (BCA), Cultural Algorithm (CA), cuckoo search algorithm (CSA), bacteria foraging algorithm, plant growth simulation algorithm etc. Many models have been developed on micro grid and several optimization techniques are described related to operating cost of micro grid. Differential evolution (DE), Bee Colony Algorithm (BCA), Cultural Algorithm (CA) and Cuckoo search are the most popular nature inspired algorithms among them.

Some reviews on application of the soft computing techniques for minimization of cost related to microgrids have been discussed in the following subsections

2.4. Application of soft computation

2.4.1. Unit Sizing optimization of Microgrid

An attempt has been made for solving hybrid energy system (HES) design problem by applying a new meta-heuristic algorithm called as Cuckoo Search algorithm. The optimal sizing is done for three different systems i.e. Photovoltaic-Battery, Wind-Battery and Photovoltaic-Wind-Battery system in a remote area located at Almora district of Uttarakhand. The effective Cuckoo Search algorithm is investigated for designing different hybrid energy system problem [41] [42]. Here in [42], its performance is compared with other well-known optimization algorithms like Particle Swarm Optimization (PSO), Genetic Algorithm (GA) .Optimization results proves that hybrid integration of photovoltaic, wind and battery storage system is most reliable and economical system using CSA for the study area.

To get optimal unit sizing of renewable hybrid energy system a method is discussed in standalone mode by using Bees algorithm [43]. To optimise the sizing, two types of renewable hybrid energy systems are considered to supply the load demand of a remote area in Kerala. Here cost per watt for solar panel is quite high in comparison to hydro plant and wind turbine. one the other hand, the hybrid system comprising of hydro-wind and fuel cell which is more feasible and cost effective.

A method is introduced in [44] to optimise the sizing of four hybrid system (PV/wind/diesel, PV/diesel/battery, PV/wind/diesel/battery and wind/diesel/battery) by using DIRECT (Dividing RECT angles) algorithm. These experiments are done with the collected hourly data of wind speed, solar radiation, and ambient temperature for a period of 5 yrs. Finally the result shows that the mathematical model of PV/wind/diesel system with battery bank is the most cost effective as it satisfies the customer load demand.

A dynamic programming procedure has been developed to design micro grid configuration that optimise the system cost by maintaining the system reliability [45]. This procedure is introduced to decide the location and possible interconnection between sources and load points. A new approach, called unit link addition-is also introduced with this dynamic programming which reduces the demand of storage units in the system.

2.4.2. Minimization of single objective function

A cost optimization scheme is discussed on minimization of fuel cost with several power sources. The micro grid is comprised with two reciprocating gas engines, a combined heat and power plant and a wind, photovoltaic cell. The main objective is based on minimization of fuel use of the system while it is maintaining the supply of load demand of the system. The optimization approach with the idea of communication infrastructure minimise not only the generation cost but also helps in coordination among easily available sources in power plant [46][47].

2.4.3. Optimization of multiobjective functions

A multi objective economic dispatching model for micro grid is used to minimise the generating cost, customer outage cost and emission cost. Here maximum fuzzy satisfaction degree method and particle swarm optimization techniques are used to convert the multi objective optimization problem into a nonlinear single objective optimization problem [48]. An economic dispatch model for micro grid with centralized controller is also used in order to minimise the production, depreciation and emission cost [49].

A non linear constrained multi objective optimization problem has proposed for a grid connected mode, where fuel cost optimization is done as well as the emissions of Nox, SO2 and CO2 reduction are taking into consideration. The micro grid model consists with photovoltaic array, wind turbine, micro turbine, diesel generator and fuel cell. The main objective function is to minimise the generation cost as well as emissions of the system while satisfying the system load demand [50].

A fitness function is presented in [51] to optimise multi objective function such as fuel cost, generation cost, depreciation cost and environmental cost. Here the micro grid consists with micro turbine, wind turbine, photovoltaic arrays and fuel cell. Weight coefficient N is considered here to maintain the proportion of generating and environmental cost in both island and grid connected mode.

2.4.3.1. Economic load dispatch problem

Generating scheduling of hydrothermal plants has played an important role in power system area. The author has applied Differential Evolution (DE) technique to solve short-term hydrothermal scheduling problem [52]. The invented algorithm is tasted on multi-chain cascade of hydro units and an equivalent thermal unit. The obtained results have compared with other effective algorithms like GA and PSO. The results show that variants of DE produce better results in terms of cost and computation time. It is found that different variants of DE can also produce good quality solution for short term hydrothermal scheduling problems

The authors presented here an economic dispatch (ECED) problem by taking both the economy and emission as objectives. Here DE technique is used to solve ECED problems with considering equality as well as non-equality constraints. The results of this method compared with fuzzy controlled genetic algorithm (FCGA) and Newton-Raphson method for six-generator system. It is noted that that proposed method provides better result in terms of less computation time, fuel cost and emission in comparison with other methods [53].

Here in [54] the authors have been introduced a solution for economic load dispatch (ELD) problem using a nature inspired algorithm called Cuckoo Search Algorithm (CSA). The proposed method has been applied to various systems like three generating unit system and six generating unit system. The author showed that the ELD problem supplies the load demand at minimum running cost. The results proved as an efficient method when compared with the other optimization algorithms.

The power generation of thermal and hydrothermal plants can be easily determined by using short term hydro-thermal scheduling (HTS) solutions, so that total fuel cost of thermal units is minimised in a given period. The cuckoo search algorithm (CSA) method is a meta-heuristic algorithm is applied on this HTS problem, while considering power loss in the transmission system and valve point loading effects in thermal units. The proposed CSA has been applied on many hydrothermal units for various fitness function i.e. fuel cost function. The literature reviews of [55] has showed that proposed CSA is very effective algorithm in comparison to other algorithms especially for non smooth fuel cost function of thermal units.

2.4.3.2. Applications based on Meta-heuristic Algorithms

A cost optimization technique by using differential algorithm (DEA) is presented in [56].The optimization technique is very effective and provides optimal power to the generator by taking consideration of cost function of each component. The system controller responses changes continuously when there is any change in operating condition like variation in load demand, variation in battery state of charge, and also mentioned that these responses are affected by several factors such as weather condition, actual power demand and maintenance cost.

Cost components of different systems like photo voltaic cell, diesel engine, wind turbine, fuel cell and micro turbine are studied in [57]. Some soft computational techniques like Particle swarm optimization (PSO), Craziness based particle swarm optimization (CRPSO), Artificial bee colony (ABC) these three algorithms are used with least use of diesel engine where the total operating cost of the microgrid is minimised. In this case ABC based algorithm has proved as best economic procedure.

The author has introduced a multi objective optimization problem where hybrid cultural algorithm (CA) is applied for minimising real and reactive power loss. Using this algorithm the real power cost is also taken as second objective function. Here sequential operation has done to minimise active and reactive power loss and cost of generation. IEEE 30 bus system is taken as standard for the proposed method. Optimisation is done in such a way that, at first generation cost is optimised and then generator bus voltages, real power outputs, tap settings of transformer is optimised. The obtained result was compared with other heuristic approaches. And the simulation result shows that the proposed algorithm is able to reduce the generation cost and provide higher power loss reduction as compared to other heuristic algorithms [58].

Artificial bee colony (ABC) algorithm has been efficiently applied to solve a DG placement problem with considering both technical and economic aspects. The technical objectives try to optimise line loss, variation in node voltage deviation and the effect of voltage sag problem in a distribution network. The other objectives i.e. economic objectives are try to optimise operational costs of DG placements. This proposed method has been implemented in a 34-bus radial distribution system. The obtained results revels that how significant amount of equivalent cost savings can be done when the system does not include any DG system [59].

Genetic algorithm is employed in an optimal model of micro grid consisting of wind turbine, PV array, CHP system and battery system [60]. A comparison has made before and after optimization and electricity is provided to the customer at a reasonable price in an optimal period and at the same time it meets with various constraints on the basis of equipment performance, weather conditions, load details, tariff details and other necessary information.

A photovoltaic based micro grid is presented as a distributed intelligent energy management system (DIEMS) to optimise system cost. Depending on the prediction module (Fuzzy ARTMAP) of the DIEMS system, an optimization approach is developed by using heuristic methods. The proposed DIEMS system reduces not only the cost, but also improves the system operation at lower maintenance of storage units and it improves battery life of the system [61].

Bacterial foraging algorithm (BFA) is used for minimization of cost and control the optimal operating strategy. Multi objective functions such as emission cost of NOx, SOx and CO2 as well as generation and maintenance costs are considered here. Battery storage unit is used to store excess energy while constraining it to meet the load demand which is beneficial for the system [62].

In this paper particle swam-based–simulated annealing algorithm and (PSO-B-SA) (SALHEEA) ALGORITHM is used respectively in order to minimise the micro grid's operating cost, emission cost and maintenance cost. The simulation study is demonstrated for 16 bus system. It is found that the optimisation technique works well and delivers optimal power to the micro sources [63].

2.4.3.3. Applications based on Modern Meta-heuristic Algorithm

A newly modified cuckoo search algorithm (MCSA) is proposed in [64] for solving short-term hydrothermal scheduling (HTS) problem. This HTS problem is used to minimize total cost of thermal generators, while satisfying other constraints such as generator operating limits and water availability. The proposed MCSA method has been tested on different systems and a good comparison is carried out with CSA and other methods available in the literature of [64]. The result has indicated that the proposed MCSA can be a new efficient method for solving short-term hydrothermal scheduling problems.

A novel optimization algorithm is proposed to optimise a multi objective problem with generation cost, emission, and total power losses as objectives. A hybrid cuckoo search algorithm (HCSA) is used which founds as a cost effective algorithm compared to other existing methods. The programming has become more complex due to increase in no of evolutionary operation which may increase execution time [65]. In another work, a hybrid cuckoo search algorithm (HCSA) is combined with fuzzy algorithm for solving multi-objective unit commitment problem [66]. In this case CSA provides best outcome with fuzzy logic algorithm.

Recently, many software tools have been developed for suitable generation technologies and their sizes. These software packages have made the study of hybrid systems easier and interesting. Some studies has analysed the reliability of hybrid systems while others consider different types and sizes of the available generation resources to reduce fuel costs, investment costs and improve system operations.

2.4.4. Soft computation based software tools for evaluating system performance

Some simulation tools are the most common tools and also applied for evaluating the performance of the hybrid system, such software tools are HOMER, HOGA, HYBRID, and HYBRID2.

HOMER (Hybrid Optimization Model for Electric Renewable) is used extensively for several case studies. HOMER is developed by national renewable energy laboratory. The software tool uses hourly based environmental data for the evaluation of performs that is based on the net present cost of HERS system [67]. HOGA (Hybrid Optimization by Genetic Algorithms) is a hybrid system simulation software tool which is produced by Electrical Engineering department of the university of Zaragoza Spain. The performance of the simulation is executed, using 1 hr intervals [68]. HYBRID software tool is developed by salaries HOMES. This is a designing tool and can simulate one configuration at a time [69]. HYBRID2 is developed by renewable energy research laboratory (RERL) of the University of Massachusetts. The simulation is executed using 10 min-1 hr intervals [70].

2.5 Conclusion

A good comparison is carried out between AC and DC microgrid where the comparison result reveals that inrush currents caused by transformers, synchronization with DG units, voltage level control and system stability are still the most important challenges to consider in the AC microgrid systems contrary to the DC microgrid systems. In addition, DC micro grid has better protection, simple control strategies and absence of skin effect as advantages over ac micro grid. Different control strategies are discussed for AC and DC microgrid. Microgrid develops day by day with advanced power electronics and control strategies. A new approach has been introduced to design an intelligent and self controllable microgrid system which can automatically manages the load demand. Still the biggest concern is high installation cost of these renewable energy systems in microgrid scheme. To optimise the cost function soft computing techniques are adopted and some literature reviews on soft computing techniques are discussed well. It has proved that cuckoo search algorithm is very effective for cost optimization in microgrid. In case of unit sizing optimization, CSA is a good approach compared to other well known techniques like PSO, GA, bacterial foraging algorithm. For economic load dispatch problem the results obtained by DE is much better compared to GA, PSO and fuzzy controlled genetic algorithm. PSO, CRPSO, ABC algorithm are used to minimise the total operating cost for different system and ABC has proved as best economic procedure. For short term hydro scheduling problem CSA is proved as an efficient algorithm especially for non smooth fuel cost function of thermal units. Again a newly modified cuckoo search algorithm (MCSA) shows better result than CSA. From the literature reviews it can be assumed that CSA would be beneficial algorithm for this cost oriented optimization problem as Cuckoo Search is very reliable process to solve complex optimization problems with various constrains.

The increasing demand of electricity is driven by the connection of electricity in new homes, businesses and increase in the use of air conditioners and high power consuming electrical equipments. This puts increased pressure on the network and requires large investments to cope with increasing demand. To deal with this increased demand in microgrid, demand side management (DSM) or energy demand management program has been introduced which is discussed in the next chapter. The aims of Energy demand management is to encourage a change in electricity use through various methods such as financial incentives and change in habit through education. Finally, DSM has a major role to play in deferring high investments in generation, transmission and distribution networks. Thus DSM applied to electricity systems provides significant economic, reliability and environmental benefits.

CHAPTER 3
ENERGY DEMAND MANAGEMENT

3. Energy demand management or Demand side Management

The electricity network is designed to accommodate peak use. Sometimes we do not require expanding the network to provide extra demand as reducing high demand will be enough. Usually, the main goal of demand side management (DSM) is to encourage the customer to use less energy by changing the patterns of energy use, especially at times of peak demand. For an example, by using energy storage units to store energy during light load period and utilize them during peak load period.

3.1. DSM programs in some leading countries

This section presents some countries where demand side management programs have implemented successfully and expected results have come.

A. Europe (the Netherlands) In Netherlands Energy efficiency has been started as a policy which gets priority to the Dutch government for 25 twenty-five years ago. Upon request from government, Dutch companies must specify what efficient technologies they are implementing. This energy efficient technology with a payback period of 4-5 years must be carried out from environmental aspects.

The Energy Premium Scheme (EPS) was established in the Netherlands for promoting high energy saving technologies in households. Demand side management has been studied on non conventional sources in the Europe. The benefit of the studies is improved the lifestyle of people in the Europe.

There is rapid growth in market for A-labelled appliances (energy efficient appliances). It has been seen that the market share of A-labelled refrigerators grew from 27% in 1999 to 68% in 2001. A-labelled washing machines sales grew from 45% to 88%; efficient freezer sales grew from 29% to 67% and energy efficient dishwasher sales grew from 27% to 73%. Furthermore, more improvements are recommended for their clients by Dutch retailers [71].

B. Japan After World War II, the energy consumption of Japan is increased rapidly along with economic development. In year 2000, Japan's energy consumption was about twice that in 1970 and nine times greater than in 1955 [71]. On the other hand, Japan has almost no domestic Energy resources; therefore, Japan's energy supply structure deteriorates gradually. In 2003, the Japanese Government published the Energy Master Plan, with the four principal objectives. They are energy efficient, diversification of imported energy sources i.e. increase the use of the domestically produced energy. In recent years Japan has implemented many solar and wind system to reduce high energy demand. As a result of these, oil's share of Japan's primary energy supply has reduced from 78% at the time of the oil crisis to about 50% and in recent Years and subsequently it has been declined to 45% in 2010 [71].

C. United States (California) In 2001, California responded against "electricity crisis", with a number of demand-side policies that were truly remarkable. A significant amount of funding is involved with these policies for energy efficiency programs. In all, more than $1.4 billion funding was approved for demand reduction scheme [72]. Demand Side Management measures are estimated at present in 2.6. It means that each dollar is invested in Energy Efficiency (EE) programs and 2.6 dollars comes out in terms of benefits. In 2001, the effect of all California programs and policies shows that a 10% cut in peak demand during the summer months. These energy efficiency and conservation efforts reduced peak demand by 5,600 MW. The direct implementation of energy efficiency program achieves significant energy demand reductions and a very cost-effective price.

D. Brazil In Brazil, a national Program i.e. PROCEL (Program National de Conservation de la Energy Electric) operates for Electricity Conservation since 1985. The main objective of the program is to encourage the efficient use of non-renewable energy sources in the residential, commercial, industrial and agricultural purposes. In the commercial sector, PROCEL optimize the energy consumption of commercial facilities through energy efficiency program. PROCEL has investment in public administration as manager of the consumer unit. These units improve in the quality of lighting systems, refrigeration and other relevant systems. The other main activities related with the program are promotion in the use of natural gas as fuel, reduction in the diesel consumption, stimulus of new technologies in the electrical devices field. Implementation of energy efficiency program achieves significant energy demand reductions at a very cost-effective price.

3.2. Basic objectives of Demand Side Management

Demand management is important to efficiently expand the network and keep electricity at a minimum price to the customer.

Two basic objectives of DSM programs are: 1) reduce total energy consumption by adding high-efficiency equipment and building design, and 2) encourage the customer to use minimum energy during peak hours, and use required energy at off-peak hours. [73].

Energy Efficiency (EE), Energy Conservation (EC) and Demand Response (DR) these three concepts enhance the basic objective of DSM.

A. Energy Efficiency (EE)

The aim of energy efficiency is to install energy efficient technologies or the elimination of energy losses in existing systems. . Some examples of energy efficiency are:

- Replacing incandescent light bulbs with compact fluorescent or LED bulbs.
- Use of automatic thermostats.
- Use halogen light bulbs for outdoor lighting because they save 25% of energy than traditional incandescent bulbs.
- Insulate home by adding new insulation to ceilings, attic and walls to make sure that it will keep warm air inside during winter and help to trap cool air from air conditioner inside during summer.
- Replace the old appliances with energy star certified appliances due to their energy efficient module.

B. Energy Conservation (EC)

Energy conservation involves using less no of resources, usually by making change in habit or life style. Some steps for energy conservation are given:

- Turn off lights while leaving the rom.
- Keep the thermostat temperature lower from 18°C to 15 °C for heating systems.
- Wait until the clothes washing machine is full to run.
- Use of light clothes during summer season.
- Use natural gas for heating purpose. Natural gas is cheaper than other heating fuels.

C. Demand Response (DR)

Demand Response involves electricity Price and market policies. Here a customer is encouraged to use minimum energy during peak hours, and utilize required energy at off-peak hours. Dynamic pricing is a new metered load management tactic that uses price signals. Demand Response (DR) includes an Advance Metering Infrastructure (AMI), in order to aware the users of his energy consumption and the related cost. [74].

It can be seen that energy efficiency programs are linked with technological solutions, whereas energy conservation are depended on the side of consumers' behavior, and finally demand response efforts are based on the price of electricity and market policies. Fig. 3.1 implies that all three types of activities are complementary and significant for saving energy.

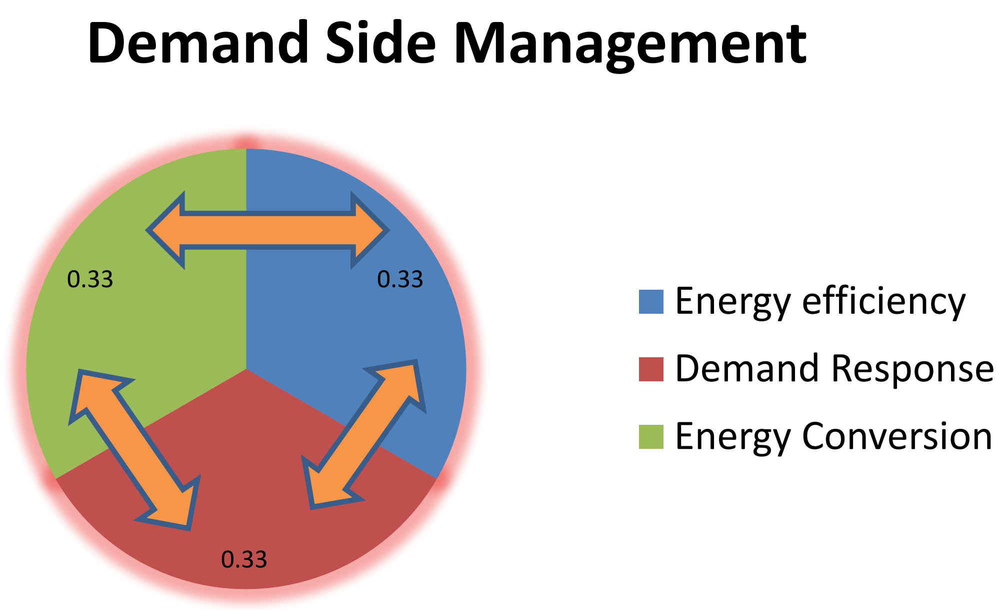


Fig:3.1 Three objectives of demand side management [71]

3.3. Benefits of DSM and future opportunities

Demand-side management (DSM) has been usually seen as a means of reducing generation margin. In fact, by reducing the overall load demand on the system, DSM has different beneficial effects. These beneficial effects are reducing the number of blackouts, mitigating electrical system emergencies, and increasing system reliability and stability. Benefits of DSM can also reduce the dependency on foreign energy sources and reducing emissions to the environment.

