Energy Management System Optimization for Grid-Connected Microgrids in Presence of Energy Storage

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ABSTRACT

The dramatic growth in energy consumption and the governments' concern about the increase in greenhouse harmful emissions caused by fossil fuel power plants which is the main reason for global warming in recent years leads to more investments in renewable energies. One of the best ways of controlling the renewable energy resources (RESs) in an economic and reliable approach is to manage them in microgrids (MGs). In this study particle swarm optimization (PSO) and genetic algorithm (GA) is used to obtain the optimal economic dispatch (ED) in a grid-connected MG in presence of photovoltaic (PV) solar energy, wind turbine (WT), microturbines (MTs), diesel generators, and energy storage system (ESS). The customers can play a major role in the energy management system by applying the demand response (DR) program which is considered in combination with other objectives in this research, power flow analysis is also investigated to check the resulted voltage level.

Keywords: Microgrid, Distributed Generation, Economic Dispatch, Power Flow, Photovoltaic, Wind Turbine, Energy Storage, Demand Response, Energy Management System.

ÖZ

Enerji tüketimindeki çarpıcı artış ve hükümetlerin son yıllarda küresel ısınmanın temel nedeni olan fosil yakıtlı santrallerin neden olduğu sera gazı emisyonlarındaki artıştan endişe duyması, yenilenebilir enerjilere daha fazla yatırım yapılmasına neden oluyor. Yenilenebilir enerji kaynaklarını (RES) ekonomik ve güvenilir bir yaklaşımla kontrol etmenin en iyi yollarından biri, onları mikro şebekelerde (MG'ler) yönetmektir. Bu çalışmada, fotovoltaik (PV) güneş enerjisi, rüzgar türbini (WT), mikro türbinler (MTs), dizel jeneratörler ve enerji depolama sistemi (ESS) varlığında şebekeye bağlı bir mikro şebekede (MG) optimal ekonomik dağıtımı (ED) elde etmek için parçacık sürü optimizasyonu (PSO) ve genetik algoritma (GA) kullanılmıştır. Müşteriler, bu araştırmada diğer amaçlarla birlikte ele alınan talep yanıt (DR) programını uygulayarak enerji yönetim sisteminde önemli bir rol oynayabilir, elde edilen voltaj seviyesini kontrol etmek için güç akışı analizi de araştırılır.

Anahtar Kelimeler: Mikro Şebeke, Dağıtılmış Üretim, Ekonomik Dağıtım, Güç Akışı, Fotovoltaik, Rüzgar Türbini, Enerji Depolama, Talep Yanıtı, Enerji Yönetim Sistemi.

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Chapter 1

INTRODUCTION

1.1 Background

Techno-economic issues in the new world lead to a change in the face of power production. Central power generations are transferring to distributed generations in order to enhance power production economically. Unplanned employment of distributed generators leads to several problems that may be solved using emerged distributed generation system which is a combination of generators and loads as a subsystem that is called a "Microgrid (MG)" [1].

A MG is described as a self-contained electrical system capable of operating without the need of a power grid (islanded mode). It includes both electrical energy suppliers and electrical power consumers. It's a small distributed system that may be connected to a power grid or an electrical utility. In both scenarios, energy is assumed to be mostly provided by locally distributed resources. Renewable energy, modest fossil-fuel-fired generators, and storage devices are all likely to form part of the system [2].

The process of establishing the quantity of power that each electrical source must provide in order to fulfill an energy demand restriction is known as ED. The relationship between the cost and the amount of power generated varies depending on the technology of the electrical power source [2]. In order to have reliable and economic power generation in a MG ED calculation should be applied.

1.2 Problem Statement

Aside from its numerous advantages, the MG structure has significant drawbacks, such as substantial resistance losses due to the low working voltage. Furthermore, because of the environmental concerns, it is commonly agreed that MGs currently rely on RESs for energy generation rather than carbon-intensive energy sources. The unpredictable character of RESs, on the other hand, poses substantial issues in MG operation. Furthermore, in addition to power supply fluctuations, energy costs, end-user demand, and the variety of electric loads have all contributed to demand-side uncertainty. Equality between generation and demanded load and stability of voltage and frequency in MGs are harmed as a result of these changes [3].

To improve the system's dependability and security, several solutions such as using ESSs, adding controlled producing units, and operational tools integration with DR programs can be used to address the aforementioned key challenges. One of the DR methods is Direct load control (DLC) which is employed for thermostatically controlled appliances (TCAs), such as ACs, refrigerators, and electric boilers, and are one of the most well-known kinds of DR. Due to their quick responsiveness and thermal inertia, for immediate changes in switching circumstances these kind of flexible loads are used as supplementary services [4]. Obviously using different programs and components in a MG needs proper managing algorithm in order to be steady with optimum cost. The problem statement is briefly described in points 1 to 3:

1. The unpredictable nature of RES that is mostly used in MGs threatens the balance between the power generation and the demanded load. ESS can play a major role in dealing with this problem.

2. Employing ESSs in MGs also has some challenges that must be taken into account, for instance, the ESS must behave as a load whenever there is excess energy in the system and behave as a generator when it is needed.
3. All of the components and programs of the MG’s energy management system must be as economic as possible, but only being economic is not sufficient to have a proper power system, the produced power must have an acceptable voltage range as well.

1.3 Objectives of Research

The following research objectives have been identified within the scope of this study:

• Research objective 1:

How ESS and DR program can affect the optimum power generation cost of the grid-connected MG which uses fossil fuel power production as well as solar and wind generation?

• Research objective 2:

After applying the ED how will be the voltage deviation results using power flow analysis?

• Research objective 3:

To investigate the difference between two selected optimization algorithms in the result of energy management system of the MG.

1.4 Thesis Organization

This thesis is divided into five sections and is ordered as follows:

- Chapter 1 presents the background and research topics, as well as the thesis's objectives and key contributions.

- Chapter 2 defines the energy management system's function and provides a review of MG energy management, as well as ESS scheduling. Grid-connected MGs' industrial perspectives are also considered.
- Chapter 3 explains the basic structure of the energy scheduling problem as well as the approach utilized to solve the MG energy scheduling problem in the thesis. And also, the optimization models designed to construct the optimal energy scheduling issue for grid-connected MGs are presented in this chapter.
- Chapter 4 describes the test case that has been investigated in simulations and the output results are presented in this chapter.
- Chapter 5 concludes the thesis and gives suggestions for further works.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Because of the present expanding need for electrical energy, small-scale RESs are increasingly being integrated into modern electric systems. Renewable energy has seen significant technical development, allowing it to be produced at low costs. This advantage helps nations to increase their energy security by reducing fossil fuel imports, which allows them to keep their costs lower than normal and raise their standard of life without affecting the environment, which is especially important given the current economic crisis. They also have the benefit of being able to readily sustain the electrical network in isolated locations and rural areas [5]. The MG provides an effective approach for the complete utilization of renewable energy, thanks to advancements in distribution technology [6]. A MG is a combination of Distributed Energy Resources (DER) such as RES and ESS, as well as loads, and other components that can be controlled locally and operates in grid-connected or islanded modes [7],[8].

CERTS [9] (Consortium for Electric Reliability Technology Solutions of the United States) defines a MG as a micro power system with a cluster of loads, storage, and numerous DGs. It is capable of meeting the load's power quality and reliability needs, as well as providing both power and heat to the surrounding region. A rapid semiconductor switch dubbed the static switch allows a MG to function in both grid-connected and islanded mode in general (SS) [10].

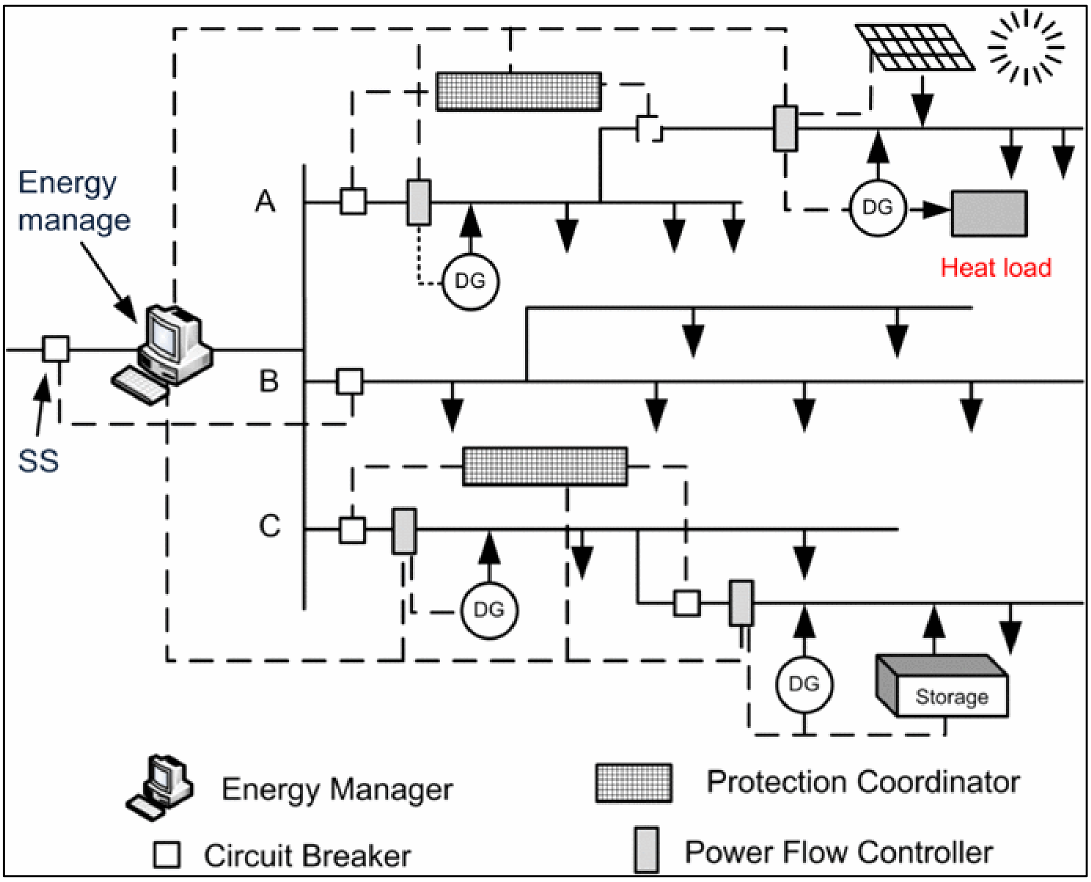

Figure 2.1: The basic MG architecture [10]

The basic MG architecture is depicted on Figure 2.1. The MG is supposed to be radial in this case, with three feeds and a collection of loads. The DGs are controlled by power electronics such as inverters, which provide power flexibility. The relay protection, flow manager, and energy optimizer are all managed by a dedicated controller. It guarantees that the MG is connected as a stable and controllable element [10].