There are various reasons for which the DSM must be promoted. Some of them are as discussed [75]

a) Cost reduction- DSM and energy efficiency efforts have been introduced where rates are higher during peak periods and lower during off-peak periods. This kind of planning will help to reduce the total costs while meeting energy demand.

b) Environmental and social improvement- Energy efficiency and DSM promote some energy efficient technologies that will reduce the energy cost leading to reduced greenhouse gas emissions.

c) Reliability and network issues- Prevention of some serious problems in the electricity network through reducing demand in ways which maintain system consistency and defer the need for network expansion for longer term.

d) Improved markets- Short-term responses to electricity market conditions particularly by reducing load demand during peak hours when market price is high. This may reduce generation or network capability.

3.4 Conclusion

DSM programs have been designed and implemented during the last three decades in various regions and nations worldwide. Still some improvements are pursuing on demand side management programs. New targets and incentives are allowed for EE, EC and DR programs. Substantial and consistent funding is provided for residential and utility energy efficiency over many years, which assures that energy efficiency programs will persist. These have helped lead to the development of a skilled and devoted energy efficiency work for sustainable development. With considering all aspects as per requirements, a system has been developed to deliver power in a small locality. After thorough review on topics on internet it can be stated that the work on non conventional subjects is not very common but several works could be found on conventional topics. In this thesis demand management programming on non conventional topics have been studied. And an demand management program is try to adopt to cope with excess energy demand in an economical way, Here an objective function is presented on nonconventional source to evaluated total annual cost of the system which is elaborated in the next chapter.

CHAPTER 4
COST OPTIMIZATION IN MICROGRID AND PROBLEM FORMULATION

4.1 Introduction

The optimum cost calculation of a microgrid system is one of the major problems in power system operation. Diesel generator sets are often used to cope with load demand variation but it is must said that it has an adverse impact by emitting harmful gases in the environment. Renewable energy sources are played vital role to reduce this adverse effect along with saving the running fuel costs. India is an agricultural country, about 65-70% of our population depends on agricultural [76]. So biomass resources are abundantly available and the potential can be used to generate electricity. According to West Bengal Renewable Development Agency (WBREDA) [77], solar potential is fair enough to generate electricity. Though wind energy is not a good substitute in west Bengal but it has 22 Mw installable potential to generate electricity [78]. Wind energy is place-dependent and usually varies from season to season. As solar system and wind turbine system does not include any operational cost, thus many experiments are carried out to extract huge amount of energy from them.

An optimum cost calculation problem has been studied here by considering two sets of distribution energy resources. Case 1 comprises of biomass gassifer unit (BMGU), solar panel system (SPS) along with battery storage system (BESS) and case 2 comprising of biomass gassifer unit (BMGU), solar panel system (SPS) and wind turbine generator (WTG) along with BESS. The load demand data is taken from the actual hourly load data for consumers in a small Indian community. Here the microgrid is driven by biomass gassifier unit, solar modules, and wind turbine along with a battery system. The test cases have been chosen on the basis of anticipation of the present scenario that uses present technology. The results show that BMGU has low operating cost and installation cost. The adopted microgrid system has been connected to the customers' load through distribution lines, transformers, circuit breakers and controller.

4.2 Objective function

Here the total annual cost is considered as an objective function of a microgrid system.

In general the microgrid cost includes four types of cost which is given in equation 4.1[35]

$$R_o + R_I + R_M + R_U \quad (4.1)$$

Where, R_O = Operating cost

R_I = Initial cost

R_M = Micro-grid cost and

R_U= Utility cost

4.2.1. Operating cost

Operating cost varies for various types of distribution energy system for different operating periods. Two cases are considered here, R_{bs} is considered as R_O for case 1(BMGU, SPS, BESS) and R_{bsw} is considered as R_O for case 2 (BMGU, SPS, WT, BESS). Initial cost is different for different renewable energy systems. Microgrid cost includes initial cost of switching equipments, transformers, cables, and controllers etc and the utility cost includes the cost when electricity is purchasing from the grid and selling to the grid. Here the objective function (R) has to be optimised with optimum power generation value and to find the optimal installed capacity of various resources. It is considered that, the control variablesP_{BM},P_{SO},P_{Bt}, P_W represents the hourly basis power generation of a day in KW and O_{BM}, O_{SO}, O_{Bt}, O_W are the operating costs of biomass gasifier unit (BMGU), solar panel system (SPS), battery energy storage system (BESS), wind turbine system (WTS) respectively in Rs/KW. The operating cost for case 1 and case 2 are given as,

Case 1

$$R_{bs} = \sum_{cons}^{n} \sum_{ss=1}^{m} Nods \times \left[\sum_{hr=t1}^{t24} P_{BM}(ss,hr,cons) O_{BM} + \sum_{hr=t8}^{t16} P_{SO}(ss,hr,cons) O_{SO} + \sum_{hr=t1}^{t24} P_{Bt}(ss,hr,cons) O_{Bt} \right] \quad (4.2)$$

Case 2

$$R_{bsw} = \sum_{cons=1}^{n} \sum_{ss=1}^{m} Nods \times \begin{bmatrix} \sum_{hr=t1}^{t24} P_{BM}(ss,hr,cons) O_{BM} + \\ \sum_{hr=t8}^{t16} P_{SO}(ss,hr,cons) O_{SO} + \\ \sum_{hr=t1}^{t24} P_{W}(ss,hr,cons) O_{W} + \\ \sum_{hr=t1}^{t24} P_{Bt}(ss,hr,cons) O_{Bt} \end{bmatrix} \quad (4.3)$$

The number of days per season is represented by Nods. $ss, cons, hr$ are season, consumer, and time index respectively. The procedure for evaluating annual running cost is as follows; from the above equation it is found that the generated power (P_{BM} in KW) of biomass gassifier is multiplied with O_{BM}(Rs./KWhr) and gives running cost for a particular hour. Similarly, when $P_{BM}O_{BM}$ is summed for 24 hours, it gives the total running cost of biomass gassifier unit for a day. This value when further multiplied with total number of days (Nods) in a season it gives the total running cost of the gassifier for a season. Mainly two seasons are considered here. One is summer for 243 days and other is winter for 122 days. Adding the cost for two seasons, we get the total annual running cost of the gassifier unit. The above procedure is repeated for SPS, BESS and WTS in a similar way and it will give the total annual running cost for the system.

The BMGU generates electric power using any kind of wastes such as agricultural wastes, wood chips, rotted trees, cattle dung etc which are easily available in nature. The transfer function is given as [84]

$$P_{BM} = \frac{M \times \eta(WNE) \times LHV}{3600 \times hr} \tag{4.4}$$

Where M is the mass flow rate of biomass waste mixture, ηe is the overall efficiency of the biomass production unit, LHV is the low heating value of the mixture, and hr is the operating hours.

The output power generated from solar energy depends on some geological and environmental factors which is given as, [89]

$$P_{SO} = \left[(Df)(RC_{PV}) \frac{G_S}{S_S} \right] \tag{4.5}$$

Where Df is the derating factor, $RC_{PV}$is the rated capacity of the solar module, GS and Ss are global solar radiation which depends on the surface of solar module and standard solar radiation for the rated capacity.

Total available power from wind turbine depends on some factors which is given as [81]

$$P = P_W A_W \eta \tag{4.6}$$

Where η is efficiency of wind turbine generator A_w is the total swept area.

The other cost evaluation equations are given as,

4.2.2. Initial Cost

Different distribution energy resources have different initial costs. To calculate initial cost, let I be the market rate of interest. I_{BM} and I_{Bt} are interest rate on initial investment of biomass and battery system. $I_{SO,}I_{W}$ are initial cost of solar array and wind system respectively. Installation costs per KW capacity of BMGU and BESS are represented by ic_{BM}, ic_{bt}respectively.

$$R_{Bs} = \sum_{Cons=1}^{n} \left[\alpha ic_{BM}(cons) + \beta ic_{Bt}(cons) + I_{BM} ic_{BM} + I_{Bt} ic_{Bt} + I_{SO}\right] \tag{4.7}$$

$$R_{bsw} = \sum_{Cons=1}^{n} \left[\alpha ic_{BM}(cons) + \beta ic_{Bt}(cons) + I_{BM} ic_{BM} + I_{Bt} ic_{Bt} + I_{SO} + I_{W}\right] \tag{4.8}$$

For determining total annual depreciation cost, the installation costs are multiplied by the factors α, β and γ. A sinking fund method is used to find the value of α, β and γ. dr represents as rate of depreciation and Lft is lifetime of each microgrid equipment.

$$\alpha, \beta, \gamma = \frac{dr^{Lft_{BM,Bt}}}{(1+dr)^{Lft_{BM,Bt}-1}} \tag{4.9}$$

4.2.3. Microgrid Cost

The microgrid cost is given as

$$R_{M} = \sigma ic_{SW} + \eta ic_{cbl} + \sigma ic_{c} + I_{SW} ic_{SW} + I_{tfm} ic_{tfm} + I_{cbl} ic_{cbl} + I_{C} ic_{c} \tag{4.10}$$

Where, ic_{SW}, ic_{tfm}, ic_{cbl}, ic_{c} are initial cost of switching equipment, transformer, cable, and controller and I_{SW}, I_{tfm}, I_{cbl}, $I_{c}$are interest rates on the primary investment of switching equipments, transformer, cable, and controller. The multiplying factors σ, η, γ are used to determine the annual depreciation values for switching equipments, transformer, cables and controllers.

4.2.4. Utility Cost

The utility cost R_{U} is included when electricity is purchasing from the grid and the selling to the grid.

Utility cost is expressed as

$$R_{u} = \sum_{Cons=1}^{n} \sum_{ss=1}^{m} Nods \times \sum_{hr=t1}^{t24} \left\{e_{p} P_{p}(ss, hr, cons) - e_{sl} P_{sl}(ss, hr, cons)\right\} + 12 e_{b} \left\{\max\left[P_{p}(cons)\right]\right\} \tag{4.11}$$

Where, ep is purchasing power, es is selling power and Pp, Psl are corresponding purchasing and selling rates. The rate of energy ep varies for normal, peak or off load time implies that the cost to purchase electricity from the grid.

4.3. Constraining function

DE is the load demand for n different consumers is expressed as,

$$\sum_{cons=1}^{n} D_E(ss,hr,cons) = P_{BM}(ss,hr,cons) + P_{SO}(ss,hr,cons) + P_{Bt}(ss,hr.cons) + P_w(ss,hr,cons) - P_{sl}(ss,hr,cons) \quad (4.12)$$

In optimization procedure the generation of BMGU, SPS, BESS, WT will never violates their constrains.

$$0 \le P_{BM}(ss,hr,cons) \ge IC_{BM}(cons) \quad (4.13)$$

$$0 \le PS_{SO}(ss,hr,cons) \ge IC_{SO}(cons) \quad (4.14)$$

$$0 \le PS_{Bt}(ss,hr,cons) \ge IC_{Bt}(cons) \quad (4.15)$$

$$0 \le PS_W(ss,hr,cons) \ge IC_W(cons) \quad (4.16)$$

$$0 \le P_{BM},P_{SO},P_{Bt},P_W,IC_{BM},IC_{SO},IC_{Bt},IC_W \quad (4.17)$$

From (13-16) represents upper and lower limits of power generation of distributed energy resources. Equation 15 ensures that all of the variables are positive. IC_{BM}, IC_{SO}, IC_{Bt}, IC_w are installed capacity of BMGU, SPS, BESS, WT. To minimise the objective function with constraining function a nature inspired algorithm is used for economic analysis of the system. In next chapter, this proposed soft computing method, which has been applied for these particular cases, is briefly discussed.

CHAPTER 5
SOFT COMPUTING OPTIMIZATION TECHNIQUES

5.1. Introduction

Professor Lotfi A. Zadeh, pioneered the concept of soft-computing and defined it as "Soft computing is a new approach to computing which imitates the remarkable ability of the human mind to reason and learn in an environment of uncertainty and imprecision" [79]. The optimization schemes are helpful in finding the optimum solution or unconstrained minima or maxima of continuous and differentiable functions. These methods are analytical approaches and help to use of differential calculus for finding the optimum solution. The classical methods have limited possibility in practical applications as some of them use objective functions which are not continuous or differentiable. The study of these classical techniques helps for developing most powerful numerical techniques that have evolved into advanced techniques to solve practical problems.

5.2. Classification of Optimization Techniques

Optimization techniques can be carried out in different ways. Considering the nature inspired algorithm and they are divided into two categories. One is deterministic technique, and other is stochastic technique. Deterministic techniques are mainly used in physical and mathematical problems when they are difficult or impossible. Deterministic techniques are used in those cases whose resulting performance is entirely determined by its primary state and input. A stochastic technique is simulation procedure that traces the evolution of variables that can change randomly with certain probabilities.

5.2.1. Conventional or Deterministic Techniques

Deterministic techniques are considered as rigorous procedure, and these approaches have several drawbacks like more computation time, less convergence speed, less accuracy etc. Most of the conventional or classic algorithms have used deterministic techniques. Newton-Raphson algorithm, linear programming belongs to deterministic techniques. Some deterministic techniques are known as gradient-based algorithms as they use gradient data. For example, Newton-Raphson algorithm is gradient-based algorithm, as it works with the function values and their derivatives, and it gives good results for smooth uni-modal problem but gradient based algorithms does not work well for discontinues objective function. In this case, non-gradient algorithms which do not use any derivative are preferred. Old optimisation techniques like iterative method, probabilistic method, graphical construction method, trade off methods, 2/3 rule, Analytical Method, Optimal Power Flow, Mixed Integer Nonlinear Programming are not used due to their drawbacks. In recent years Stochastic Techniques are widely used.

5.2.2. Stochastic Techniques

Stochastic techniques use random variables. Stochastic techniques give better accurate results with less computation time and fast convergence speed. Stochastic techniques are classified into two categories; heuristic and meta-heuristic.

5.2.2.1. Heuristic Techniques

A heuristic is a technique designed to solve problems by using trial and error method. This technique converges very quickly but there is no guarantee that it will give optimal solution in a finite amount of time. Heuristic techniques further develop to Meta heuristic techniques.

5.2.2.2. Meta-heuristic Techniques (Artificial Intelligent Techniques)

Meta heuristic algorithms perform better result than heuristic algorithms. Many Heuristics are very specific and problem-dependent techniques where Meta-heuristics are problem-independent techniques. To find the solution they accept a temporary deterioration which allows them to explore more thoroughly the solution space and thus help to coincide with the global optimum value.

Intensification and diversification are two major components of any meta-heuristic algorithms. Diversification creates diverse solutions in such a way that the search space is explored on the global scale and intensification focus on the search in a local region by exploiting the information so that a current good solution is found in this region. Randomization associated with diversification, avoids the solutions being trapped at local optima and it increases the diversity of the solutions. The proper combination of these two major components ensures global optimum value of the solution. Examples of some popular meta-heuristic algorithms are genetic algorithm (GA), Differential evolution (DE), Particle swarm optimization (PSO) and Ant colony optimization (ACO) etc. There are some other meta-heuristic techniques such as cuckoo search, bacteria foraging algorithm, Imperialist competition Algorithm, and artificial immune system algorithm.

5.2.2.2.1. Modern Meta-heuristic Techniques (Hybrid intelligent techniques)

Further meta-heuristic techniques improved to Modern Meta-heuristic Techniques. These hybrid optimization techniques use two or more optimization techniques together instead of a single optimization technique. Some modern meta-heuristic techniques such as Genetic-Fuzzy, Genetic -Particle swarm Optimization, Genetic- Optimal Power Flow, Particle Swarm Optimization-Optimal Power Flow.

Many models have been developed on micro grid and several optimization techniques are described related to operating cost of micro grid. GA, PSO, DA, Bacterial foraging algorithm, ABC, Cuckoo search, and Bat algorithms are the most popular nature inspired algorithms. Various optimization techniques are shown though the following block diagram.

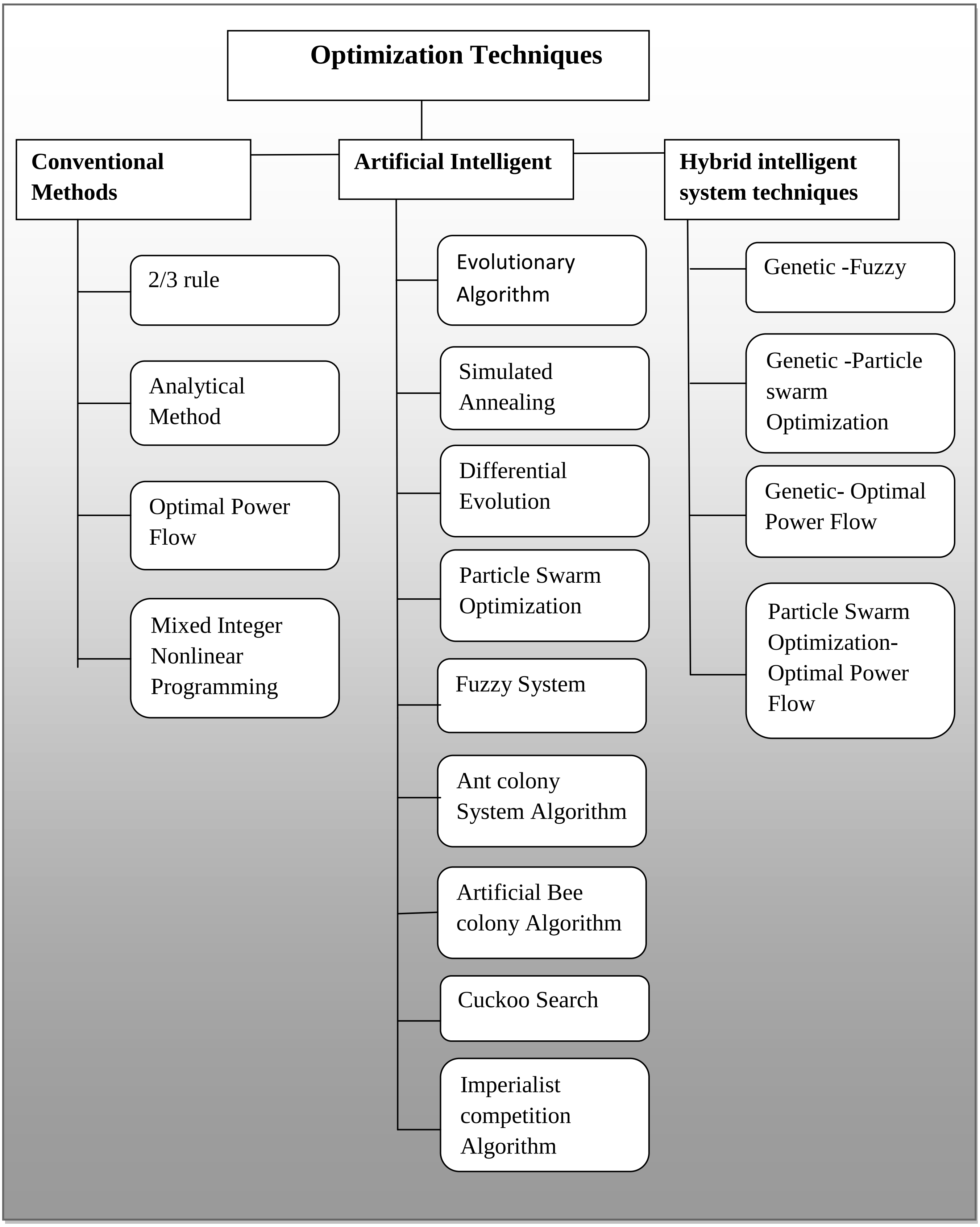


Figure 5.1: Developed various optimization techniques [79]

Optimise the cost of microgrid a new Meta-heuristic optimization technique namely cuckoo search is used. In order to apply this algorithm in cost optimization a basic knowledge is required. Hence, the following sections offer a basic outline of the cuckoo search algorithm.