2.2 MG Classification

Based on the system design and voltage characteristics, MGs may be divided into three categories: 1) AC MG, 2) DC MG, and 3) Hybrid AC/DC MG. MGs can also be categorized according to their intended use, such as 1) utility MGs, 2) institutional MGs, 3) commercial and industrial MGs, 4) transportation MGs, and 5) remote-area MGs (e.g., King Island MG). Figure 2.2 depicts the MG categorization [11],[12],[13],[14].

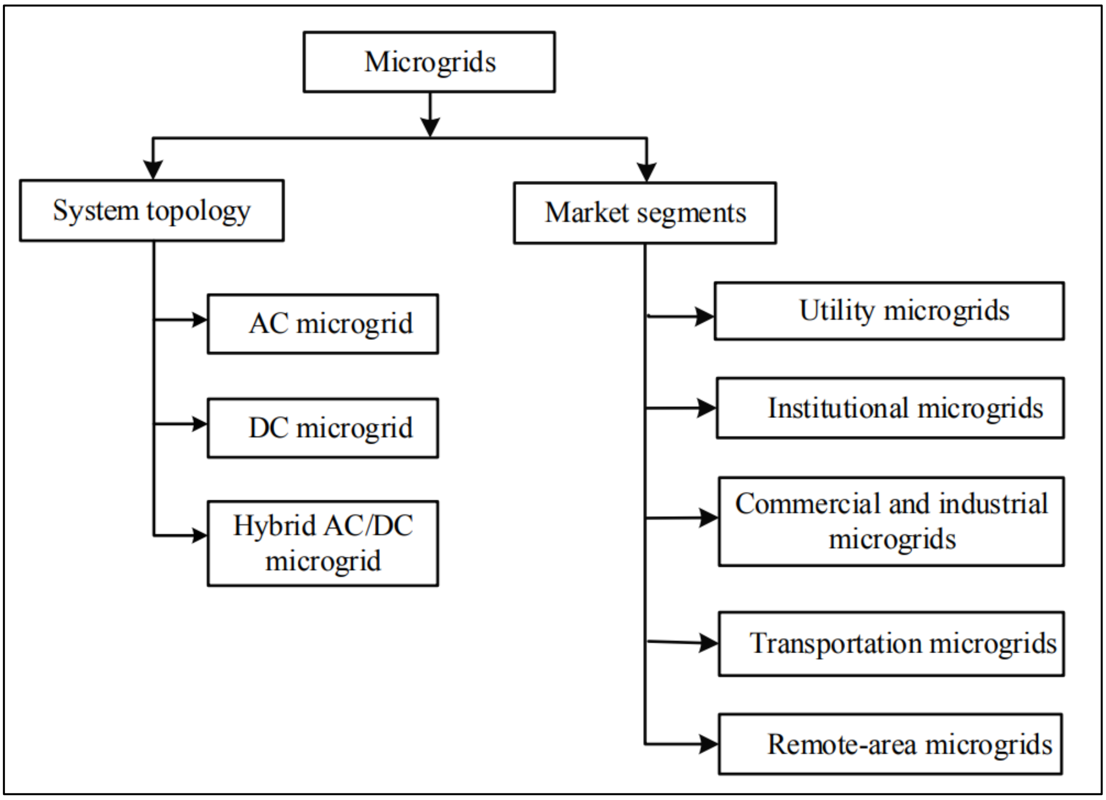

Figure 2.2: MGs classification [15]

2.2.1 AC MGs

The most popular type of MG is the AC MG. PECs are used to integrate several types of DERs into power networks, such as WT generators, MTs, solar PV, and fuel cells [16]. Because typical power networks use AC, AC MGs require little changes to interface with the current main grid. AC MGs are connected to MV and LV distribution networks, with the potential to improve the distribution networks voltage stability while lowering the losses of connecting conductors. They do, however, create additional difficulties, such as unstable power system, low power quality, synchronization of DER, and lack of reactive power, which may be addressed by using sophisticated control approaches [17].

2.2.2 DC MGs

A vast variety of converters and DC loads have been employed for many sorts of applications as a result of technical advancements in Power Electronic Converters (PECs). Furthermore, DERs which generate DC as initial output, and other types of energy storage systems provide up new possibilities for DC MGs. Before being used, around thirty percent of the produced AC power flows through a PEC [18]. The key benefits of DC MGs are the reduction of the amount of power conversion steps and the lack of circulation of reactive current [19], [20].

2.2.3 Hybrid AC/DC MGs

DC and AC MGs are combined to produce AC/DC hybrid MGs, that has the advantages of both MGs in terms of greater reliability, efficiency, and generation cost. The combined AC/DC MG allows the whole system to be directly coordinated with the current distribution system. DC loads can be residential and commercial consumers and needs AC to DC transformation. Hybrid AC/DC MGs cut down on the number of power converters needed, lowering power losses. Furthermore, as compared to the rectifier, the inverter's power losses are minimal [15].

2.3 MG Energy Management

The diverse DER resources inside the MG must be operated in a coordinated and coherent manner in order to produce electricity of the needed quality in a secure, cheap, and clean manner. To that purpose, a MG control system is required. To plan and schedule operational set points and linkages with the main grid in terms of both market participation and ancillary service supply, the control system must take into account expected demand, power and fuel costs, and technical limits on devices [21].

2.4 MG Components

A MG can be consisting of RESs such as PV panels, WTs, biomass power generators as well as fossil fuel generation like diesel generators and MTs which operate as a backup for the system. ESSs can be genuinely functional in combination with RESs because of their unforeseeable nature to act as a load or a generator depending on the decision which is made by the energy management system, and all mentioned generators and storage systems must operate in an approach to deliver reliable and inexpensive electrical power to domestic, commercial and industrial loads in the MG. Figure 2.3 shows a sample grid connected MG structure.

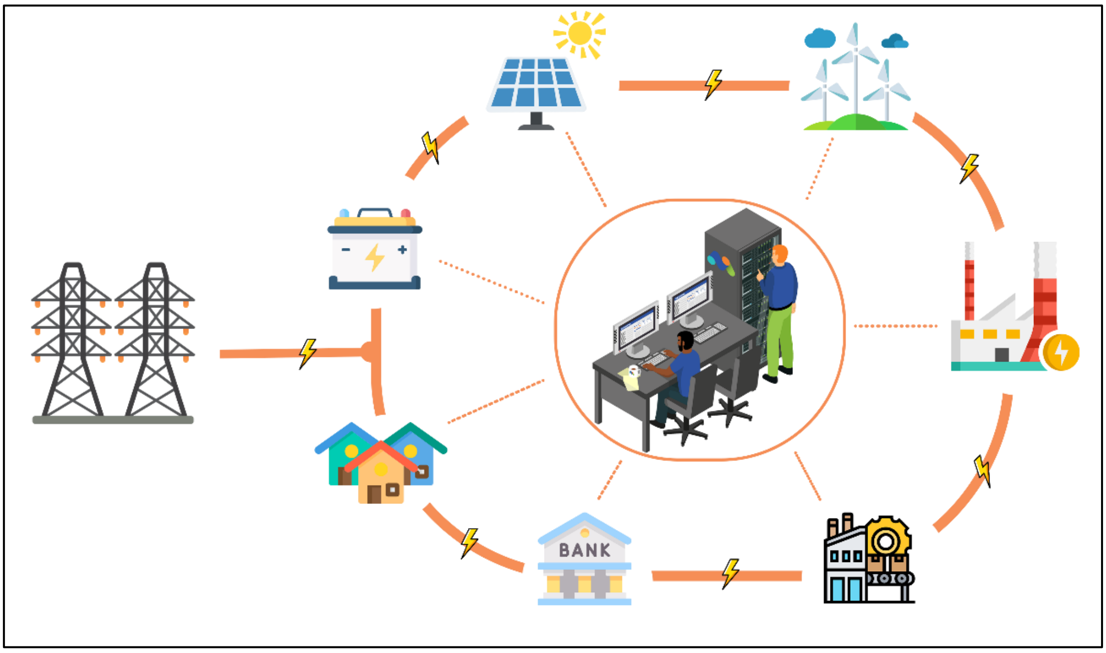

Figure 2.3: Sample grid-connected MG structure

2.4.1 Solar Energy Generation

For the following reasons, solar energy may be the greatest choice for the future: First, solar energy is the most plentiful form of RESs. The sun generates it at a rate of 3.8×10^{23} kW, of which the earth absorbs 1.8×10^{14} kW. The planet receives solar energy in a variety of ways, including heat and light. The majority of this energy's part is lost during transit due to cloud absorption, reflection, and dispersion. Studies have shown that solar energy, which is abundant in nature and a cost-free source of energy, may properly meet the world's energy needs. The fact that it is non exhaustible and provides stable and rising production efficiency compared to other sources of energy makes it a potential source of energy in the globe. Two important aspects that affect the solar PV industry's efficiency are the dispersion and intensity of solar radiation. These two variables vary greatly between nations. Figure 2.4 makes a clear mention of it. As a result of their high annual sunlight duration, Asian nations have the best capacity to receive solar radiation compared to other temperate nations. It is significant to highlight that a large portion of solar energy is essentially wasted. Solar radiation is a natural resource that is abundant in many nations, especially developing nations [22].

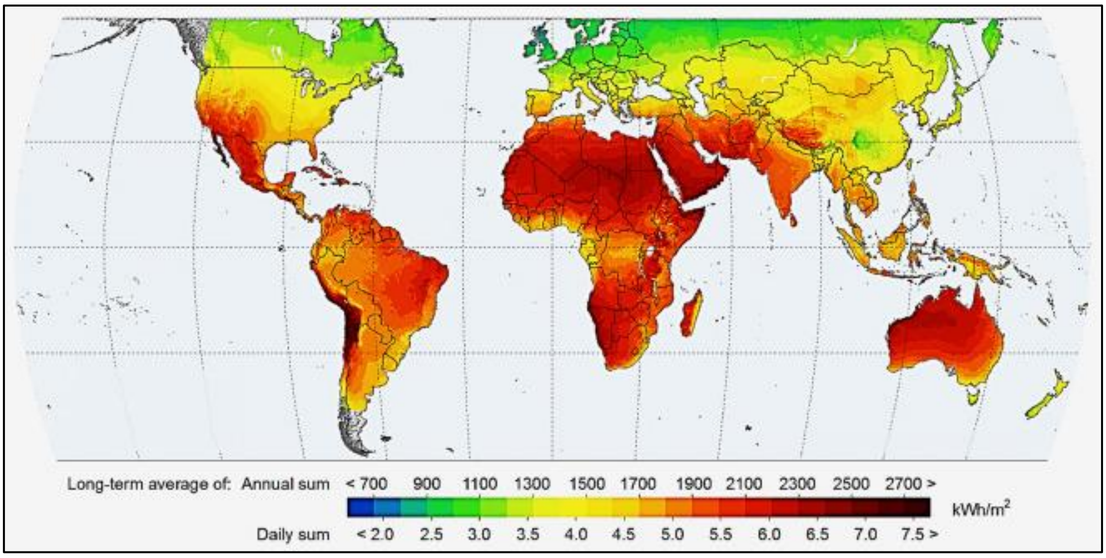

Figure 2.4: Global horizontal irradiation (GHI) map [22]

A photovoltaic cell is an instrument which employs the PV impact to produce electric current. Electric voltage is created between two electrodes that are coupled to a solid or liquid system in the PV effect. As a result of illuminating it. A PV cell usually contains PN junction across therefore voltage on PV will be applied [23].