5.3. Cuckoo search Algorithm

5.3.1. Introduction

Cuckoo search is developed in 2009 by Xin-She Yang and Suash Deb [80] and it is one of the recent nature-inspired meta-heuristic algorithms. The concept of Cuckoo search is based on brood parasitism of cuckoo species. Cuckoos generally lay their eggs in the nests of other host birds (of other species). However, if a host bird discovers that eggs are not their own, it will simply throw these alien eggs away or simply abandon its nest and make a new one somewhere else. This parasitic behaviour increases the chance of survival of the cuckoo's generation. These cuckoo behaviours found in nature and that can be applied for various optimization problems.

In describing Cuckoo Search algorithm, three idealized rules should be followed. They are,

i. Each cuckoo lays one egg at a time, and randomly dumps its egg in a specific nest.
ii. The best nests with consisting high quality eggs will carry over the next generations.
iii. Total number of available host nests is fixed, and discovery of alien egg by the host bird with a probability $Pa \in [0, 1]$.
In this case if the host bird identifies the alien egg then it simply throws the egg away or abandons the nest, and builds a new nest somewhere else. There is few control parameters used for cuckoo Search method. This nature makes Cuckoo search very robust and reliable process to solve complex optimization problems with various constrains. It can also be fruitfully combined with other optimization techniques.

5.3.2. Flow chart of Cuckoo Search Algorithm

Flow chart for cuckoo search algorithm is given in Fig 5.2 and different stages of the algorithm are described in the following subsection.

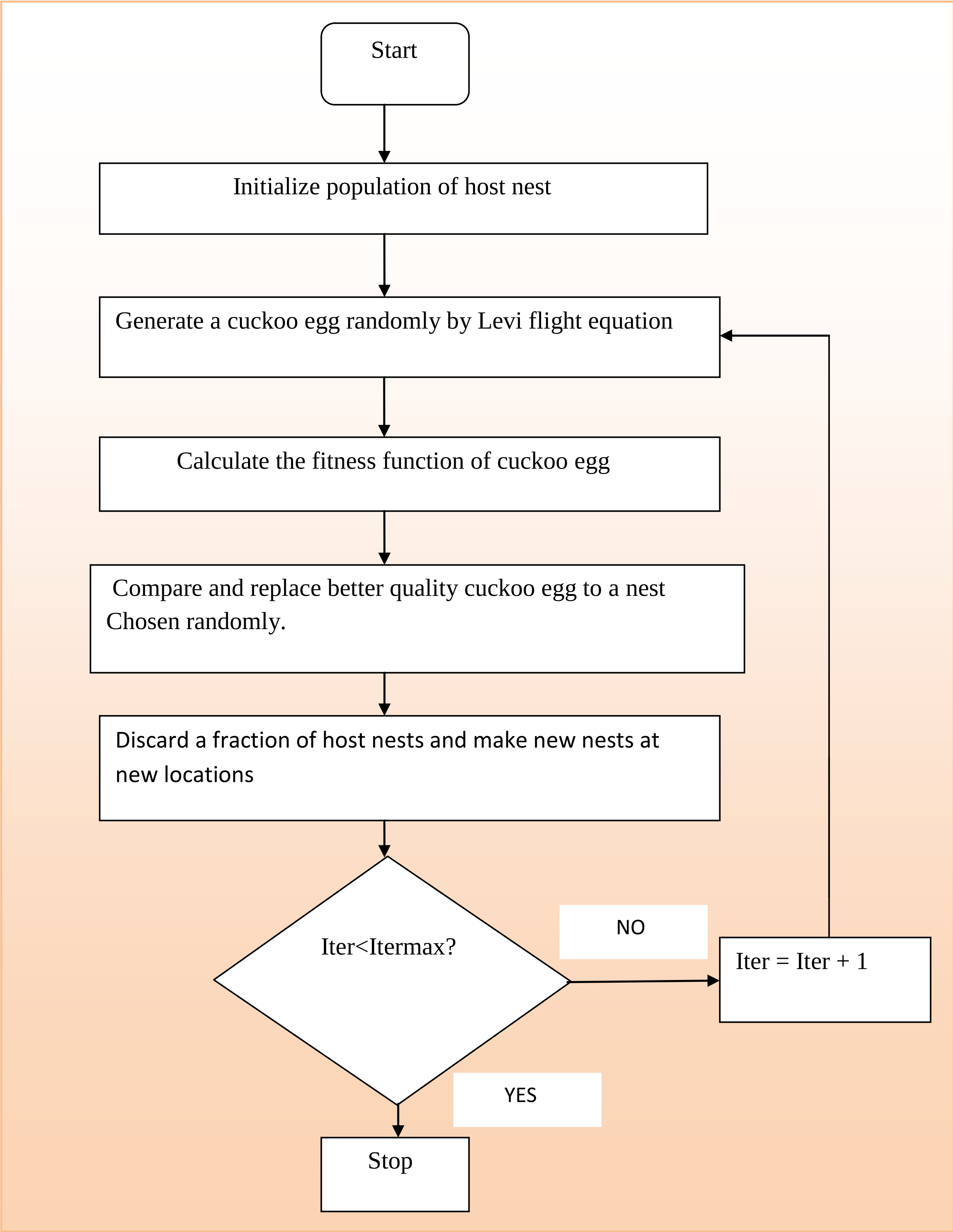


Figure 5.2: Flow chart of cuckoo search Algorithm

5.3.2.1. Different stages of cuckoo search algorithm

A. Step 1 (Initialization of Cuckoo Search Parameters)-

In this step cuckoo search parameters such as maximum number of generation, number of population (n), number of parameter (α), probability of nest to discarded (Pa) are set in the problem.

B. Step 2 (Generation of population in Nests)-

Population are generated in each nest by assigning a set of random values. This random value depends on following equation. [55]

$$nest_{(i,j)}^{(0)} = x_{j,min} + rand(x_{j,max} - x_{j,min}) \tag{5.1}$$

Where $nest_{(i,j)}^{(0)}$ represents the initial value of the j^{th} variable of i^{th} nest, $x_{j,max}$ and $x_{j,min}$ indicates the maximum and minimum limit for j^{th} variable, rand is a random number between [0,1].

C. Step 3 (Generate New Cuckoo Eggs by Levy Flights equation and find the current best)-

Obtain the best fitness value by comparing all the fitness values and also obtain the best nests corresponding to the best fitness value. New cuckoo eggs are produced with Levy flights and replace other eggs in other nests. New cuckoo eggs generation process is given as, [49]

$$nest_i^{(t+1)} = nest_i^{(t)} + \alpha.S.\left(nest_i^{(t)} - nest_{best}^{(t)}\right).r \tag{5.2}$$

Where, S is step length based on Levy flights, α is the step size parameter, r is a Matlab command and it gives random values between zero to one, $nest_i^{(t)}$ is the current position of i_{th} nest and $nest_{best}^{(t)}$ is the position of the best nest.

Now Step length S can be calculated by the following equation, [55]

$$S = \frac{\sigma_U}{|v|^{1/\beta}} \tag{5.3}$$

Where β is a parameter between [1, 2] normally it is taken as (3/2=1.5).

Determine sigma value from the following equation, [54] σ_U where are drawn from normal distribution as

$$\sigma_U = \left\{ \frac{\Gamma(1+\beta).\sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left[\frac{1+\beta}{2}\right].\beta.2^{\frac{\beta-1}{2}}} \right\}^{1/\beta} \quad (5.4)$$

D. Step 4 (Compare and replace with better quality cuckoo egg)-

Then a comparison carried out between host eggs and cuckoo eggs, if cuckoo eggs are better then it will replace the host nest and carry over next generation. The replacement is done in the basis of poor fitness function.

E. Step 5 (Alien egg discovery)-

The probability of alien eggs discovery is $Pa \in [0\ 1]$. A fraction of total number of eggs in nests is replaced by new random solutions. Generally replaced solutions are of poor quality with lower fitness values.

F. Step 6 (Termination)-

If the iteration no is equal with maximum iteration number then the Generation of new cuckoo eggs and alien egg discovery process is stopped otherwise the process will continue until a termination criterion is met.

5.4. Development of the proposed algorithm in this work

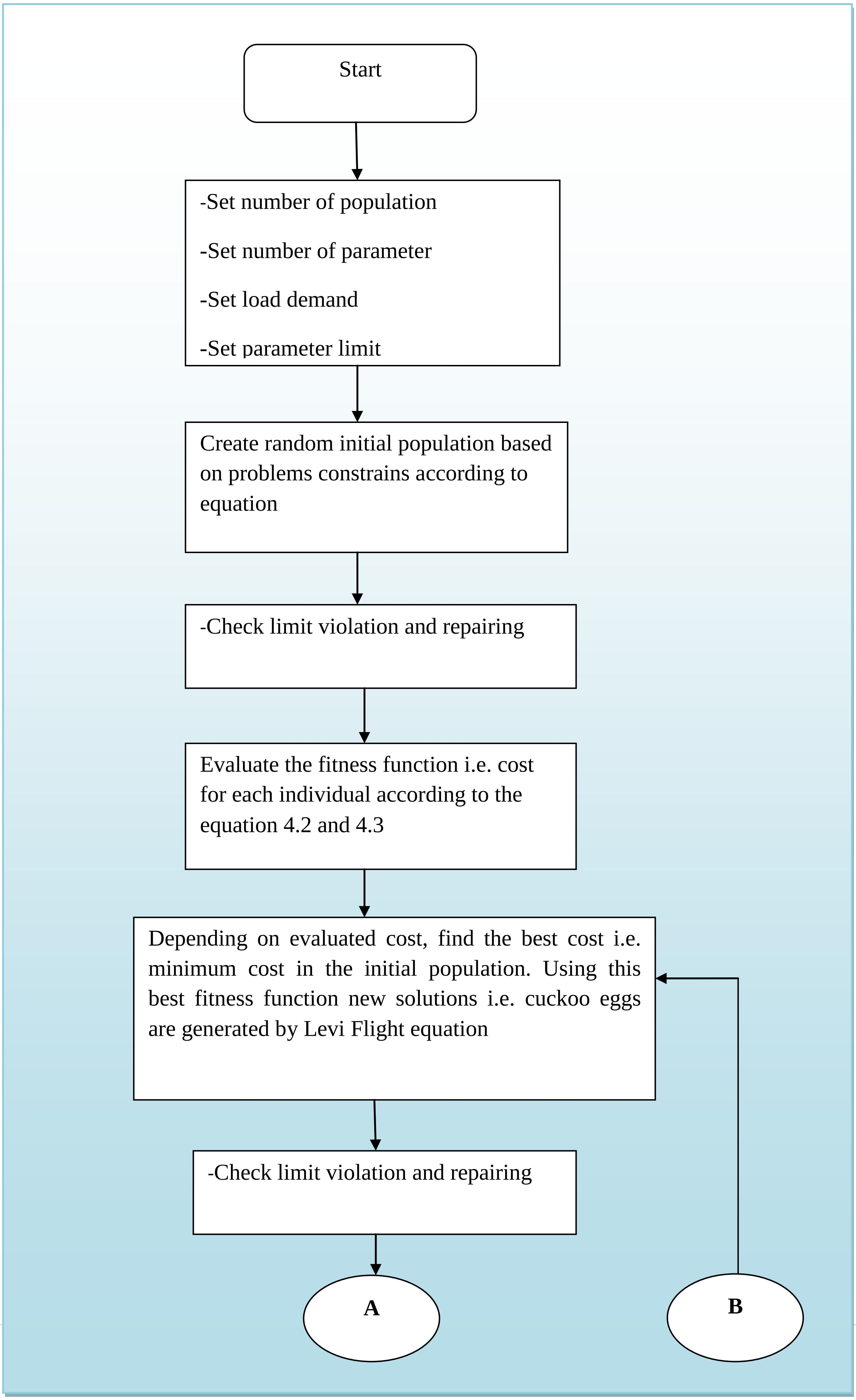
This Cuckoo Search method has been efficiently utilized to have the optimal value for the two types of cases, according to equations 4.3 and 4.2. The logic steps and Flow chart and of this evolutionary method is briefly described in the following steps.

A. Step 1 (Initialization of Cuckoo Search Parameters)

In this program Cuckoo search parameters are set at following data for initialization. Where,

Number of parameters=4 (for case 1) and Number of parameters=5 (for case 2).

Load demand data is set for 24 hrs for both cases.


Start
-Set number of population
-Set number of parameter
-Set load demand
-Set parameter limit
Create random initial population based on problems constrains according to equation
-Check limit violation and repairing
Evaluate the fitness function i.e. cost for each individual according to the equation 4.2 and 4.3
Depending on evaluated cost, find the best cost i.e. minimum cost in the initial population. Using this best fitness function new solutions i.e. cuckoo eggs are generated by Levi Flight equation
-Check limit violation and repairing
A
B

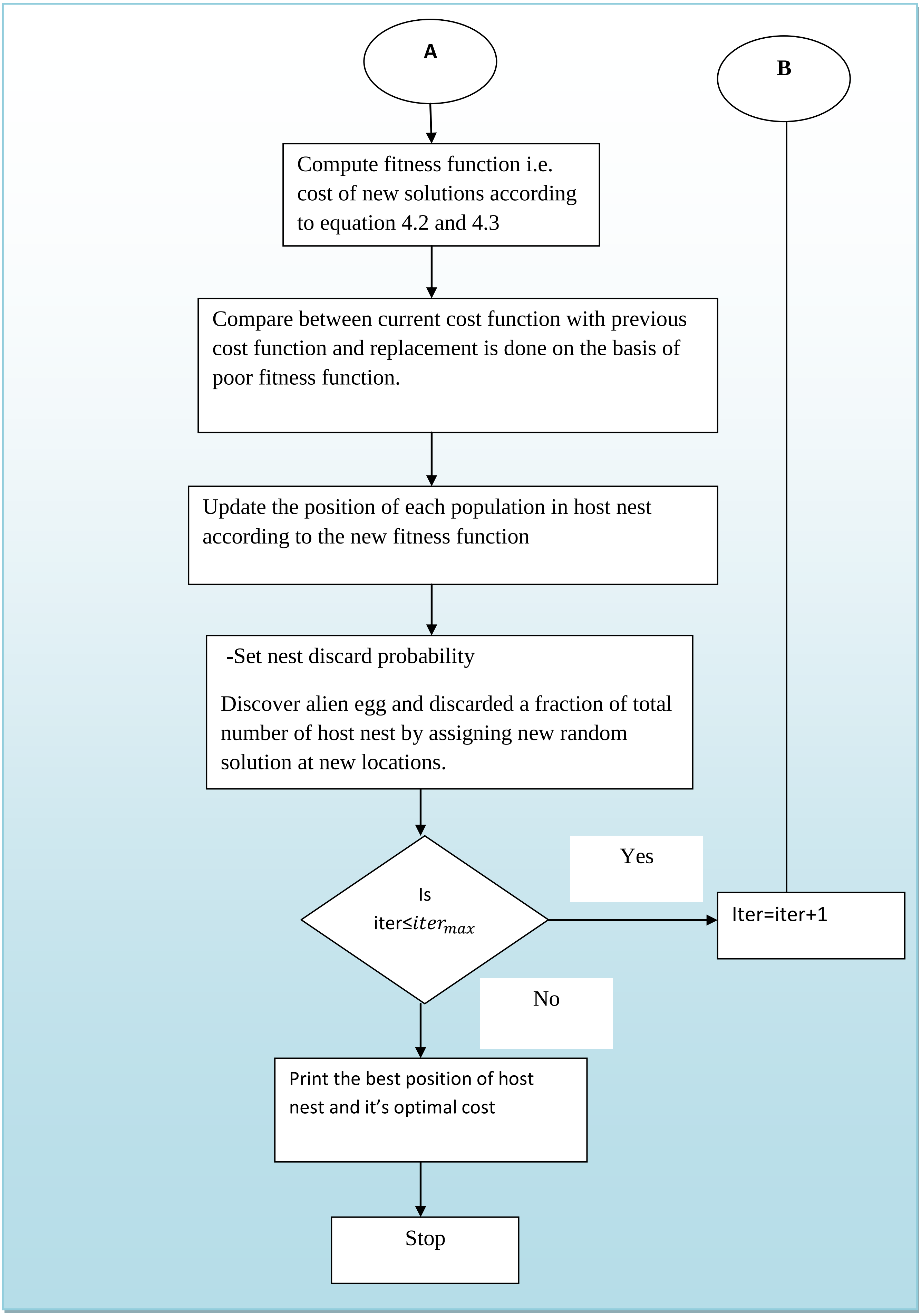


Figure 5.3: Developed flow chart using cuckoo search algorithm

Parameter limit is set for case 1 where Column 1 and 2 shows the maximum and minimum limits of power generation for BMGU, SPS, BESS and grid)

Parameter limit= $\begin{bmatrix} 1000 & 70 \\ 350 & 0 \\ 170 & 0 \\ 20 & -20 \end{bmatrix}$

Parameter limit is set for case 1 where Column 1 and 2 shows the maximum and minimum limits of power generation for BMGU, SPS, BESS, WTG and grid)

Parameter limit= $\begin{bmatrix} 1000 & 70 \\ 350 & 0 \\ 170 & 0 \\ 170 & 0 \\ 20 & -20 \end{bmatrix}$

For biomass it is assumed that it will always provide some minimum power to the system. Solar cell and wind turbine are weather depended. So maximum limit is 350 and minimum is zero. For wind turbine it is set at 170 for maximum. It is assumed that maximum and minimum power purchased and selling capacity is 20 KW.

B. Step 2 (Generation of population in Nests)

Create random initial population based on problems constrains according to equation   in each nest by assigning a set of random values. This random value depends on following equation

$$P_{BM,S,Bt,W_{i,j}} = x_{j,min} + rand(x_{j,max} - x_{j,min}) \quad (5.5)$$

And then evaluate the fitness function i.e. cost for each individual according to the 4.2 and 4.3.

C. Step 3 (Generate New Cuckoo Eggs by Levy Flights equation and find the current best)

Depending on evaluated cost, find the minimum cost in the initial population. Using this best fitness function new solutions i.e. cuckoo eggs are produced with Levy flights and replace other eggs in other nests.

D. Step 4 (Compare and replace with better quality cuckoo egg)

Compute fitness function i.e. cost of new solutions according to equation 4.2 and 4.3. Compare between current cost function with previous cost function and replacement is done on the basis of poor fitness function and Update the position of each population in host nest according to the new fitness function.

E. Step 5 (Alien egg discovery)

The probability of alien eggs discovery is $Pa \in [0\ 1]$. A fraction of total number of eggs in nests is replaced by new random solutions. Generally replaced solutions are of poor quality with lower fitness values.

F. Step 6 (Termination)

If the iteration number is equal with maximum iteration number then the Generation of new solution and discard process is stopped otherwise the process will continue until a termination criterion is met. Print the best generation of host nest and optimum cost.

Cuckoo search algorithm is proved as an efficient algorithm in this work. To initialize the program, basic system configuration and mathematical formulation are required to know thus minimum and maximum limit can be set. In the next chapter a brief discussion are given on biomass gasifier model, solar photovoltaic system, wind energy system and battery storage of these renewable energy systems.

CHAPTER 6
NON CONVENTIONAL GENERATION BASED SYSTEM MODEL

6.1. Introduction to the System Model

Microgrid is mainly powered by two or more renewable energy sources which provide small scale power to a small community. This HRES system consists of a group of radial feeders, which are the main parts of a distribution system. Here the feeders consists a group of combination of photovoltaic cell (PV), wind turbine (WT), diesel generator (DG), fuel cell (FC), micro-turbine (MT) etc and conventional loads. . To supply the load demand, electrical power can be generated either directly by PV, WT, DG, MT, FC or any other non renewable resources. The fuel input is required only for the diesel generator, micro-turbine and fuel cell. Natural gas is a fuel input to a fuel processor to produce hydrogen from the fuel cell whereas the diesel oil is input to a diesel generator. Each component of the MG system is designed separately based on their constraints and characteristics [50].