2.4.2 Wind Energy Generation

Since at least three thousand years ago, people have used the power of the wind. Wind energy was employed to generate mechanical power up to the early 20th century to pump water or grind grain. When modern industrialization first began, fossil fuel-fired engines or the electrical grid, which offered a more reliable power source, replaced the usage of the variable wind energy supply [24].

The first oil price shock at the beginning of the 1970s rekindled interest in wind power. However, this time, electrical energy rather than mechanical energy was the major focus of attention. By employing the electrical grid as a backup for alternative energy sources, it became feasible to offer a regular and dependable source of electricity [24].

At the start of the 20th century, the first WTs for the production of energy had already been created. Since the early 1970s, technology has gradually advanced. Wind power has returned by the 1990s' end as one of the most significant sources of renewable energy. The capacity of wind energy has doubled on average every three years during the final ten years of the 20th century. Since the beginning of the 1980s, the cost of electricity produced by wind energy has decreased to around one-sixth, and the trend appears to be continuing [24].

The technological potential of onshore wind energy is significantly high- $20{,}000 \times 10^9$–$50{,}000 \times 10^9$ kWh yearly- in comparison to the current global yearly power consumption. Average wind speed, statistical wind speed distribution, turbulence intensities, and the cost of WT systems all influence the economic potential of wind generation [25].

The lack of toxic pollutants and the economic efficiency of this energy source are its key advantages. The kinetic energy of the wind is captured in a rotor with two or more blades that are mechanically connected to an electrical generator. To improve energy capture, the turbine is installed on a tall tower [26].

2.4.3 Fossil Fuel Generation

Peaks, falls, and depletions in fossil fuel output are influenced by their proven reserves, exploration, and consumption rates. There are 1688 billion barrels (Bb), 6558 trillion cubic feet (TCF), and 891 billion tons (Bt) of recognized oil, gas, and coal reserves in the world. These resources are utilized at rates of 0.092 Bb, 0.329 TCF, and 7.89 BT each day, respectively. The reserves of oil, gas, and coal are growing by 600 million barrels (Mb), 400 billion cubic feet (BCF), and 19.2 giga tons of oil equivalent (GTOE) each year, respectively. 1.4 Mb, 4.5 BCF, and 3.1 million tons respectively, are the rates of yearly consumption growth for oil, gas, and coal (Mt). When the world's annual energy consumption exceeds 12 billion tons of oil equivalent (BTOE), 39.5 giga tons (Gt) of carbon dioxide are released into the atmosphere, and when future energy demand rises to 24–25 BTOE, the yearly CO_2 emission might reach 75 Gt. Even though oil, gas, and coal may still exist for the foreseeable future, the energy transition to low carbon intensity fuels is necessary to combat the escalating effects of climate change [27].

Although fossil fuel generation can harm the environment by releasing greenhouse emissions into the atmosphere Diesel generators and MTs can be employed as a backup system for the MG.

2.4.4 ESS

Energy storage technologies have been in use for many years and have undergone constant development to achieve their current levels of maturity, which are for numerous storage kinds. There are several types of ESSs, and they may be divided into numerous categories. For applications needing various energy storage capabilities and variable power production rates, A "Ragone plot," which aids in identifying the potentials of each storage type and contrasting them, is widely used to display the storage properties of electrochemical energy storage types in terms of specific energy and specific power. The plot also assists in determining which energy storage option is the best for a given application or necessity which can be seen in Figure 2.5. The Storage Power density is the rate at which energy is transferred per unit volume or mass, whereas energy density is the amount of energy collected per unit volume or mass. A high energy density device with a big energy storage capacity is needed when generated energy is not immediately accessible. A high-power density device is needed when the discharge duration is brief, such as for instruments having discharge/charge swings over brief intervals. Systems for storing energy can also be categorized according to how long they are kept. Short-term energy storage, usually from a few hours to a few days. Long-term storage, on the other hand, refers to the retention of energy for a season (between three and six months). A long-term thermal ESS, for instance, stores thermal energy underground during the summer for use in the winter. The Ragone plot is often primarily used for batteries, fuel cells, and capacitors, therefore only a few different forms of energy storage are included in Figure 2.5. For better comparison, a more thorough comparison of the particular power and energy in addition to other technical information of various ESSs is provided in the Figure 2.6 [28].