In this project work, biomass, solar cell, wind and battery systems are considered here. Biomass energy is clean energy. It does not create any harmful carbon dioxide emissions. Biomass unit generate power using any kind of wastes such as wood chips, sewage, rotted trees, manure, mulch, and tree components, cattle dung etc which are easily available in nature. Though installation cost for husk system is very high but running cost is low compared to other systems expect solar and wind system. Wind turbines and solar cells create power without producing greenhouse gases or radioactive waste because they do not use fossil fuels. Both systems have high installation cost still they are productive and efficient system due to their least running cost. One major disadvantage of solar and wind systems is they are weather depended. To make assure uninterrupted power supply to the system, battery or storage unit is provided with the system. Figure 6.1 shows an overview of a microgrid with all its components.

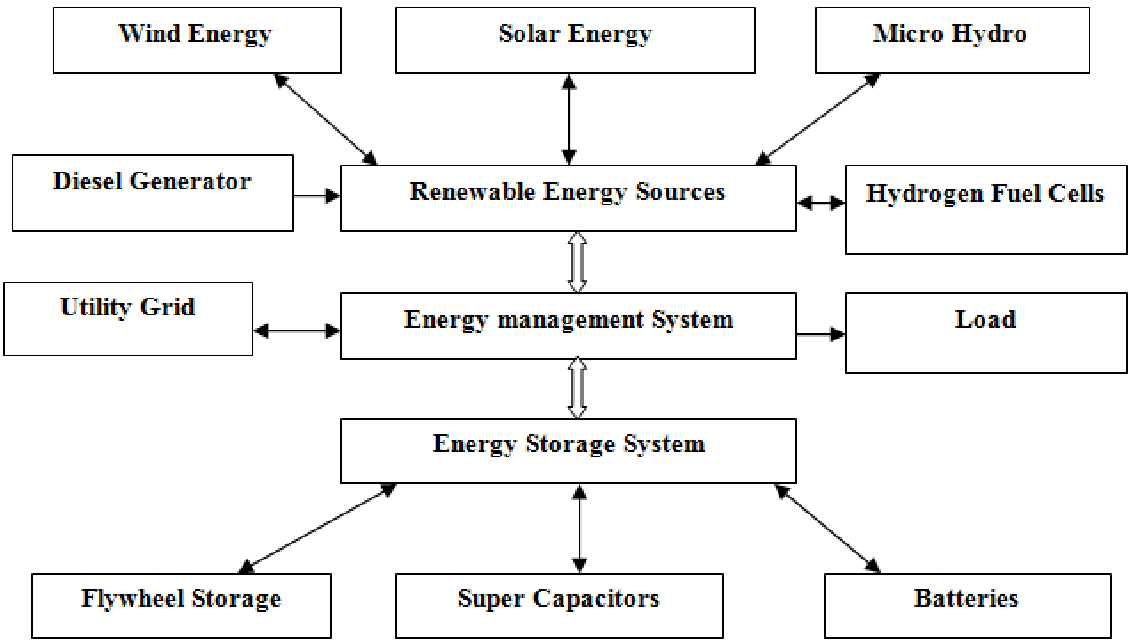


Figure 6.1: overview of a Microgrid with all its components. [81]

A basic microgrid model is mainly combination of non-renewable energy sources, renewable energy sources and the system always consists with Storage Unit, power monitoring unit, load and grid connection which is optional.

- The renewable sources that are mainly used now days are solar PV/thermal, wind, biomass, geothermal, tidal/wave, hydro/micro hydro, fuel cell and micro turbine.
- In some cases to meet the load requirements non renewable energy sources are used because renewable sources are difficult to generate the necessary energy due to the unpredictable weather patterns.
- Energy storage systems (ESS) are one of the vital components for a microgrid system. These storage units includes super capacitor, pumped hydro, flywheel storage, flow batteries etc in order to deal with the unpredictable variation of the energy supplied by renewable energy sources.
- AC or DC loads are connected with the system using suitable converters.
- A microgrid system can be operated either in grid connected or disconnected mode. In fig a block diagram is presented here to show the operation of a grid connected system.

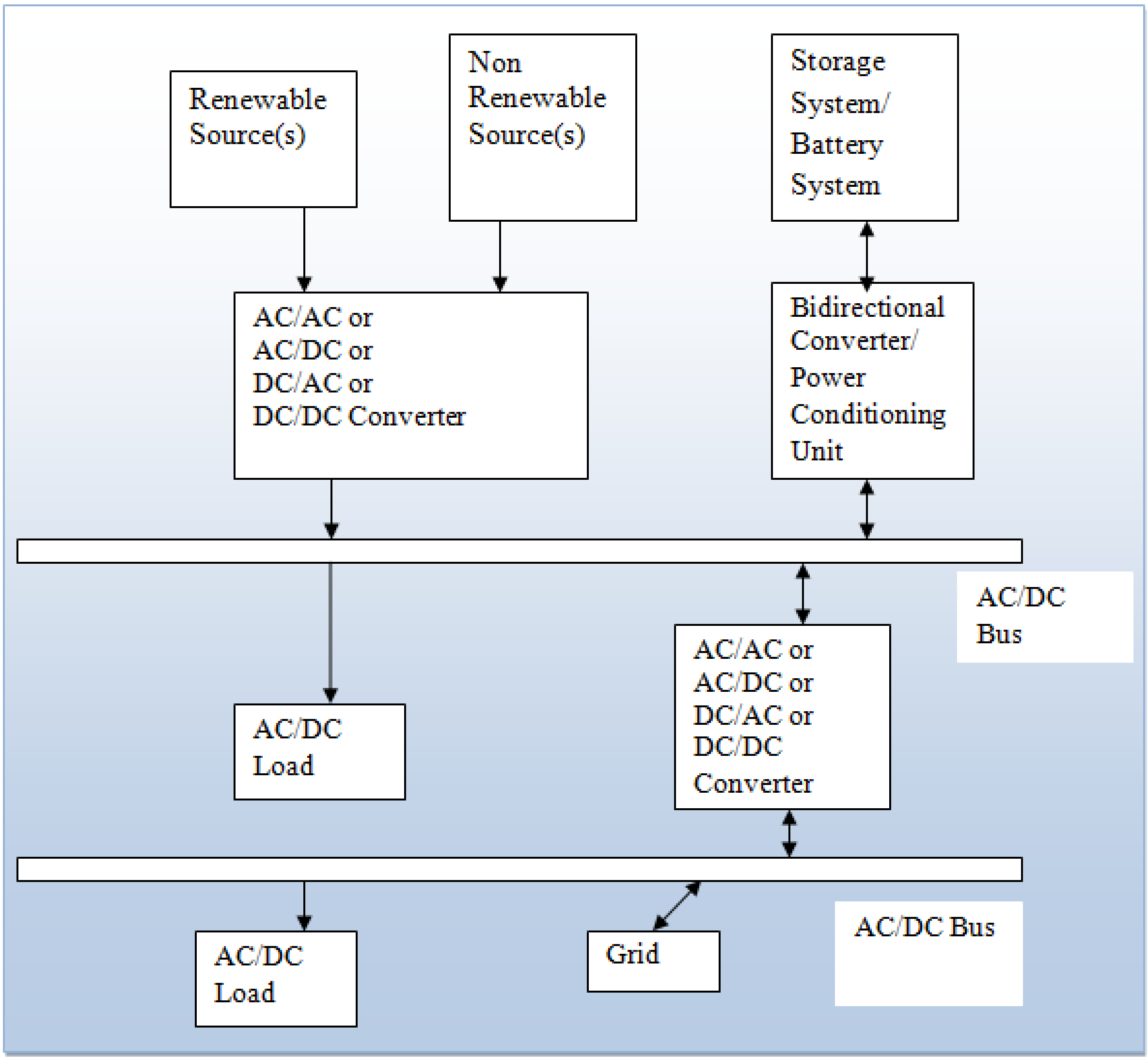


Figure 6.2: Operation of a grid connected system [82]

The various configurations that could be possible from various combinations of renewable energy sources, storage system and loads are described in the following subsections. Many researchers have developed various configuration techniques to design different components of microgrid. Design a microgrid system, the main focus has been given on the several combinations of photovoltaic, wind and diesel generator. Some renewable energy system configurations are possible such as PV–diesel, PV–battery, wind–diesel, wind–battery and PV–wind–diesel–battery. It is necessary to select a proper combination for the right application in which it is being used.

Physical, mathematical and circuit configurations of components like Biomass, PV, wind, and battery system is described in the following sections.

6.2. Biomass

Biomass resources are easily available in nature. The alteration of biomass to such useful forms of energy, also called bio-energy, can be obtained using a number of different techniques. This bio-energy can be used to generate electricity, provide process heat for industrial facilities and also for other purposes such as heating homes and fuelling vehicles. Generally biomass resources are wood and wood wastes, animal wastes, agricultural crops, municipal solid waste (MSW), waste from of food processing and aquatic plants and algae. Generally average majority of biomass energy is extracted from wood and wood wastes (66%), followed by municipal solid waste (23%), agricultural waste (5%), and landfill gases (4%). [83]

6.2.1. Plant configurations

Typical plant architecture of a bio-mass gasifier unit consists following components for power generation:

- Combustion process includes fluid bed combustion, followed by steam turbine cycle (C/ST).
- Gasification process includes fluid bed gasification, followed by a combined gas–steam cycle (G/CC).

In C/ST cycle, plant configuration is consists with a biomass storage and handling section, combustion and steam generation section [84]. Combustion process includes a fluid bed combustor and a boiler that produces steam. Steam is processed by the hot gases generated in the combustion process. At last, the steam is fed into the energy recovery section where it expands through turbine to generate electricity. Similarly the plant configuration of G/CC cycle is composed by a storage and handling section [84]. Subsequently the biomass is fed to a heat recovery dryer (HRD) in order to reduce the moisture content (about 20%). The obtained dry biomass is then supplied to a constant pressurized fluid bed gasifier (15 bars) to produce a gas stream having low heating value. The produced gas stream expands through turbine to generate electricity.

A generalised plant configuration of a biomass unit with various components is shown in fig 6.3. Subsequently working method is described for C/ST and G/CC cycle.

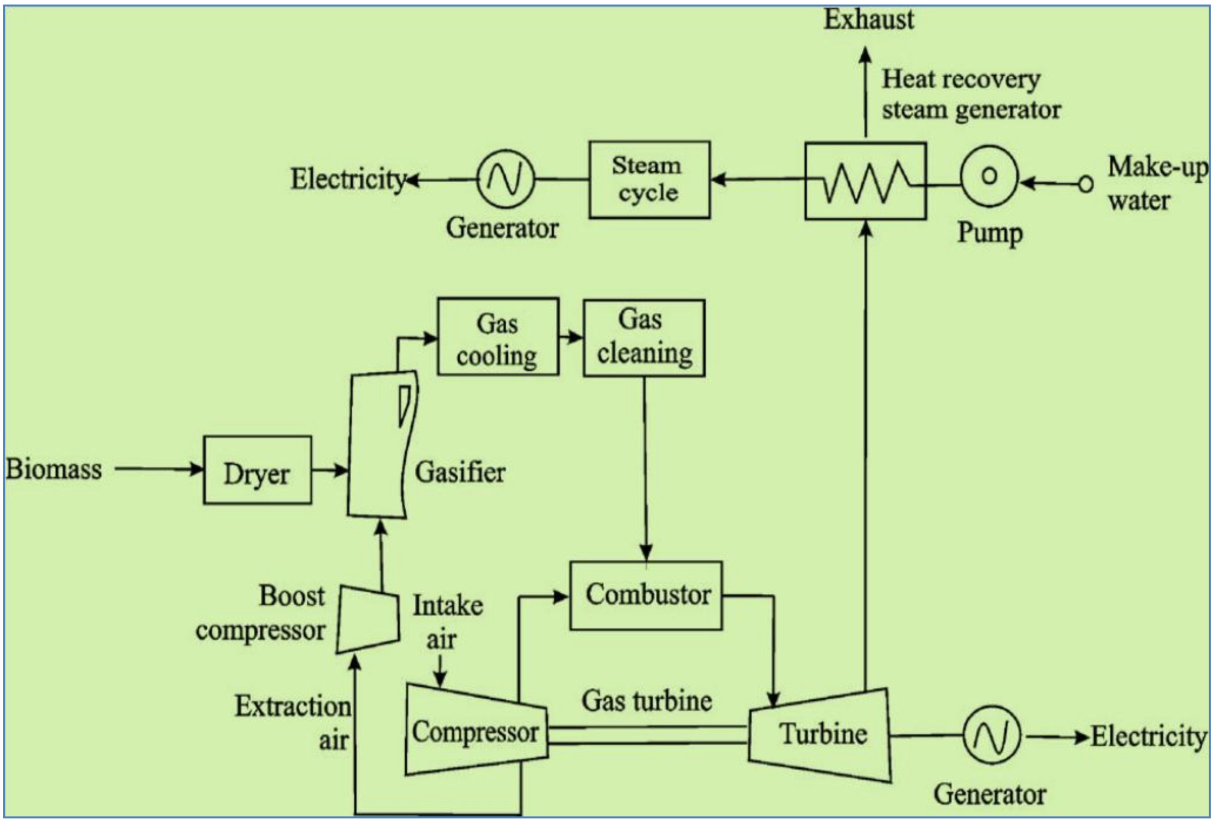


Figure 6.3: A biomass-gasifier/gas turbine combined cycle [85]

To calculate output of a plant, the plant model is simply considered as black boxes having a transfer function between the input and output. Here input is biomass flow rate (M) and the output is net electrical power (WNE). The output power is directly proportional to mass flow rate. The biomass low heating value (LHV) and the plant energy conversion efficiency ηe, is inversely proportional to the plant operating hours OH. This following equation represents relation between mass flow rates with output power [84].

$$P_{BM} = \frac{M \times \eta (WNE) \times LHV}{3600 \times hr} \tag{6.1}$$

6.2.2. Bio-energy conversion: process

A brief overview of energy conversion process is presented here [76]. Conversion of biomass to energy is consisting two main procedures: 1) thermo-chemical conversion process 2) bio chemical or biological conversion process.3) Mechanical extraction is the third process for producing energy from biomass. One such example is bio-diesel. Thermo-chemical conversion is undertaking combustion, Pyrolyis, gasification and liquefaction. Another method, Bio-chemical conversion encompasses two process options: and fermentation (production of ethanol) and digestion (production of biogas, which is mixture of methane and carbon dioxide). Various processes are described in the following sections.

6.2.2.1. Thermo-chemical conversion

Three main processes are consisting with thermo-chemical conversion of biomass.

1) Combustion-

The combustion process is used over a wide range by burning biomass in air. The output of biomass stored as chemical energy converts into heat energy, mechanical power, electricity. Combustion of biomass produces hot gases at high temperatures, typically in the range 800–1000° C. This hot gas is used in gas turbine to produce electricity.

2) Gasification- In gasification process flammable gas mixture is obtained by the partial oxidation of biomass at high temperatures around 800–900 °C where gas turbine converts the gaseous fuel to electricity with a high overall conversion efficiency [85].

3) Pyrolysis- Pyrolysis is the conversion of biomass to solid, liquid (bio-oil or bio-crude), and gaseous fractions, by burning the biomass in the absence of air to around 500° C

4) Other processes**-** Other processes are hydro thermal upgrading (HTU) and liquefaction that produce bio-oils [76].Hydro thermal upgrading converts biomass to partly oxygenated hydrocarbons in the presence of wet environment at high pressure.

Liquefaction is the conversion of biomass at low temperatures and high hydrogen pressures to a stable liquid hydrocarbon. [86][87]

A generalised conceptual flow sheet for thermo-chemical conversion is illustrated in the flowchart, shown in Fig 6.4.

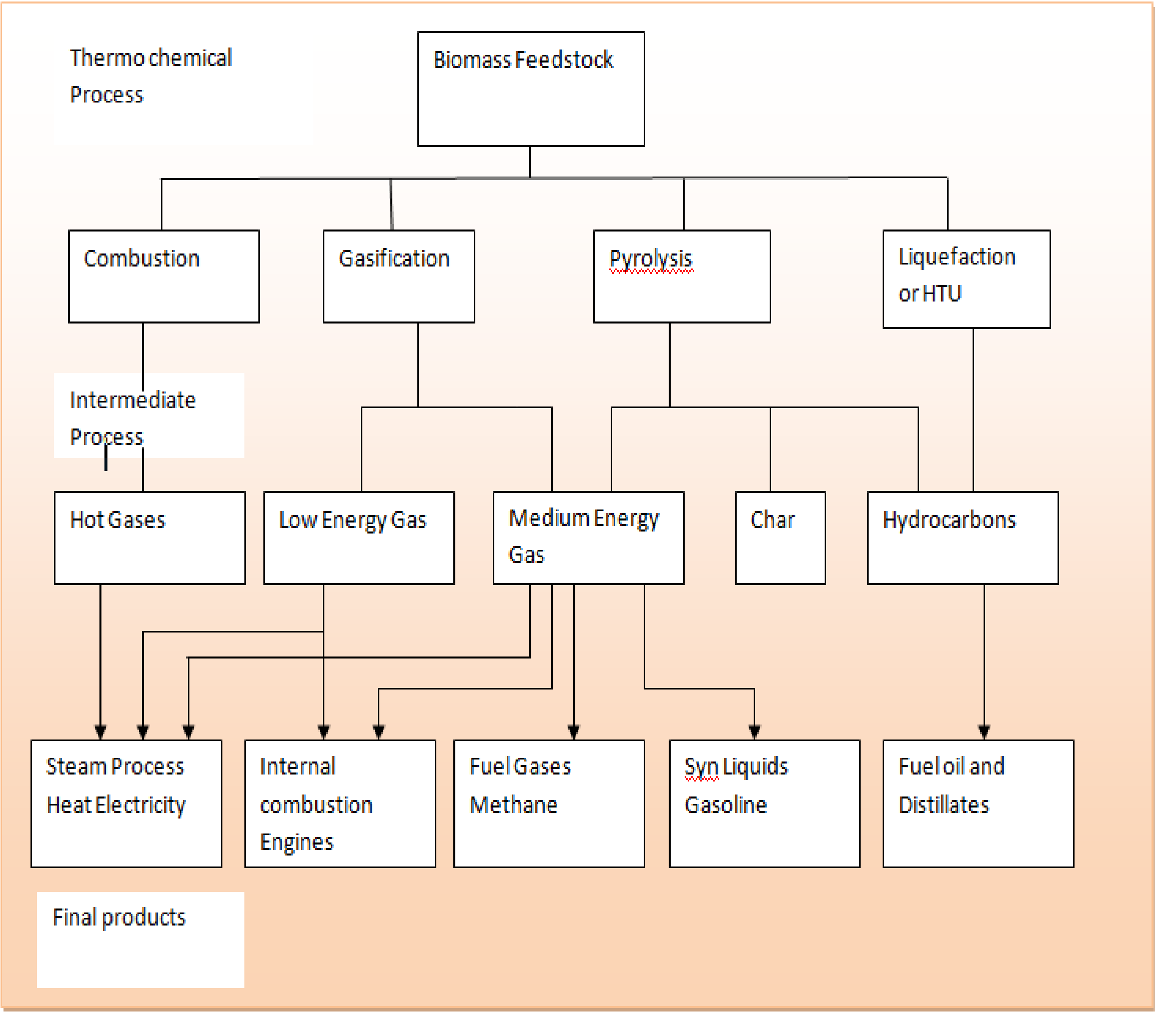


Figure 6.4: Main processes, intermediate process and final energy products from the thermo chemical conversion of biomass [76]

6.2.3. Bio-chemical conversion

Two main procedures are associated with bio-chemical conversion are fermentation and anaerobic digestion (AD). This process has lesser use than mechanical extraction or chemical conversion [88].

6.2.3.1. Fermentation

Fermentation is used commercially on a large scale in different countries to produce ethanol from sugar crops. (e.g. sugar beet ,sugar cane) and starch crops (e.g. wheat ,maize). Ethanol fuel is used as a motor fuel, mainly as a bio fuel.

6.2.3.2. Anaerobic digestion (AD)

Anaerobic digestion process is the conversion of biomass directly to a gas, namely biogas, a mixture of methane and carbon dioxide with little amount of other gases such as hydrogen sulphide. In an anaerobic environment the organic material (biomass) is converted into gas with an energy content of about 20–40% by bacteria with lower heating value. The overall efficiency of conversion from biomass to electricity is about 10–15% [88]. AD is a commercially established technology and is extensively used for treating high moisture content organic wastes. Any power generation system is associated with an internal combustion engine, prime mover, water-cooling systems, and exhaust could be recovered using combined heat and power cycle. A typical flow diagram for processing electricity from biomass using anaerobic digestion is shown in Fig 6.5

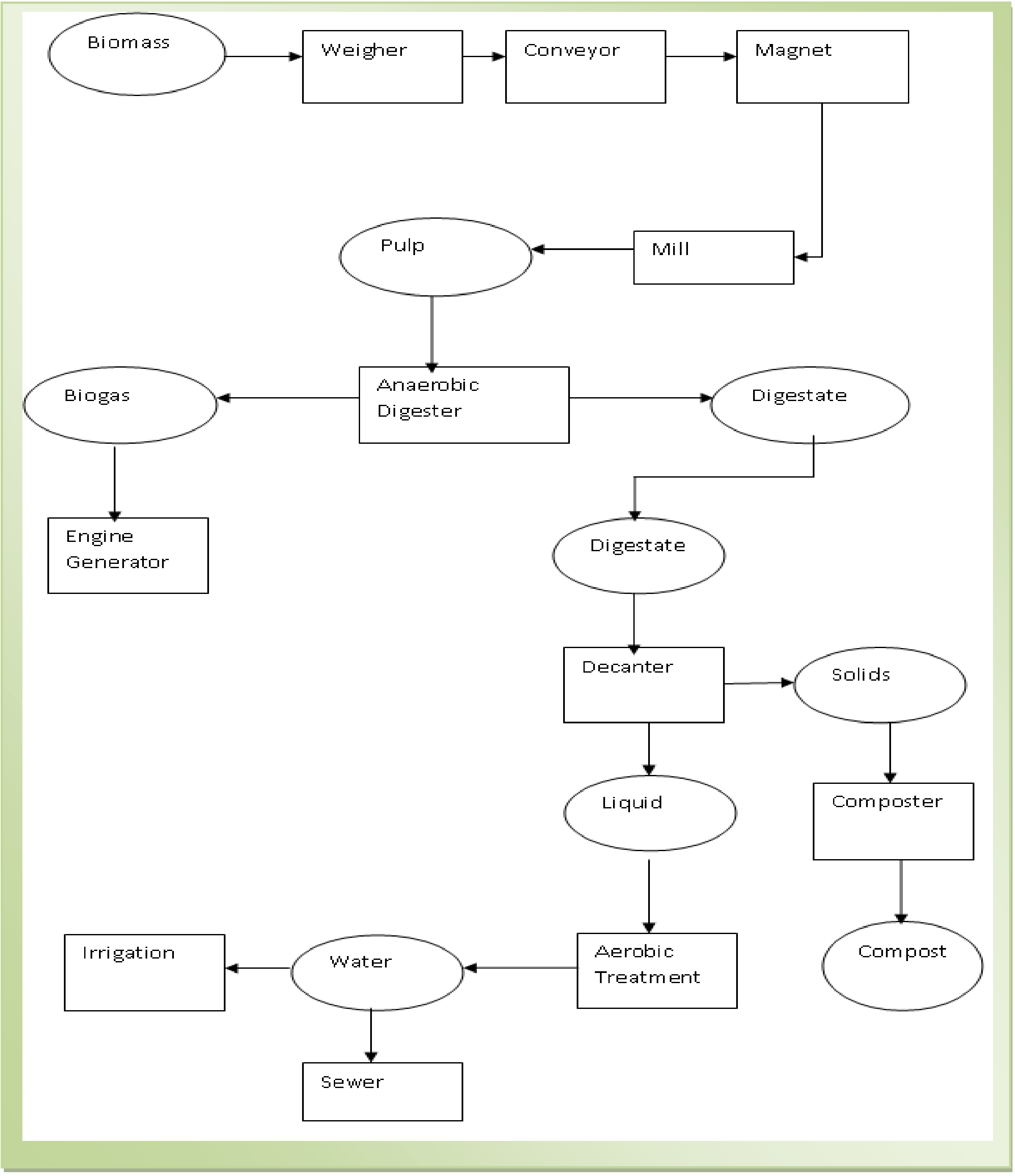


Figure 6.5: Flow diagram for anaerobic digestion [88]

6.2.4. Mechanical extraction

Mechanical extraction is a conversion process of oil from the seeds of various biomass crops, such as cotton, oilseed rape and groundnuts. This oil can be processed further with alcohol using a process termed as esterification to obtain bio-diesel. Fig. 6.6 depicts a generalised flow diagram for the production of bio-diesel and the by-products of glycerine.

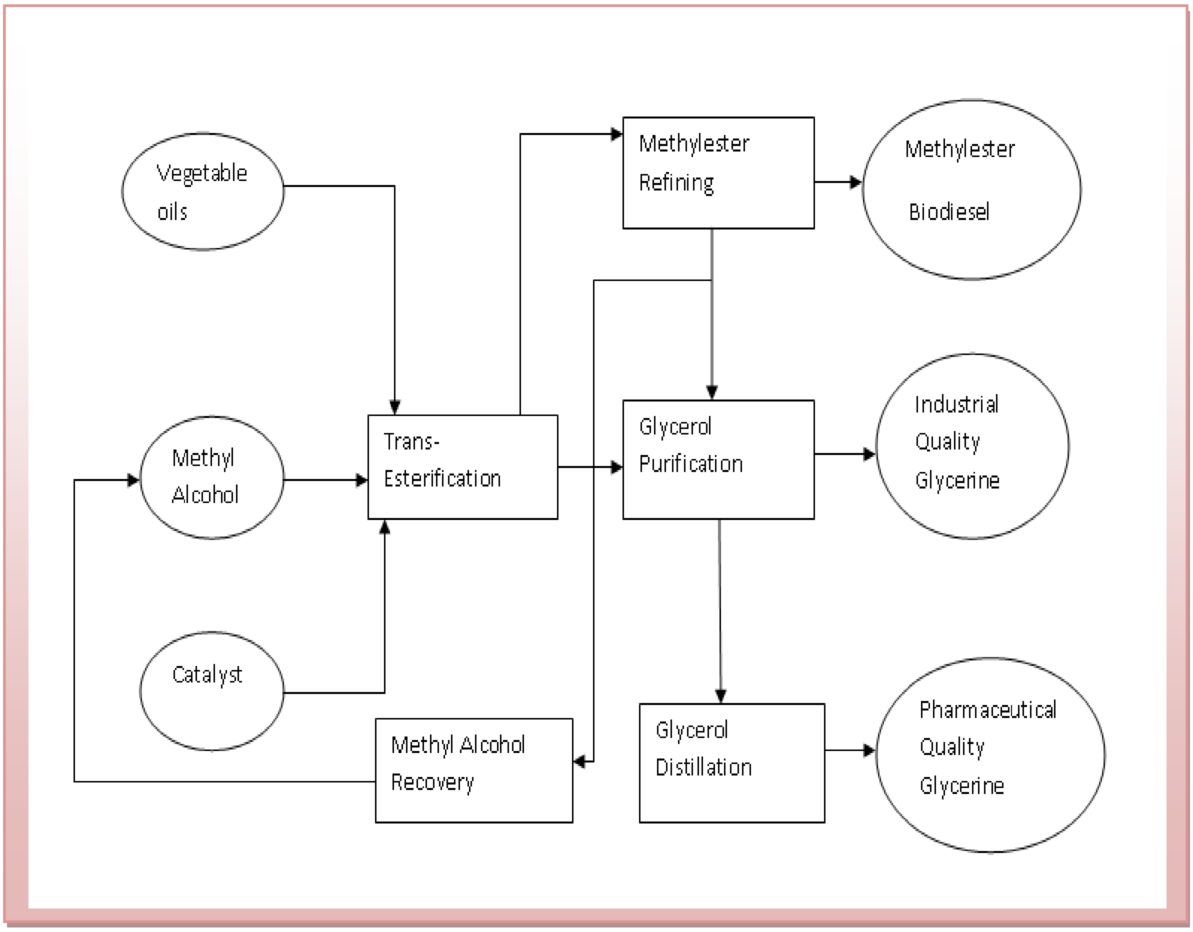


Figure 6.6: Production of bio-diesel and the by-products of glycerine from mechanical extraction [76]

Biogas has several advantages, when it compared to other renewable energy alternatives. It can be produced when it is needed and can easily be stored. The biogas can directly be used for transportation fuel, domestic cooking or used as the natural gas. As far as renewable energy sources are concerned solar energy is the most abundant source. Here basic configuration, equivalent circuit model and equations are discussed in another subsection.

6.3. Photovoltaic System

6.3.1. Basic Configuration of Photovoltaic System

Solar energy is radiated by the sun, which can be used by tapping light photons to generate electricity. A solar panel consist a number of solar cells which are connected together in series. Similarly a number of Solar panels are connected together in series and/or parallel combination to form a solar array to generate electricity in large scale.

For uninterrupted power supply electricity storage devices such as batteries are required because PV system does not operate during bad weather condition or night. A typical PV generator generates direct current (DC). According to use in different applications DC converters are used and for alternating current (AC) requirement the DC/AC inverters are provided in PV systems. The installation cost for PV is very high. Recently, solar energy is now generated on a large scale and many energy investing companies promoting it. But it requires a lot of expertise for execution, site designing and development. Now a day, maximum power point tracking (MPPT) scheme are available to extract maximum power from solar PV cells. Indian states like Gujarat and Rajasthan are harnessing solar energy, so if there is PV generation available and the maximum profit is done from that PV then it can be used to generate huge amount of power because the operational cost of PV is almost zero [90] [91].Finally, the household appliances, such as radio or TV set, lights and other equipment being powered by the PV system.

Generally a PV modules or arrays consist of three parts:

- PV modules or solar arrays
- Balance of system (consists of mounting structure, control devices, charge regulators, converter/ inverter, MPP tracker)
- Electrical load

Physical Model of Photovoltaic System is represented in Figure.6.7

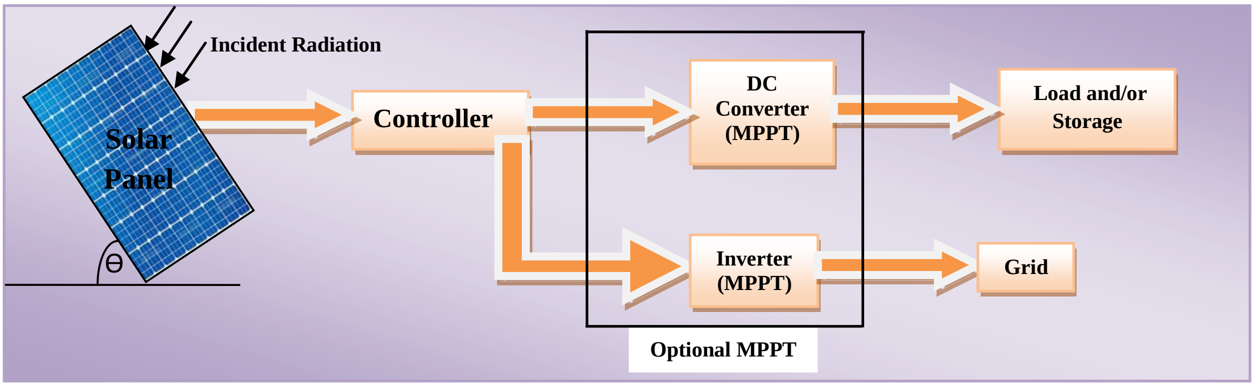


Figure 6.7: Basic Model of Photovoltaic System [92]

6.3.2. Properties of solar cell meterial

A solar cell is a solid-state electrical component (p-n junction) that converts the energy of sun in terms of light directly into electricity (DC). The process of conversion first requires a material which absorbs the solar energy (photon), and then raises electron to a higher energy state, and then the flow of this high-energy electron to an external circuit as a current. Silicon is one such material that uses in this process. In Fig 6.8 a picture is depicted for silicon material which shows that how it responds with respect to photovoltaic effect.

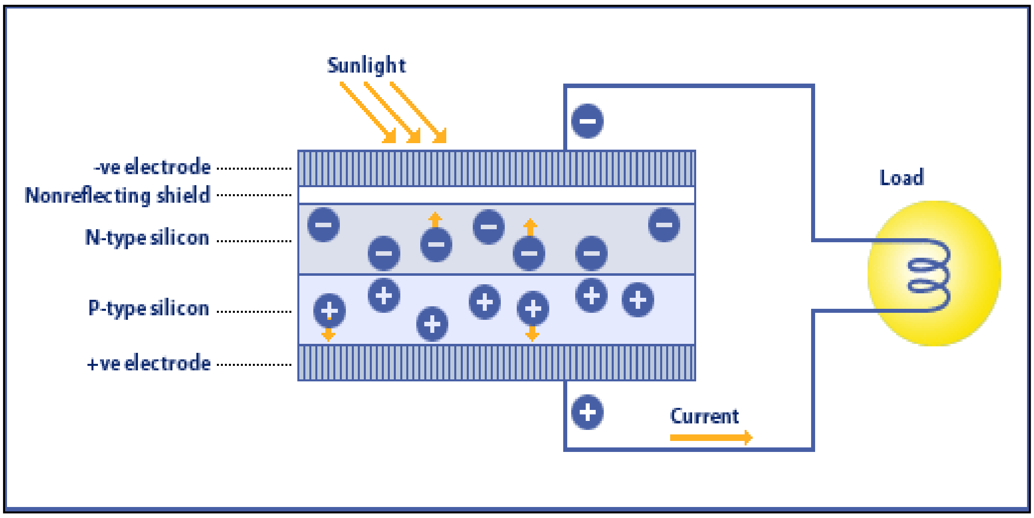


Figure 6.8: Photovoltaic effect on silicon material [89]

6.3.3. Equivalent circuit of solar cell

To understand the behaviour of a solar cell, it is useful to create an electrically equivalent model. An ideal solar cell is modeled by a current source in parallel with one diode. Generally no solar cell is ideal, because a small leakage current is always associated with. So a shunt resistance and a series resistance component are added to the model. Here an equivalent circuit of a solar cell is shown in fig 6.9.

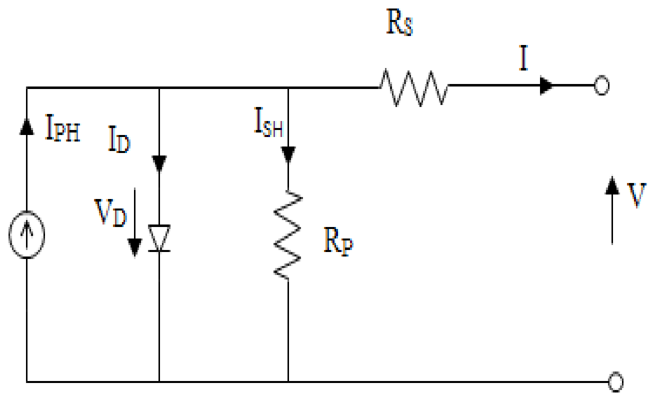


Figure 6.9.: Single diode model of a solar cell [92]

Hence, a typical PV cell circuit consists of a current source, in parallel with a diode (D). The produced current (I_{PH}) is proportional to incident light. Shunt resistance (R_{SH}) is connected with the circuit to provide low resistance path in case of any short circuit condition occurs. In some cases, leakage current can be neglected due to its small value .PV module with two diode models [93][94] are also available but only single diode model is considered here. Figure 6.9 represents a single PV cell made up of a resistance (R_S) that is connected in series with a parallel combination of current source, one exponential diode & shunt resistance respectively [92].

6.3.4. Characteristic equations

From the equivalent circuit, the output current generated from the PV cell is equal to that current produced by the photo current generator (I_{PH}), minus the current which flows through the diode, minus the current which flows through the shunt resistor. The output current represents by the following current equation [95].

$$I = I_{PH} - I_D - I_{SH} \quad (6.2)$$

Where, I= Output current in the solar cell (amp).

I_{PH} = Photo generated current (amp).

I_D = Diode current (amp).

I_{SH} = Shunt current (amp).

Again, the current through these elements is maintained by the voltage across them so voltage across diode is,

$$VD = V + I.R_S \quad (6.3)$$

Where, V_D = Voltage across both diode and resistor R_{SH} (volt).

V = Voltage across the output terminals (volt).

R_S= Series resistance (Ω).

The photo generated current is given by:

$$I_{PH} = \{I_{SC} - K_I(T - T_{REF})\} \times {}^{G}/_{G_N} \quad (6.4)$$

Where, I_{SC}=Short circuit current at reference temperature (A).

K_I = Short circuit current temperature coefficient at I_{SC}, which is usually provided by the manufacturer.

T = Cell temperature in Kelvin (^{0}K).

T_{REF} = Reference temperature (^{0}K).

G = Solar irradiation (W/m^2).

G_N = Nominal solar irradiance (1000W/m2).

Now, by Ohm's law, the current through the shunt resistor is:

$$I_{SH} = \frac{V_D}{R_{SH}} \quad (6.5)$$

Where, R_{SH} = Shunt resistance (Ω).

I_{SH} = Shunt current (amp).

The diode current (I_D) can be written as

$$I_D = I_O \left\{exp\left(\frac{qV_D}{nKT}\right) - 1\right\} \quad (6.6)$$

Where, I_O= Reverse saturation current (A)

q= Elementary Charge, 1.6×10^{-23} C.
k= Boltzmann's constant, 1.38×10^{-19J}/K.
n = Diode ideality factor (practical value range 1 to 2).
T= Absolute Temperature (^{0}K).

Diode saturation current is expressed as

$$I_O = I_{OR}\left(\frac{T}{T_{REF}}\right)^3 exp\left\{\frac{qE_g}{k}\left(\frac{1}{T_{REF}}-\frac{1}{T}\right)\right\} \tag{6.7}$$

Where, T_{REF}= Reference temperature (^{0}K).
T = Cell temperature in Kelvin (^{0}K).
I_{OR} = Cell saturation current at T_{REF} (A).
Ego = Band gap energy for silicon (1.11 eV).

To calculate the generated output current, substituting the values of equations (2)-(6) in equation (1)

$$I_{OUT} = N_P.I_{PH} - N_P.I_O\left[exp\left\{q.\frac{V/_{N_S} - I.^{R_S}/_{N_P}}{a.k.t}\right\}\right] - \frac{V.^{N_P}/_{N_S} + I.R_S}{R_{SH}} \tag{6.8}$$

Where, I_{OUT} = Module output current (A)
N_P = Number of solar cells connected in parallel in the module
N_S = Number of solar cells connected in series in the module

It is seen from the characteristic equation that output current depends on the number of solar cells connected in parallel and number of solar cells connected in series position and the current variation is less dependent on the shunt resistance and is more dependent on the series resistance.