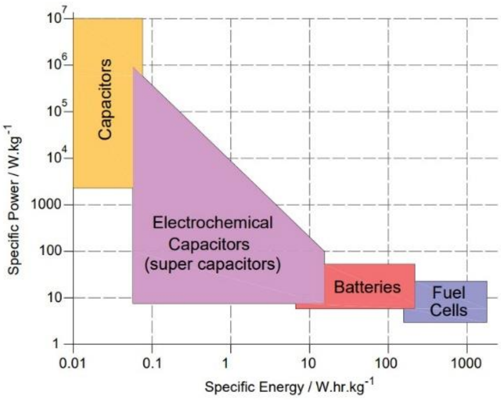

Figure 2.5: The Ragone plot of different types of energy storages [28]

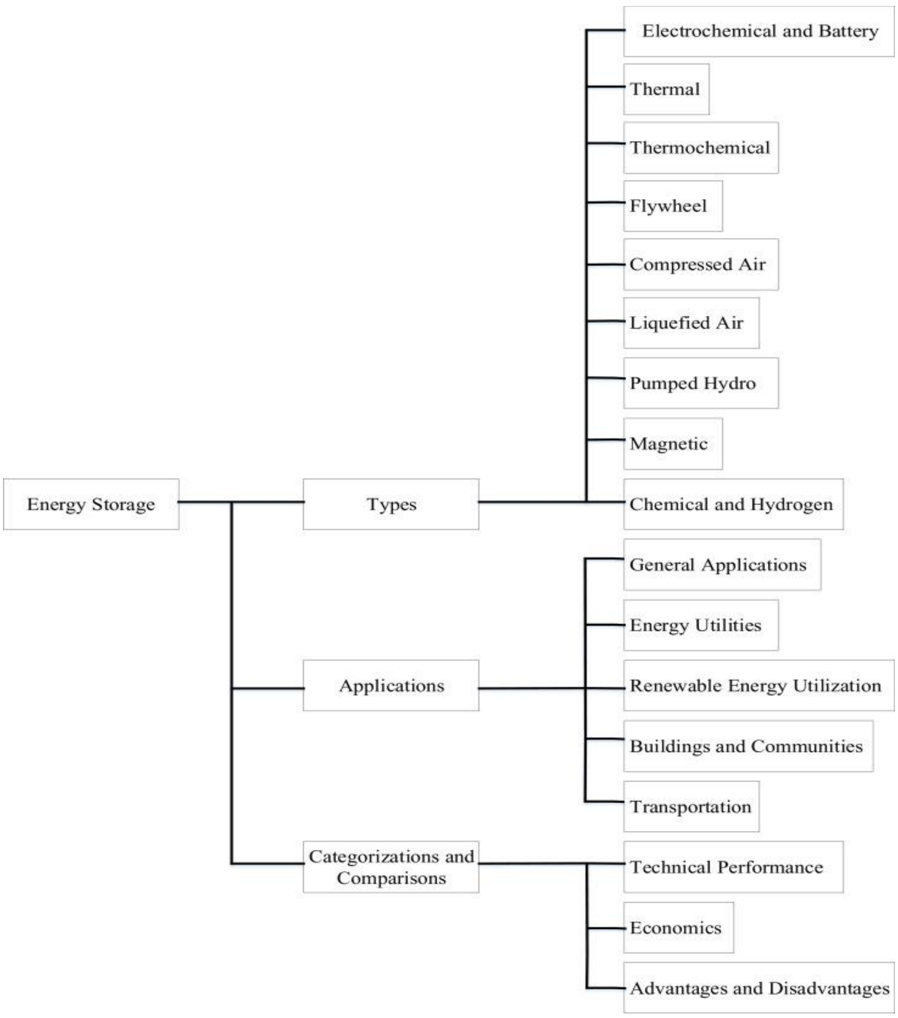

Figure 2.6: Energy storage types classifications [28]

Electrical energy can be stored by converting it to another form, such as mechanical or thermal energy. Moreover, ESSs are classified into three parts: central storage, control, and power transformation. After conversion, energy is reserved in the central storage, and the power transformation behaves as a two-way bridge between the central storage and the power system. Sensors and additional measurement apparatus are employed in the control stage to identify the level of discharge or charge of the stored energy. ESSs are not the most efficient way to store energy. Therefore, at every stage of the storage process they experience losses [29]. The devices' energy production and loss may be expressed as follows:

$$E_{generate} - \Delta E_{loss} = E_{out} \tag{2.8}$$

$$\Delta E_{loss} = \Delta E_{ch} + \Delta E_{st} + \Delta E_{dch} \tag{2.9}$$

The total efficiency of ESS is:

$$\eta_{st}^{total} = \frac{E_{out}}{E_{generate}} = \eta_{ch} \times \eta_{st} \times \eta_{dch} \tag{2.10}$$

In which $E_{generate}$, E_{out}, E_{st}, E_{ch}, E_{dch} are generated, output, stored, charge, and discharge energy respectively. η_{st}^{total} is the total efficiency of storing energy and η_{ch} , η_{st}, η_{dch} are the efficiencies of charging, storing, and discharging energy respectively [30].

2.4.5 Load

The basic goal of utilizing grids, MGs, storing energy, using DERs, employing energy management methods, and so on is to offer reliable and cost-effective power to the customers known as electrical load. There are three different types of electrical loads, as listed below:

2.4.5.1 Interruptible Load

The interruptible load can be off-loaded at any moment, according to the DR strategy, and the interruptible load has no precise constraints on overall power consumption [31].

2.4.5.2 Adjustable Load

In the DR execution phase, the adjustable load can be reduced regarding to the energy management system, but the load reduction cannot exceed the allowed reduction load [31].

2.4.5.3 Transferable Load

A transferable load is one that has no preset power consumption limits and may be transferred regarding to a energy management system over a certain time interval. The transferable load can be moved at a reasonably relaxed time throughout the scheduling procedure. And the transferrable weight has to be transported in a short amount of time [31].

2.4.5.4 Point of Common Coupling

The “point of common coupling” (PCC) is the site of the equipment authorized to interrupt, separate, or sever the connection between the producing facility and the utility at which the MG links to that system’s electrical infrastructure.

2.5 Problem Objectives

In order to obtain the optimum generation cost which is satisfying the demanded load in the MG for all-time series, the ED calculations must be applied to manage the production share of each component and also DR program must be taken into account. The other issue that should be considered is to have standard voltage level of the MG which can be calculated using power flow analysis.

2.5.1 ED

The solution to the ED issue is now essential to the management and planning of the power system. The main goal of ED is to plan the output of the committed generating units in order to fulfill all unit and system operating restrictions while meeting the needed load demand at the lowest possible cost. Significant cost savings may result from better unit production scheduling. The initial formulation of the ED problem was as an economic cost dispatch problem, but subsequent amendments to the Clean Air Act in the 1990s resulted in the existence of emission dispatch, which led to the formulation of combined emission ED and emission controlled ED problems. Individual optimization of these two conflicting objectives would not be helpful in solving the problem, so these problems were combined. To tackle these issues, a variety of traditional techniques are utilized, including the Bundle approach, nonlinear programming, mixed integer linear programming, dynamic programming, quadratic programming, Lagrange relaxation method, network flow method, and direct search method. Due to the presence of the valve point loading effect, various fuel alternatives, and a variety of equality and inequality restrictions, the ED problem is practically nonlinear, non-convex, and has several local optimum points. Due to their sensitivity to starting assumptions, convergence to local optimum solutions, and computing complexity, traditional approaches have not been able to handle these challenges. Modern heuristic optimization techniques, such as evolutionary programming, GA, simulated annealing, ant colony optimization, Tabu search, neural networks, and PSO, proposed by researchers based on operational research and artificial intelligence concepts, offer a better solution. Each approach has benefits and drawbacks of its own [32]. In this research GA an PSO methods are employed to obtain the optimal ED and the results of these methods are compared together.

2.5.1.1 GA Optimization

When a predetermined formula is unknown, genetic programming is a method of developing algorithms that will map input to a certain outcome. Mathematicians and computer programmers may readily come up with techniques to solve issues involving five or less variables, but when there are ten, twenty, fifty, or more variables unknown, the problem becomes nearly insoluble. A GA may be used to 'evolve' an expression tree to provide a very tight match to the data in situations where the mathematical data is there, the solutions are present, but the expression that connects the data to the answers is absent. The 'highest-fitness' tree for the given issue is bred using mutation, crossover, and the other GA components. At its best, this will precisely match the input variables to the output, but it can also provide output that is extremely near to the target output [33].

2.5.1.2 PSO

The PSO method finds several solutions in parallel, much like GA method. Contrary to GA, who uses a "competition" strategy, PSO, on the other hand, uses a "cooperative" technique. Suboptimal solutions might therefore persist in the PSO algorithm and aid in the search at a later stage of the iteration. It has been demonstrated that the PSO method outperforms the GA algorithm in several situations, such as developing the weights for a neural network [34].

The PSO does not explicitly employ knowledge about the derivative, in contrast to many other optimization procedures. However, it will be demonstrated that if traps caused by local minima can be avoided, derivative information may be employed to quicken convergence. In other words, the algorithm must be able to search various parts of the solution space in addition to exploring local minima [34].

Traveling in the direction of the gradient's inverse always results in the global minimum in the case of a unimodal function (which lacks local minima). Moving in any other way will not result in a larger decline since the cost function decreases as much as it can in the direction that is opposite to the gradient. As a result, the gradient descent approach is the preferred algorithm for smooth unimodal functions. The gradient may result in a shallow local minimum in the case of multimodal functions, which contain several local minima. As a result, a method that makes advantage of gradient information while avoiding local minima is desirable [34].

2.5.2 DR Program

One of the fundamental ideas behind smart grids is the improvement of system management and control via the use of more automated and intelligent technology. From a demand perspective, a smart management system is referred to as a DR system, which enables the actions taken by customers to alter their usual power consumption patterns in response to changes in electricity prices over time or the incentives provided. When prices are high or the stability of the power system is in risk, these incentives are offered to encourage users to cut back on their consumption [35].

2.5.3 Power Flow Analysis

The modernization of distribution systems poses a number of difficulties for system analysis [36]. One issue, for instance, is that the inclusion of DGs may cause the direction of power flow in numerous branches to shift, which can lead the load flow approach to be used to diverge. The topology of the system is constantly changing as a result of MGs' capacity to self-heal and the reconfiguration application, both of which are seen to be necessary components of contemporary distribution systems [37]. This is another example of a new difficulty. In other words, when used to solve distribution system difficulties, traditional load flow algorithms have convergence issues. The

Newton-type power flow algorithms may encounter difficulties since the structure of distribution systems is often radial or poorly meshed networks and the ratio of R/X is high [38],[39]. On the other hand, approaches with weak convergence include Gauss-Seidel methods and fixed-point-type techniques. An effective and reliable load flow solution is needed for this kind of systems with large number of nodes and different levels of voltage that may connect imbalanced loads and dispersed random selected type of energy supplies [40].