6.3.5. Characteristic equation curve

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The P vs V' and 'I vs V' curves for a solar cell are given in the following Figure 6.10. When the solar cell is short circuited, the short-circuit current *(I_{SC})* through the solar cell and voltage which is zero across the solar cell is shown on the IV curve below. The open-circuit voltage, (V_{OC}), is the maximum voltage available from a solar cell, and it occurs when the current is zero. This maximum open-circuit voltage is shown on the IV curve below. This characteristic curve is very much required for maximum power point tracking (MPPT) scheme to extract maximum power from solar PV cells. [96]

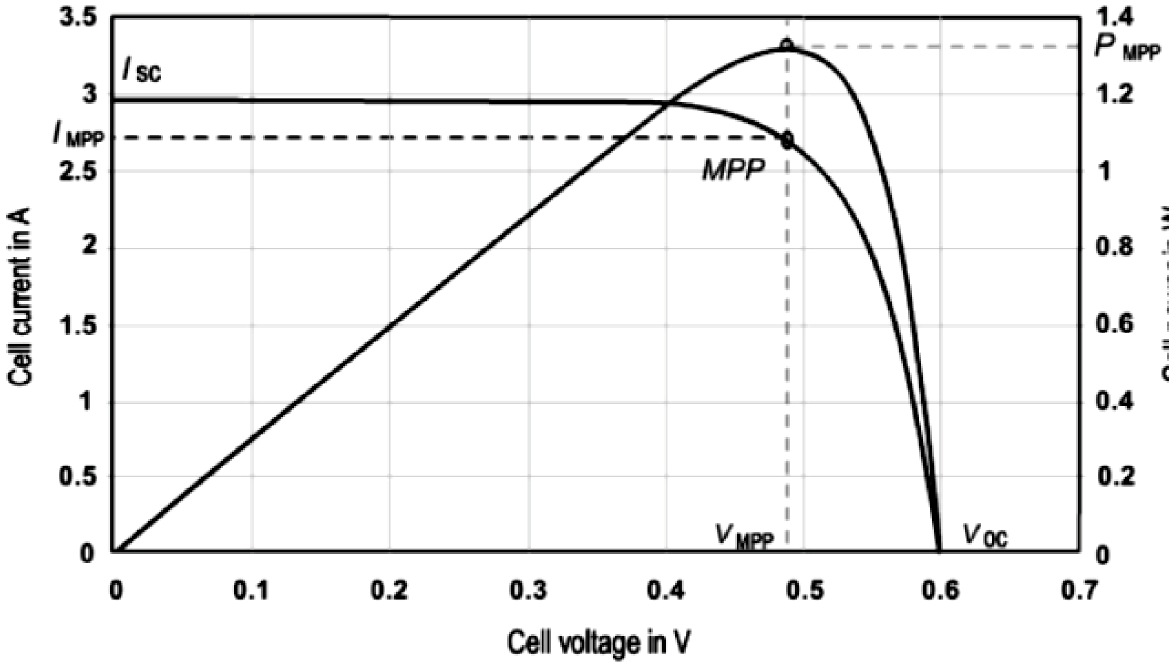

Figure 6.10: P-V, I-V curve of a solar cell at given temperature and solar irradiation [97]

Other than solar energy systems, wind energy is the other vital renewable energy source and hence the configuration of a wind energy system is described in the next subsection.

6.4. Wind Energy system

6.4.1. General configuration of Wind Energy System

Wind energy system converts wind power to electrical power from wind energy. It includes a wind turbine, a generator configuration to generate electrical energy, an inertial storage device configured to receive electrical energy from the generator and to store it as kinetic energy. Power electronic converters may be employed to regulate the real and reactive power output of the turbine. A model of wind turbine is considered here to know the Conversion from wind power to electrical power.

6.4.1.1 A Model Wind Turbine System

A wind-energy conversion system consists at least three primary subsystems, an aerodynamic system (includes rotor blades), the mechanical transmission system (includes gears, bearings) and the electrical generating system. The physical configuration of the wind-energy system produces an asymmetric force to control the air movement. The controlled air movements cause flow directing structures to rotate, oscillate. Thus providing a mechanical energy from which electrical power may be generated. Here, a typical wind turbine model is shown in Figure 6.11 which generally consists of the following subsystems.

- Rotor (consists of blades and hub)

- Drive-train (consists of shafts, gearbox, couplings, mechanical brake, and electrical generator)
- Nacelle and main-frame (consists of housing, bedplate, and yaw system)
- Tower and foundation
- Electrical system (consists of cables, switchgear, transformers, and power electronic converters)

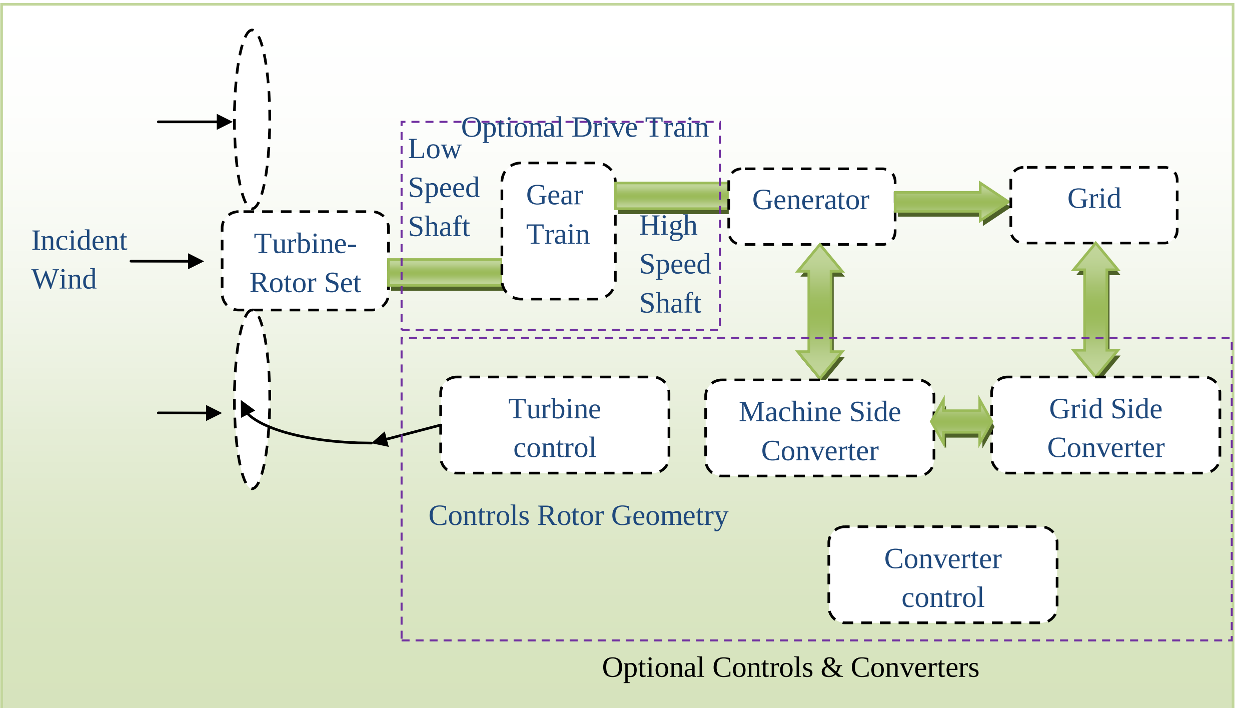

Figure 6.11: Model of wind energy system [100]

6.4.2. Mathematical expressions for Wind Turbine

The power output of wind turbine is depends on rotor speed as well as the wind speed and the equation is expressed as, [98]

$$P_m = \frac{1}{2}\rho A V^3 C_p(\lambda, uw) \qquad (6.9)$$

Where, ρ = Density of air (kg/m^3)

A = Area swept by the rotor (m^2)
v = Pitch angle
$C_p(\lambda, v)$ = Power coefficient
λ = Tip speed ratio
u_w= Wind speed (m/s)

The tip speed ratio which depends on the wind and rotor speed is expressed as

$$\lambda = \frac{\omega_r \eta R}{V} \qquad (6.10)$$

Where, η= Gear ratio
R= Turbine rotor radius (m)

Power output of wind turbine for a specified area depends on wind speed at hub height and speed characteristics of the turbine. At a specific hub height the speed of the turbine is given by using power-law equation [99]

$$\frac{V_{hub}}{V_{ref}} = \left(\frac{h_{hub}}{h_{ref}}\right)^n \qquad (6.11)$$

Where, V_{hub} and V_{ref} are the wind speed at hub and reference height respectively. h_{hub} and h_{ref}, and n is power law exponent.

Total available power from wind turbine is given as

$$P = P_W A_W \eta \qquad (6.12)$$

Where A_w is the total swept area, η is efficiency of wind turbine generator and corresponding converters.

Different wind turbines have different power output and performance curves. Therefore, the modelling equation of a wind turbine is strongly influenced by the power curve of the wind system that is used. A typical wind turbine power curve characteristics is shown below and using this curve electrical power output P_W (kW/m2) from wind generator can be calculated as follows

$$PW = \begin{cases} 0, & for\ V < V_{ci} \\ aV^3 - bP_r, & for\ V_{ci} < V < V_r \\ P_r, & for\ V_r < V < V_{co} \\ 0, & for\ V > V_{co} \end{cases} \tag{6.13}$$

Where, V_{ci},V_{co} and V_r are cut-in, cut-out and rated speed of turbine respectively and $a = \frac{P_r}{V_r^3 - V_{ci}^3}$ and $b = \frac{V_{ci}^3}{V_r^3 - V_{ci}^3}$.

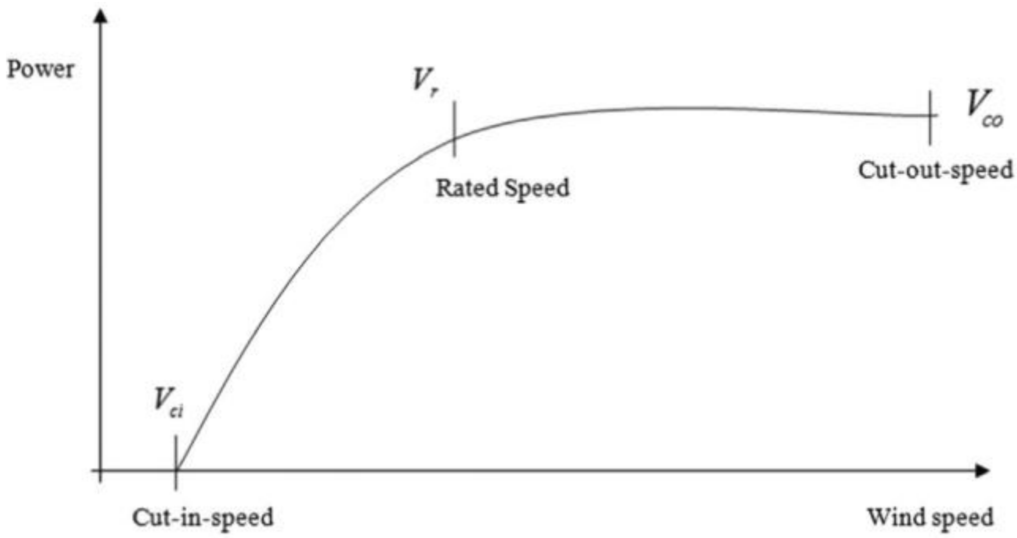

Figure 6.12: wind turbine power curve [100]

Though USA and China are the fastest growing countries in wind power generation in the world, European countries are the actual leaders. Spain and Germany have the highest installed wind generation capacity of the world. India has started developing wind power from 90s century and now it become fifth largest wind power installation in the world. In India, Tamil Nadu is generating more than 7000 MW and become the leading state contributing to about 40% of India's wind power [101]. If there is wind generation available and the maximum profit is done from that wind turbine, then the optimization purpose can be used. In the present of peak load, to meet the load requirements battery storage systems are used. So a battery configuration is needed to be analyzed in the following subsection.

6.5. Configuration of Battery System

Energy storage system has now become an integral part of an HRES system. For the storage purposes, no operation cost is associated with it. Battery storage is included in the hybrid energy system to meet the load demand in the absence of renewable energy sources, commonly known as days of autonomy. The selection of the energy system depends on some factors such as installation cost, energy price arbitrage, reducing transmission access cost, deferring facility investment, balance of plant cost, efficiency and life time, operation and maintenance expenses and revenues including energy cost. A survey has been done on various efforts to optimise energy storage system in microgrid. Thus optimization techniques have been widely applied for effective utilization of energy storage system, in the design process [102][103].

6.5.1. Different kinds of storage system and their applications

Different kinds of storage devices such as battery, compressed air, Flywheel, Hydrogen, pumped Hydro, SMES, and Super capacitor have widely used. BESS in hybrid and fuel cell powered electric vehicles [104]. BESS-applications in renewable autonomous energy supply systems mainly based on battery and hydrogen combination [105][106]. BESS applications for large scale PV- and wind power management [104]. Other BESS-configurations such as SMES/battery-BESS [107], Flywheel/battery-BESS [108] have large applications.

6.5.2. Basic structure of a Battery energy storage system (BESS)

Batteries have been most commonly used in hybrid system due to their low running cost and easy availability. Main advantages of a BESS are: 1) Increase of storage and system lifetime.2) Reduction of total investment costs compared to a single storage system. 3) Increase of total system efficiency. Battery sizing depends on several factors such as temperature correction, maximum depth of discharge, rated battery capacity and battery lifetime. Required battery capacity in ampere hour (Ah) is given by [104]:

A simple structure is shown that how the storage system is connected with hybrid energy system.

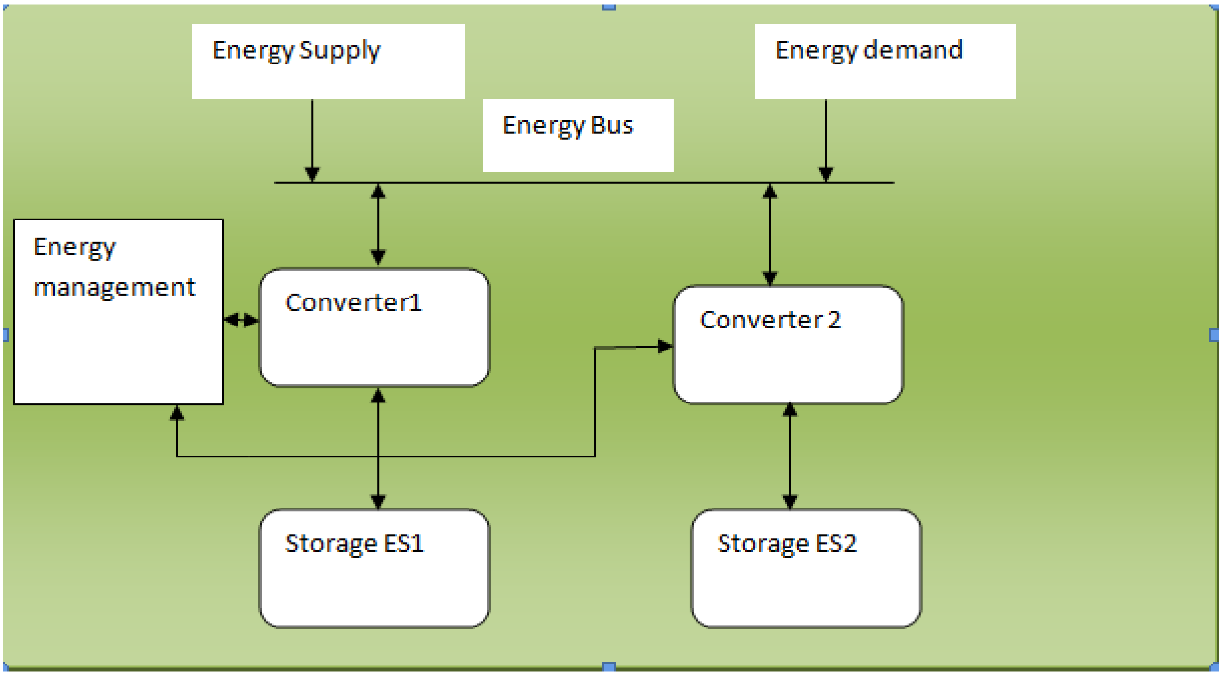

Fig6.13: structure of Battery Energy Storage System [104]

Here in this Fig 6.13 one storage device (ES1) is devoted to cover high demand, transients and rapid load fluctuations and therefore it is designed for high efficiency and high cycle lifetime. The other

Storage (ES2) has high energy storage with a low self-discharge rate. Using of dual storage system optimized the operation and reduction of dynamic stress of ES2 which increase storage and system lifetime. Optimization in operation of ES2 increases efficiency at operating points and reduction of dynamic losses of ES2. Thus total investment costs of the system are reduced compared to a single storage system.

6.5.3. Equations of battery configuration

Battery is designed as a nonlinear voltage source whose output voltage depends not only on the current but also on the battery state of charge (B_{rc}), which is a nonlinear function of the current and time. The battery state of charge is described by the follow equation

$$Brc = \frac{E_{c(Ah)}D_s}{(DOD)_{max}\eta_t} \tag{6.14}$$

Where, $E_{c(Ah)}$ is the battery capacity in Ah, D_s is the battery autonomy or storage days, $(DOD)_{max}$ is the maximum battery depth of discharge, η_t is the temperature correction factor.

Depending on the difference between generated power and load, it will be decided whether battery is in charging or discharging state. Whether the battery bank will charge or discharge can be calculated by the following equation [109]:

During charging process

$$SOC\ (t+1)\ = SOC\ (t)\ [(1-\sigma)(t)] + [(EGA(t) - EL(t)/\eta inv)]/\eta battery \qquad (6.15)$$

During discharging process

$$SOC\ (t+1)\ SOC\ (t)\ [(1-\sigma)(t)] - [(EGA(t) - EL(t)/\eta inv)]/\eta battery \qquad (6.16)$$

Where, *SOC (t)* = charge quantities of battery bank at the time *t*.

And *SOC (t+1)* = charge quantities of battery bank at the time *(t+1)*.

E_{GA} *(t)* = total energy generated by renewable energy source generator after energy loss in controller.

E_L *(t)*= is load demand at the time t.

ηinv = efficiency of inverter.

$\eta battery$ = charge efficiency of battery bank. Charge quantity of battery bank is subject to the following constraints [84]:

$$SOCmin \leq SOC\ (t) \leq SOCmax \qquad (6.17)$$

Where, SOC_{min} and SOC_{max} are the minimum and maximum charge quantity of battery bank.

To generate power from renewable energy sources it is required to know the system model and its operation. In this chapter biomass gasifier model, solar photovoltaic system, wind energy system and battery storage system with basic configuration and mathematical formulation are discussed well. A block diagram is presented here to understand the proposed system.

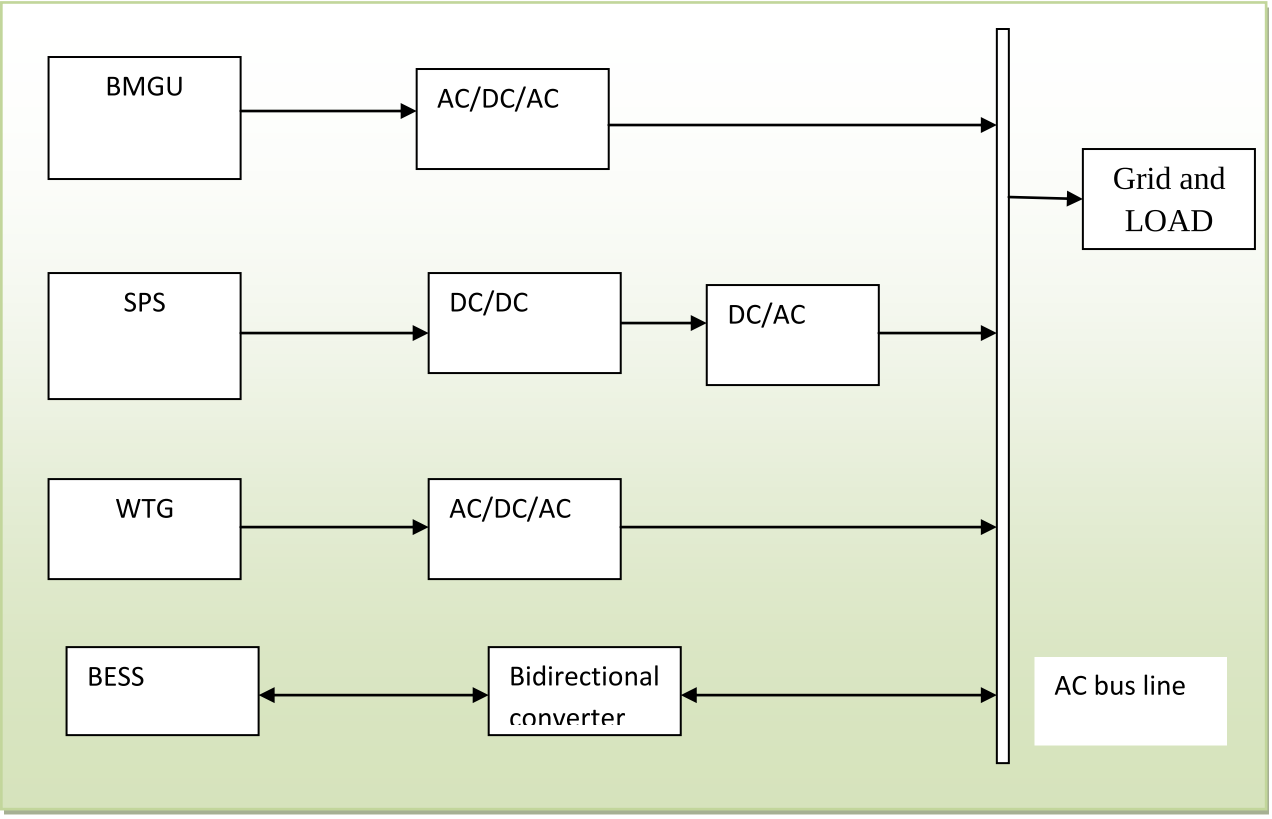

Fig 6.14: Block diagram of the proposed system model

In the next chapter all input parameters i.e. installation cost, running cost, microgrid forming equipment cost of these renewable systems are discussed. .The simulation results are presented for different cases to provide data for a comparative study.

CHAPTER 7
RESULTS AND DISCUSSIONS ON DATA GENERATED FROM DIFFERENT SYSTEM MODELS

7.1. Introduction

In this present work, a consumer based power delivery system has been developed consisting of four renewable energy sources, biomass gassifier unit, solar module, wind energy system in combination with battery storage system. Using this distribution energy resources (DERs) two cases are considered here, i.e. ***case 1*** (BMGU, SPS, BESS) and ***case 2*** (BMGU, SPS, WT, BESS) for the same input data. This work deals with power demand and supply demand in a small community. This small community comprises five types of consumers, namely, hostel, campus quarters, hospital, bank and post office, and market with two types of seasonal load variations (summer and winter). The load demand is set for 24 hrs. Load demand variation between the summer and winter seasons have considered to cover up the total power demand of every customer over a whole year. A comparative study has been conducted for these two cases through the application of cuckoo search algorithm (CS) in MATLAB environment. At first the results will be represented and comprehensive explanation will be given for each cases. The results for specific two cases will be compared using CS and again the obtained result will be compared with another well-known technique (GA) for the same input data. Finally, a discussion about the entire study will be provided.

7.2. Input parameters

7.2.1. Load demand variation

The input parameters are required for evaluating the optimum cost of a microgrid power-delivering system. Input parameters includes load demand data, installation cost, running cost of different types of DERs, cost of microgrid forming equipments and their lifetime periods and electricity rates from the conventional power grid.

From Fig 7.1 it is found that load demand is high between 12 P.M and 4 P.M and low at 3 A.M on a basis of a day in summer. In winter season load demand is high between 12 P.M and 1 P.M and low at 12 A.M for a day. For case 1 demand is supplied by biomass, solar cell and battery from 8 A.M to 4 p.m. whereas biomass and battery supplies power for the remaining hours. From 8 A.M to 4 P.M (for 8 hrs) intensity of solar energy is high so it can be utilised to generate electricity. For case 2, demand is supplied by biomass, solar cell, wind turbine and battery system from 8 A.M to 4 P.M where biomass, wind turbine and battery supplies power for the remaining hours [35].

Time(hr)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
sum	140	138	135	135	198	390	580	700	900	950	1100	1190	1100	1050	1000	1190	1100	1110	1000	850	810	650	380	160
win	120	115	110	112	195	380	500	690	810	890	960	1040	1090	920	798	890	910	930	920	830	700	510	350	100

Summer and winter Load demands in KW

Figure 7.1: Load demand variation in a microgrid system for a day during summer and winter season.

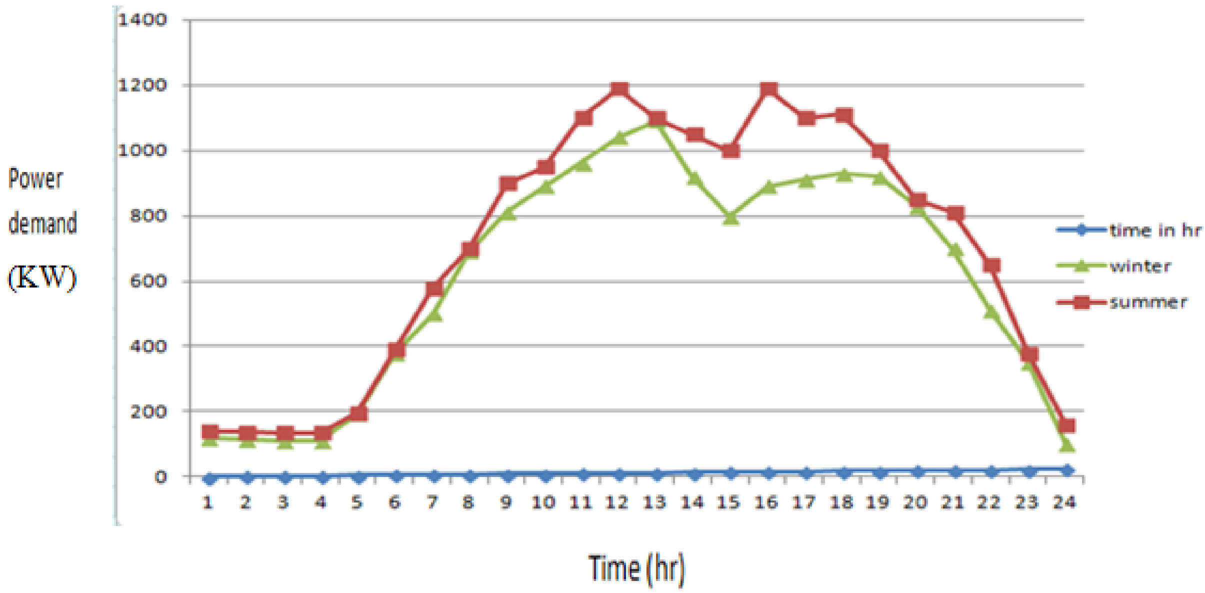

Figure 7.2: load demand variation curve in a microgrid system for a day during summer and winter season

The typical load variations in the microgrid system for 24 hrs in summer and winters are represented by the following curve in Fig 7.2. As seen in the figure for the time period 10A.M to 6 P.M the load demand is relatively high in summer months than in winter season.

7.2.2. Installation cost and running cost

Maximum installable capacity of BMGU, SPS, WT and BESS are set to consider load in each hour in such a way that they can supply the total load demand in every hour. Installation cost varies with maximum installable capacity. Though installation cost for husk biomass system is very high compared to other systems, except solar system, still the potential can be used to generate large amount of electricity. Biomass resources are abundantly available in nature and it does not depend on weather pattern where solar and wind energy depends on weather pattern. Thus a husk biomass system is considered here to provide reliable operation in each hour. Table 7.1 shows the total installation cost in (Rs./KW) and installed capacity for BMGU [112], SPS [35], WT [113], and BESS [111] in KW.

Table 7.1: Installation cost of the different renewable energy sources

Cost of DERs	**Installation cost (Rs/KW)**	**Maximum installed capacity (KW)**
BMGU	72,000	1000
SPS	1,39000	350
WT	40,000	170
BESS	725	100

Table 7.2 represents operating cost for two particular test cases 1 and 2. Solar panel system and wind turbine system does not include any running cost. The operating costs of BMGU [35] and BESS [111] have been mentioned in table 7.2.

Table 7.2: Running cost of the different renewable energy sources		
DERs	**(case 1)Operating cost (Rs/KWh)**	**(case 2)Operating cost (Rs/KWh)**
BMGU	2.5	2.5
SPS	nil	nil
BESS	5	5
WT	-	nil

7.2.3. Cost of Equipments of Microgrid

To deal with large load demand, an enormous amount of Joule heating may occur due to large current flow through the system. To avoid damage from Joule heating it is seen from that costs associated with the cables are much larger than the costs associated with setting up transformers. Hence, a step-up transformer is required to set up at the generation site and a step-down transformer at the consumers' end for reliable and safe power transmission. The other equipments such as circuit breakers, controller, change-over switches, are placed at a common point of the SPS, BMGU, WT and battery storage system. The equipment forming costs [35] of micro-grid system are tabulated in Table 7.3.

Table 7.3: Cost of equipments of Microgrid [35]				
Equipments forming microgrid	**Case 1**		**Case 2**	
	Cost (Rs.)	**Life time (years)**	**Cost (Rs.)**	**Life time (years)**
Switching equipments	437000	6	437000	6
Transformers (step up and step down)	3350000	15	3350000	15
Controller	20000	30	20000	30
Cables (underground and overhead)	10900000	20	50000000	20

7.2.4. Energy tariff

The microgrid model is grid connected and maximum purchased capacity from grid is 20 KW. To supply the load demand a minimum amount of power is to be extracted from the grid because non conventional sources are nature dependent and their generation vary time to time. Here 20 KW is assumed as a maximum purchased power. Higher amount of extracted power from conventional grid that means high utility cost will increase the total annual cost of the system which is not desirable. So there should be a limit to draw power from conventional grid. Costs of generated energy from DERs vary from time to time and place to place. It is assumed here that cost of generation from hybrid system and cost of purchase from conventional grid is same for different case studies. Assumed tariff to purchase and sell is shown in Table 7.4 [37] [111].

Table 7.4: Rate of energy tariff [37][111]

Maximum purchased capacity from grid (KW)	**Rate (Rs/KWH)**		
	Normal	**Peak**	**Off-peak**
20	6.12	8.10	4.04

7.3. Results and analysis

In this work, an economic analysis has been made to implement distributed generation using DERs through the application of cuckoo search algorithm. A comparison is carried out to evaluate total annual cost of these consumer-based power delivery systems for two different cases of DERs. In case 1 the DERs comprises of 2 systems i.e. BMGU, SPS and case 2 consists of 3 systems i.e. BMGU, SPS and WT. In both cases BESS is taken as backup system.

7.3.1. Study of case 1 during summer

Considering the 1st case of distributed generation, Cuckoo Search algorithm provides the best data in 24 hours basis for summer and winter as shown in Table 7.5A and Table 7.5B. It is observed from Table 7.5A during the off peak periods of summer days for case 1, from 12 A.M to 8 A.M, the power demand is low and can be supplied by the Biomass system alone with the Battery system being the standby. This incurs lower cost due to the implementation of these DERs. The entire running cost of operation is around Rs. 350 at an average as

BMGU is only the operational DER during this period. To supply the load demand during (8 A.M to 4P.M) solar cell is generating energy for 8 hours along with battery and biomass system. Again from 4 P.M to 12 A.M the power demand is supplied by the Biomass system alone with the Battery system. For peak load demand extra powers are purchased from a conventional power grid and extra generated powers are sold to the conventional power grid during light load period. In real application biomass does not generate power in fraction but using optimization techniques fractional power generation (i.e. 650.225 KW, 830.995 KW) has been obtained and it is used in this work for mathematical analysis purpose. From Table 7.5A, it is found that running cost of the system varies with load demand. The running cost for battery and biomass unit is high compared to another case when the system includes biomass, solar and battery system. For an example, running cost varies for the same load demand (1100 KW) with various combinations. It is Rs.3030 for the system consists of biomass and battery during 4 P.M to 5 P.M and Rs.1905 for the system consists of biomass, solar and battery during 12 P.M to1 P.M. Since solar does not include any running cost, the cost of energy is lower than solar is introduced.

Table 7.5A: Results analysis for case 1 (summer)

Input= Number of host nest=60, β=1.5, no of iteration=100, nest discard probability=0.25.

Time (hr)	Load demand (KW)	BMGU	SPS	BESS	Grid system	Running cost (Rs)
12:00-1:00	140	140	-	0	0	350
1:00-2:00	138	138	-	0	0	345
2:00-3:00	135	135	-	0	0	337.50
3:00-4:00	135	135	-	0	0	337.50
4:00-5:00	198	198	-	0	0	495
5:00-6:00	390	390	-	0	0	975
6:00-7:00	580	580	-	0	0	1450
7:00-8:00	700	330	350	20	0	905
8:00-9:00	900	530	350	20	0	1405
9:00-10:00	950	580	350	20	0	1530

10:00-11:00	1100	730	350	20	0	1905
11:00-12:00	1190	820	350	20	0	2150
12:00-13:00	1100	730	350	20	0	1905
13:00-14:00	1150	780	350	20	0	2030
14:00-15:00	1000	656.226	350	13.7738	-20	1620
15:00-16:00	1190	830.9925	350	9.0675	0	2150
16:00-17:00	1100	1000	-	80	20	3030
17:00-18:00	1110	1000	-	90	20	3430
18:00-19:00	1020	1000	-	20	0	2530
19:00-20:00	850	850	-	0	0	2199
20:00-21:00	810	810	-	0	0	2025
21:00-22:00	650	650	-	0	0	1625
22:00-23:00	380	380	-	0	0	950
23:00-24:00	160	160	-	0	0	400
Total running cost for 24 hrs is Rs.36079						

7.3.2. Study of case 1 during winter

Cuckoo Search algorithm provides the best data in 24 hours basis for winter load variations which is shown in Table 7.5B. It is observed that system running cost is Rs. 1725 for 690 KW during 7 A.M to 8 A.M when load demand is supplied by biomass only and Rs. 1180 for 810 KW during 8 A.M to 9 A.M which is comparatively low due to load demand is supplied by three sources. It is also analysed that the running cost for battery and biomass unit is high compared to another case when the system includes biomass, solar and battery system. Running cost varies for the same load demand (920 KW) with various combinations. It is Rs. 2310 during 6 P.M to 7 P.M for the system consists of biomass and battery and Rs. 1440 during 1 P.M to 2 P.M for the system consists of biomass, solar and battery because solar does not include any running cost. In real case biomass does not generate fractional power, but the fractional values are considered here for mathematical analysis purpose. For high load demand extra power is purchased from grid in the absence of solar cell. It is observed that for 930KW and 910KW load demand, extra 20 KW power is purchased from the grid.

Table 7.5B: Results analysis for case 1(winter)						
Input= Number of host nest=60, β=1.5, no of iteration=100, nest discard probability=0.25.						
Time (hr)	Load demand(KW)	BMGU	SPS	BESS	Grid system	Running cost (Rs)
12:00-1:00	120	120	-	0	0	300.00
1:00-2:00	115	115	-	0	0	287.50
2:00-3:00	110	110	-	0	0	275.00
3:00-4:00	112	112	-	0	0	280.00
4:00-5:00	195	195	-	0	0	487.50
5:00-6:00	380	380	-	0	0	950
6:00-7:00	500	500	-	0	0	1250
7:00-8:00	690	690	-	0	0	1725
8:00-9:00	810	440	350	20	0	1180
9:00-10:00	890	520	350	20	0	1380
10:00-11:00	960	590	350	20	0	1555
11:00-12:00	1040	670	350	20	0	1755
12:00-13:00	1090	720	350	20	0	1880
13:00-14:00	920	578.8454	341.1546	0	0	1440
14:00-15:00	798	443.1254	350	4.9	0	1130
15:00-16:00	890	520	350	20	0	1380
16:00-17:00	910	810	-	80	20	2275
17:00-18:00	930	820	-	90	20	2325
18:00-19:00	920	914.7631	-	5.2369	0	2310
19:00-20:00	830	829.40	-	0.5981	0	2075
20:00-21:00	700	700	-	0	0	1750
21:00-22:00	510	510	-	0	0	1275
22:00-23:00	350	350	-	0	0	875
23:00-24:00	100	100	-	0	0	250
Total running cost for 24 hrs is Rs.30390						

The convergence characteristics for case 1 are shown in Figure.7.3. Here cost is optimised with the number of iteration increasing. Value remains almost same from 1-5th iteration and minimum value of the fitness function is found to be Rs 2125 at 9th iteration.

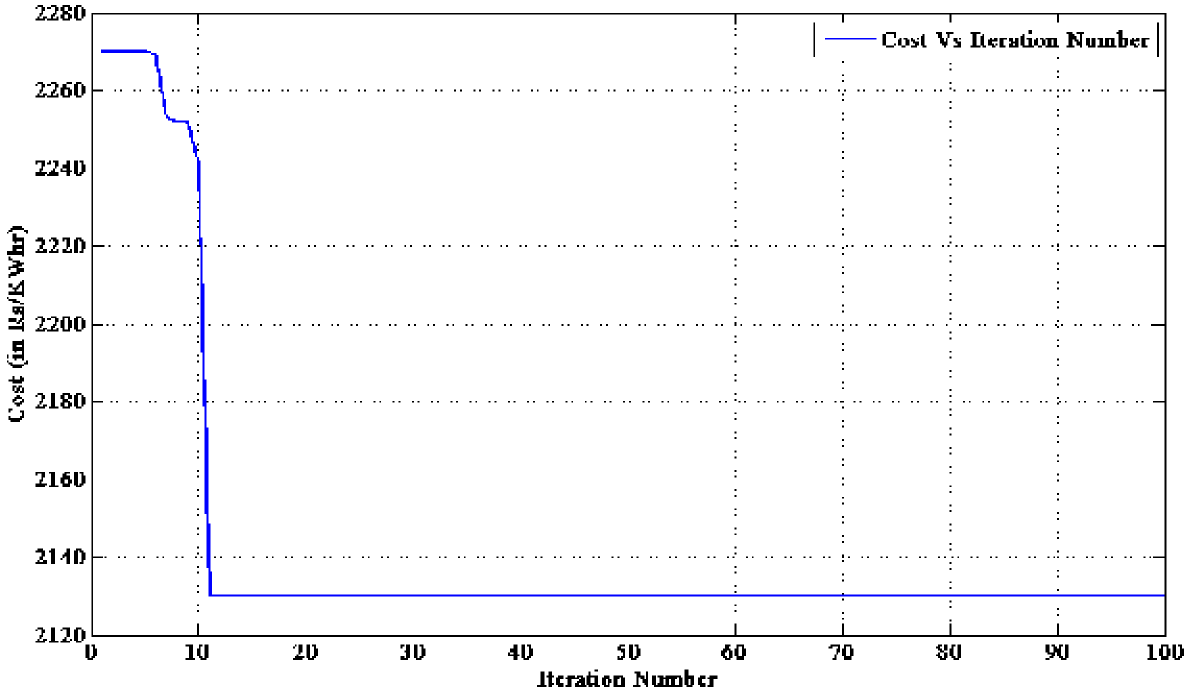

Figure 7.3: convergence characteristics for cost optimisation using cuckoo search algorithm

7.4.1. Study of case 2 during summer

After considering the 2nd case of DERs set, Cuckoo Search algorithm data is represented in Table 7.6A and Table 7.6B on 24 hours basis for summer and winter. During the off peak periods from 12 A.M to 6 A.M, the power demand is low and is supplied by the Biomass system and the wind energy system keeping the battery system as substitute. This incurs lower operating cost due to the implementation of these DERs. The entire cost of operation further lowers from Case 1 to around Rs. 175 at an average. To supply the load demand during (8 A.M to 4P.M) solar cell is generating energy for 8 hours along with battery, wind and biomass system whereas biomass unit is running for remaining hours along with battery and wind turbine generator system. For an example, running cost varies for the same load demand (1100 KW) with various combinations. It is Rs. 2355 during 4 P.M to 5 P.M for the system consists with biomass and battery and Rs. 1565 during 10 A.M to 11 A.M for the system consists with biomass, solar and battery because solar does not include any running cost.

Table 7.6A: Results analysis for case 2(summer)							
Input= Number of host nest=60, β=1.5, no of iteration=100, nest discard probability=0.25.							
Time (hr)	Load demand(KW)	BMGU	SPS	BESS	WTG	Grid system	Running cost (Rs)
12:00-1:00	140	70	-	0	70	0	175
1:00-2:00	138	70	-	0	68	0	175
2:00-3:00	135	70	-	0	65	0	175
3:00-4:00	135	70	-	0	65	0	175
4:00-5:00	198	70	-	0	128	0	175
5:00-6:00	390	200	-	20	170	0	175
6:00-7:00	580	390	-	20	170	0	580
7:00-8:00	700	525.24	-	4.75	170	0	1323
8:00-9:00	900	376.7741	350	3.2259	170	0	958.06
9:00-10:00	950	410	350	20	170	0	1190
10:00-11:00	1100	560	350	20	170	0	1565
11:00-12:00	1190	650	350	20	170	0	1790
12:00-13:00	1100	574.36	350	4.6312	170	0	1540
13:00-14:00	1050	510	350	20	170	0	1440
14:00-15:00	1000	498.92	350	1.0727	170	-20	1250
15:00-16:00	1190	650	350	20	170	0	1790
16:00-17:00	1100	910	-	20	170	0	2355
17:00-18:00	1110	920	-	20	170	0	2380
18:00-19:00	1000	853.50	-	1.8824	164.6624	-20	2060
19:00-20:00	850	660	-	20	170	0	1730
20:00-21:00	810	639.69	-	0.3090	170	0	1600
21:00-22:00	650	460	-	20	170	0	1230
22:00-23:00	380	239.55	-	0	160.4496	-20	518.876
23:00-24:00	160	110	-	0	50	0	275
Total running cost for 24 hrs is Rs.26624.936							

7.3.4. Study of case 2 during winter

It is observed from Table 7.6B that during the off peak periods of winter days for case 2, from 12 A.M to 8 A.M, the power demand is low and can be supplied by the Biomass system, wind turbine and battery system. This incurs lower cost due to the implementation of these DERs. The entire running cost of operation is around Rs. 175 at an average as BMGU is only the operational DER at this period. To supply the load demand during (8 A.M to 4P.M) solar cell is generating energy for 8 hours along with battery and biomass system. Again from 4 P.M to 12 A.M the power demand is supplied by the Biomass wind and battery system. For peak load demand extra powers are purchased from a conventional power grid and extra generated powers are sold to the conventional power grid during light load period. In real application biomass does not generate power in fractions but using optimization techniques fractional power generation has been obtained and it is used in this work for mathematical analysis purpose. The running cost for battery wind and biomass unit is high compared to another case when the system includes biomass, solar, wind and battery system because both solar and wind does not include any running cost.

Table 7.6B: Results analysis for case 2(winter)

Input= Number of host nest=60, β=1.5, no of iteration=100, nest discard probability=0.25.

Time (hr)	Load demand(KW)	BMGU	SPS	BESS	WTG	Grid system	Running cost (Rs)
12:00-1:00	120	70	-	0	50	0	175
1:00-2:00	115	70	-	0	45	0	175
2:00-3:00	110	70	-	0	40	0	175
3:00-4:00	112	70	-	0	42	0	175
4:00-5:00	195	70	-	0	125	0	175
5:00-6:00	380	190	-	20	170	0	555
6:00-7:00	500	310	-	20	170	0	855
7:00-8:00	690	519.2765	-	0.7235	170	0	1300
8:00-9:00	810	270	350	20	170	0	755
9:00-10:00	890	350	350	20	170	0	955

10:00-11:00	960	420	350	20	170	0	1130
11:00-12:00	1040	500	350	20	170	0	1330
12:00-13:00	1090	558.0542	350	11.945 8	170	0	1450
13:00-14:00	920	380	350	20	170	0	1030
14:00-15:00	798	258	350	20	170	0	725
15:00-16:00	890	350	350	20	170	0	955
16:00-17:00	910	700	-	20	170	0	1830
17:00-18:00	930	759.611	-	0.3811	170	0	1900
18:00-19:00	920	748	-	1.9610	170	0	1870
19:00-20:00	830	654	-	5.1907	170	0	1660
20:00-21:00	700	538.97	-	0.2660	160.7622	0	1340
21:00-22:00	510	320	-	20	170	0	880
22:00-23:00	350	160	-	20	170	0	480
23:00-24:00	100	70	-	0	30	0	175
Total running cost for 24 hrs is Rs. 22050							

It is recognized from the above data that summer season consumes more energy than winter season. The total running cost for case 2 is less than case1 because case 2 includes solar and wind energy system with least running cost along with biomass gasifier unit, where case 1 includes only solar system with biomass unit.

The convergence characteristics for case 2 are shown in fig 7.4 where minimum value of the fitness function is found at 4th iteration. To evaluate the total annual cost, running cost is added with installation cost and microgrid forming equipments cost.

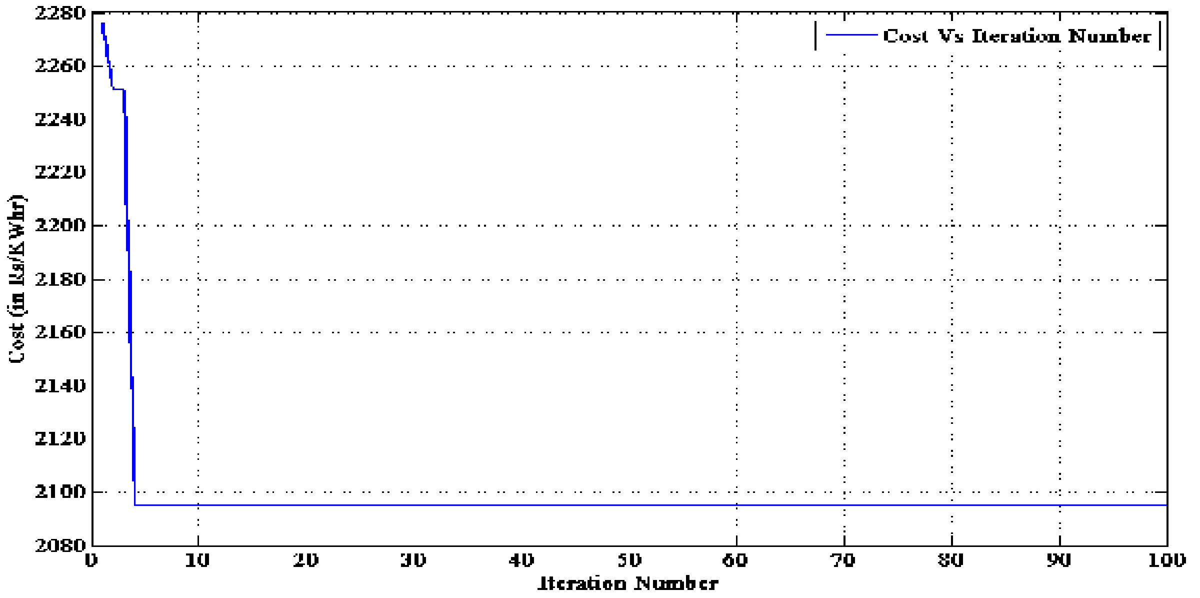

Fig 7.4: convergence characteristics for cost optimisation using cuckoo search algorithm.

The average capacity of the different renewable sources for the two systems has been calculated on per hour basis depending on the whole power demand of the society. The table reveals that the average capacity of biomass in both the cases is the highest while for the battery system it is quite low. To get the best value 5 consecutive results are taken by the MATLAB R2013a software. The results are tabulated in Table 7.7.

Table 7.7: Total annual cost (Rs.) for the microgrid system

			Total annual cost (Rs.)
Case 1	Average biomass generation (KW)	834	1.3200×10^{8}
	Average solar cell generation (KW)	350	1.3196×10^{8}
			1.3197×10^{8}
	Average BESS generation (KW)	78	1.3195×10^{8}
			1.3199×10^{8}

Case 2	Average biomass generation (KW)	559	1.3553×10^8
	Average solar cell generation (KW)	350	1.3555×10^8
	Average WT generation (KW)	170	1.3554×10^8
	Average BESS generation (KW)	53	1.3557×10^8
			1.3552×10^8

It is observed that the optimal power generations of BMGU are different for different consumers because BMGU generates power depending on different load demands. SPS mainly delivers the optimal power to every consumer during day time. As the operating cost of the SPS and WT is nil, the average capacity of SPS and WT have been optimally chosen to be more. The average capacity of BESS is low in case 2 from that of case 1 due to presence of wind turbine beside BESS. Presence of wind turbine beside BESS found to be cheaper than case 1.

7.3.5. Result analysis with parameter variation of CS

7.3.5.1. Study of case 1with new parameters (β=0.9) of CS during summer

It is also observed that all optimum values are better for case 1 than case 2. Among all the consecutive results Rs. 1.3195×10^8 is found as minimum annual cost by using CS for case 1. In cuckoo search algorithm the optimum values depends on cuckoo parameters. By changing the parameter values, again some results are analysed whether any minimum value is found or not for case 1. It is observed from the Table 7.8A that the optimum value depends on cuckoo search parameters. Running cost for each hour varies a very little from the values that obtained in Table 7.5A and total running cost obtained from Table 7.5A has been compared with Table 7.8A and the result shows that Table 7.5A (Rs. 36079) provides less running cost compared to 7.8 A (Rs. 36081.1).

Table 7.8A: Results analysis for case 1(summer)						
Input= Number of host nest=40, β=0.9, no of iteration=50, nest discard probability=0.25.						
Time (hr)	Load demand(KW)	BMGU	SPS	BESS	Grid system	Running cost (Rs)
12:00-1:00	140	140	-	0	0	350
1:00-2:00	138	138	-	0	0	345
2:00-3:00	135	135	-	0	0	337.50
3:00-4:00	135	135	-	0	0	337.50
4:00-5:00	198	198	-	0	0	495
5:00-6:00	390	390	-	0	0	975
6:00-7:00	580	580	-	0	0	1450
7:00-8:00	700	330	350	20	0	905
8:00-9:00	900	530	350	20	0	1405
9:00-10:00	950	580	350	20	0	1530
10:00-11:00	1100	730	350	20	0	1905
11:00-12:00	1190	820	350	20	0	2150
12:00-13:00	1100	730	350	20	0	1905
13:00-14:00	1150	780	350	20	0	2035
14:00-15:00	1000	658.226	350	11.7738	-20	1620
15:00-16:00	1190	830.9925	350	9.0675	0	2150
16:00-17:00	1100	1000	-	80	20	3030
17:00-18:00	1110	1000	-	90	20	3430.9
18:00-19:00	1020	1000	-	20	0	2530
19:00-20:00	850	850	-	0	0	2199
20:00-21:00	810	810	-	0	0	2025.2
21:00-22:00	650	650	-	0	0	1625
22:00-23:00	380	380	-	0	0	950
23:00-24:00	160	160	-	0	0	400
Total running cost for 24 hrs is Rs.36081.1						

7.3.5.2. Study of case 1with new parameters (β=1.2) of CS during summer

Table 7.8B: Results analysis for case 1(summer)

Input= Number of host nest=40, β=1.2, no of iteration=60, nest discard probability=0.25.

Time (hr)	Load demand(KW)	BMGU	SPS	BESS	Grid system	Running cost (Rs)
12:00-1:00	140	140	-	0	0	350
1:00-2:00	138	138	-	0	0	345
2:00-3:00	135	135	-	0	0	337.50
3:00-4:00	135	135	-	0	0	337.50
4:00-5:00	198	198	-	0	0	495
5:00-6:00	390	390	-	0	0	975
6:00-7:00	580	580	-	0	0	1450
7:00-8:00	700	340	350	10	0	905
8:00-9:00	900	540	350	10	0	1405
9:00-10:00	950	590	350	10	0	1530
10:00-11:00	1100	730	350	20	0	1904
11:00-12:00	1190	820	350	20	0	2150
12:00-13:00	1100	730	350	20	0	1905
13:00-14:00	1150	780	350	20	0	2032
14:00-15:00	1000	656.226	350	13.7738	-20	1628
15:00-16:00	1190	830.9925	350	9.0675	0	2150
16:00-17:00	1100	1000	-	80	20	3030
17:00-18:00	1110	1000	-	90	20	3430.3
18:00-19:00	1020	1000	-	20	0	2530
19:00-20:00	850	850	-	0	0	2194
20:00-21:00	810	810	-	0	0	2025
21:00-22:00	650	650	-	0	0	1625
22:00-23:00	380	380	-	0	0	950
23:00-24:00	160	160	-	0	0	400
Total running cost for 24 hrs is Rs.36080.4						

Similarly, the values of cost figure that obtained in Table 7.5A has been compared with Table7.8B and the result shows that Table 7.5A (Rs. 36079) provides less running cost compared to 7.8B (Rs. 36080.4) due to changes in cuckoo search parameters where number of host nest=40, β=1.2, no of iteration=60, nest discard probability=0.25. It is also noticed that the best result is found with the number of increasing host nest and β value for a certain iteration number and then convergence criteria is matched.

7.3.5.3. Study of case 1 with new parameters (*β=0.9*) of CS during winter

Table 7.9A: Results analysis for case 1(winter)

Input= Number of host nest=40, β=0.9, no of iteration=50, nest discard probability=0.25.

Time (hr)	Load demand(KW)	BMGU	SPS	BESS	Grid system	Running cost (Rs)
12:00-1:00	120	120	-	0	0	300.00
1:00-2:00	115	115	-	0	0	287.50
2:00-3:00	110	110	-	0	0	275.00
3:00-4:00	112	112	-	0	0	280.00
4:00-5:00	195	195	-	0	0	487.50
5:00-6:00	380	380	-	0	0	950
6:00-7:00	500	500	-	0	0	1250
7:00-8:00	690	690	-	0	0	1725
8:00-9:00	810	440	350	20	0	1180
9:00-10:00	890	520	350	20	0	1380
10:00-11:00	960	590	350	20	0	1555
11:00-12:00	1040	670	350	20	0	1755
12:00-13:00	1090	720	350	20	0	1880
13:00-14:00	920	578.8454	341.1546	0	0	1440
14:00-15:00	798	442.1254	350	5.87	0	1130
15:00-16:00	890	520	350	20	0	1380
16:00-17:00	910	810	-	80	20	2277
17:00-18:00	930	820	-	90	20	2325
18:00-19:00	920	914.7631	-	5.2369	0	2310

19:00-20:00	830	829.40	-	0.5981	0	2075
20:00-21:00	700	700	-	0	0	1750
21:00-22:00	510	510	-	0	0	1275
22:00-23:00	350	350	-	0	0	875
23:00-24:00	100	100	-	0	0	250
Total running cost for 24 hrs is Rs.30396.5						

It has been noticed from the previous Table 7.9A that the optimum value depends on cuckoo search parameters. Running cost for each hour varies a very little from the values that obtained in Table 7.5B and total running cost obtained from Table 7.5B has been compared with Table 7.9A and the result shows that Table 7.5B (Rs. 30390) provides less running cost compared to 7.9 A (Rs. 30396.5). By changing the value of β from 0.9 to 1.2, the possible outcomes are tabulated in the next table.

7.3.5.4. Study of case 1 with new parameters (*β=1.2*) of CS during winter

Table 7.9B: Results analysis for case 1(winter)

Input= Number of host nest=40, β=1.2, no of iteration=60, nest discard probability=0.25.

Time (hr)	Load demand(KW)	BMGU	SPS	BESS	Grid system	Running cost (Rs)
12:00-1:00	120	120	-	0	0	300.00
1:00-2:00	115	115	-	0	0	287.50
2:00-3:00	110	110	-	0	0	275.00
3:00-4:00	112	112	-	0	0	280.00
4:00-5:00	195	195	-	0	0	487.50
5:00-6:00	380	380	-	0	0	950
6:00-7:00	500	500	-	0	0	1250
7:00-8:00	690	690	-	0	0	1723
8:00-9:00	810	450	350	10	0	1180
9:00-10:00	890	520	350	20	0	1380
10:00-11:00	960	590	350	20	0	1555
11:00-12:00	1040	670	350	20	0	1755

12:00-13:00	1090	720	350	20	0	1880
13:00-14:00	920	578.8454	341.1546	0	0	1435
14:00-15:00	798	443.1254	350	4.9	0	1130
15:00-16:00	890	520	350	20	0	1386
16:00-17:00	910	810	-	80	20	2265
17:00-18:00	930	820	-	90	20	2325
18:00-19:00	920	914.7631	-	5.2369	0	2310
19:00-20:00	830	829.40	-	0.5981	0	2074
20:00-21:00	700	700	-	0	0	1750
21:00-22:00	510	510	-	0	0	1275
22:00-23:00	350	350	-	0	0	875
23:00-24:00	100	100	-	0	0	250
Total running cost for 24 hrs is 30392						

Total running cost obtained from Table 7.5B has been compared with Table 7.9B and the result shows that Table 7.5B (Rs. 30390) provides less running cost compared to 7.9B (Rs. 30392). Running cost figure obtained from Table 7.5A has been compared with Table7.8A and 7.8B and it is observed that Table 7.5A provides less running cost for summer season. Similarly 7.5B has compared with Table 7.9A and 7.9B and provides less running cost for winter season. Thus total annual cost is calculated in best cases. On the basis of generation power deviation is an important term in microgrid system. When load demand is greater than total power generation from all DERs then it is considered as positive power deviation, while negative power deviation implies that more power is generated with respect to the load demand. In both cases positive and negative power deviations arise. Extra powers are purchased from a conventional power grid during peak load period and extra generated powers are sold through contract with the conventional power grid during light load period. The computational value for case 1 (with BMGU and SPS as DERs) and case 2 (with BMGU, SPS and WT as DERs) are compared in Table 7.10. The result revels that the total annual cost relating to microgrid operation using BMGU and SPS is better than that using biomass, solar and wind turbine for the same load demand. Table 7.10 show that the total annual cost related with case 1 is 2.6% less than that obtained in case 2.

Table7.10: Comparison results of total annual cost between case 1 and 2	
Microgrid operation	**Total annual cost (Rs.)**
Case 1	1.3195×10^8
Case 2	1.3552×10^8

Per unit energy cost for each consumer based power delivery system is calculated by dividing the total annual cost with the total power consumption of the whole year. This comparison for the two cases has shown in Table 7.11.

Table7.11: Cost of electricity for consumers	
Microgrid operation	**Electricity price per unit [Rs./KWH]**
Case 1	19.44
Case 2	19.97

Table7.12: Compared result between cuckoo search algorithm and genetic algorithm		
Numerical methods	**CS**	**GA**
	Total annual cost (Rs)	**Total annual cost (Rs)**
Microgrid(case 1)	1.3195×10^8	1.3257×10^8

Different soft computing techniques can give marginally different optimal solutions. The obtained result using cuckoo search algorithm is compared with another well-established nature inspired algorithm using the same input data for case 1[35]. Here, the genetic algorithm (GA) has been applied to evaluate total annual cost for the same input parameters. The total annual cost presented in Table 7.12 reveals that cuckoo search algorithm gives better optimal solution than GA in this specific case. The result shows that GA data perform better than the CS by 0.47%.

An attempt has been made to apply a new meta-heuristic algorithm called as Cuckoo Search algorithm for solving cost optimization problem here. A theoretical analysis has been done to implement a microgrid system from the economic prospective. It is observed that total annual cost for case 2 is high from that of case 1 due to high installation cost of wind turbine generator though it does not include any running cost. Total cost of a microgrid system varies with system installation cost, running cost and microgrid forming equipment cost. So it is necessary to select a proper combination of renewable energy sources to get optimum energy cost. Here case 1 consisting of biomass, solar and battery system has proved as an efficient system. From the result of this whole work conclusions are drawn which is discussed in the next chapter.

CHAPTER 8
CONCLUION AND FUTURE SCOPE OF THIS WORK

8.1. Conclusion

A theoretical survey has been conducted from an economic perspective for different combination of DERs connected to microgrid Models by using cuckoo search algorithm. The CS method is a new nature inspired meta-heuristic algorithm where the obligate brood parasitism of some cuckoo species lay their eggs in the nests of another host birds of other species for better optimization based offspring survival. The proposed CS has been tested for two case studies for optimizing total annual cost of a consumer based power delivery system. MATLAB codes are developed to evaluate the fitness function of this problem. The comparison result indicated that the case 1(BMGU, SPS as DERs) is more cost effective than case 2 based solution sets (BMGU, SPS, WTG as DERs). It can be noted that different soft computing techniques can give various optimum solutions. In addition, here the obtained result is also compared with another technique caller genetic algorithm (GA) and CS is found as a better technique for this specific problem in terms of less computational time with faster convergence.

8.2. Future scopes of this work

Many researchers have been carried out on renewable sources based systems. There is chance that in future a huge number of conventional grids will be converted to hybrid by incorporating renewable resources. It can be assumed that the installation and running costs of different renewable consisting system will definitely be minimised in near future and they will come up with greater effectiveness. In present work the cost optimizing problem is solved with CS. In future other modern meta-heuristic techniques such as hybrid cuckoo search algorithm, gravitational search algorithm, bacteria foraging, can also be applied to examine whether these algorithms can provide better solution than the implemented ones.

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