2.5.3.1 Backward/Forward Sweep Method

The most often used approach for calculating distribution load flow is this one. Berg et al. initially presented this approach in 1967, utilizing a model of the radial system that just PQ nodes were taken into account [41]. Numerous advancements have been made since 1967 to address weakly mesh systems [42],[43] voltage dependent load distribution systems [44], distributed generation systems [45], and three-phase distribution systems [46],[47]. In [48], a strategy for solving radial and mesh systems only by backward sweeping was discovered. In [49] backward/forward sweep methods are compared together.

2.5.3.2 Newton-Raphson Type Methods

A subroutine for optimal capacitor size was introduced as one of the basic approaches to tackle convergence issues in standard Newton-Raphson for unconditioned power systems [50]. This approach uses an iterative process similar to the backward/forward sweep method, but instead assuming a bus as the slack bus, it solves both equations of active and reactive powers at the slack bus. With this approach, the chain rule is used to calculate the Jacobian matrix. Three methods were derived from the approach given in reference [51]. Based on the current injection technique [52] and unbalanced three-phase [53], and nodal current injection, this approach was enhanced for distribution systems which their loads are dependent on voltage. [54] compares the current injection technique's convergence and the backward/forward sweep technique.

2.5.3.3 Gauss-Seidel Type Methods

Three-phase distribution systems were solved using the Gauss-Seidel methodology in [55]. In [56] to solve three phase unbalanced distribution systems a reference loop frame and Grid Lab-D is employed as additional technique to a method based on based on Gauss-like approaches.

Table 2.1 provides a complete examination of several MGs, taking into account the kind of load, optimization methods, and outcomes.

Table 2.1: A review on MG analysis investigated by other researchers [57]

Ref.	Components	Optimization Techniques	Load Types	Results
[58]	DG, ESS, Switch, DR	HRDS	General	Reduction in generation cost
[59]	PV, BESS, WT	HOMER	General load for a campus	Reduction in greenhouse emission production cost
[60]	All RESs, ESS	Various Techniques	General	Reduction in generation cost
[61]	DG and ESS, battery bank, PV, WT, FC	Control and management system operation	General, EV.	EMS
[62]	PV, FC, MT	LaCER	General and transportation	MG-EMS
[63]	WT, PV, ESS	Mixed integer LP, Mixed integer CP	General	Reduction in generation cost
[64]	Control system, Utility network, RES, Diesel generator	Various Techniques	General	Reliable and stable power and reduction in dependency
[35]	Diesel generator, PV, BES, metering	IBM ILOG CPLEX	General	Efficient
[65]	Diesel generator, WT, MT, BES, metering	GAMOM, TLBO, and PSO	General	Reduction in generation cost and fast result
[66]	PV, FC, inverters	a multiagent system (MAS)-based	General	Simplify Communication
[67]	PV, WT, ESS, Diesel generator	MILP	Industrial load	Reduction in generation cost
[68]	Gas engine, MT, PV, FC, ESS	Two-stage stochastic programming	General	Increase the income of MG while decreasing the electricity cost of consumers
[69]	MT, GE, WT, PV, ESS, FC	Mixed integer LP	General	Most reliably and economical
[70]	PV, WT, ESS, diesel generator, FC	Mixed integer LP, CPLEX 11	General	Reduction in generation cost and

		under general algebraic modeling		Organize energy resources to best meet demand loads
[71]	ESS, PV, WT, ESS	Mixed integer LP, Gurobi	EV, General	Reduction in generation cost, and customer interruption cost
[72]	MT, PV, ESS	bi-level model Optimization, general algebraic modeling	General	Reduction in generation cost
[73]	GE, PV, ESS, WT, MT	Mixed integer NLP, non-dominated sorting GA	General	Increase the income of MG and reduction in greenhouse emission
[74]	GE, PV, WT, ESS	Mixed integer LP	Thermal, General	Reduction in generation cost
[75]	Diesel Generator, WT, ESS, PV,	YALMIP and CPLEX solver	General	Reduction in generation cost
[76]	ESS, PV	MOSEK SOCP	General	Reduction in generation cost

Chapter 3

RESEARCH METHODOLOGY

3.1 Energy Management System

In this research, an ED for a grid-connected MG consists of DERs such as PVs, WTs, MTs, and diesel generators with ESS in presence of a DR program for a time series of 24-hours of a complete day is calculated using two different optimization methods - GA and PSO - and the results are compared together.

3.1.1 Objective Functions

The Objective functions of this study are the cost function of the MG components which are mostly dependent on the power generated by each of them.

3.1.1.1 PV Solar Generation

The efficiency and cost of a solar PV cell are identified by the material employed. Many studies have been conducted to determine the most efficient and economically optimal material for PV cells [23]. The PV production is dependent on daily solar radiation and its generation cost is calculated using the produced power by panels considering the investment cost.

$$P_{PV}(t) = \left[P_{PV,ST} \times \frac{G_T(t)}{1000} \times \left[1 - \gamma(T_j - 25)\right]\right] \times N_{PVs} \times N_{PVp} \tag{3.1}$$

$$C_{PV} = C_{inv} + (C_{pkWh} \times P_{PV}) \tag{3.2}$$

In which P_{PV} is output power, $P_{PV,ST}$ is rated power, G_T is solar radiation, γ is power temperature coefficient, T_j is panel temperature, N_{PVs} and N_{PVp} are number of modules that are connected in series and parallel respectively, C_{inv} is the investment cost, C_{pkWh} is the generation cost per kWh, and C_{PV} is PV generation cost.

3.1.1.2 WT Generation

The WT Generation function variable is the wind speed, and the cost function is dependent on the power generated by the turbine in all-time intervals. The following equation is used to forecast the output power of WTs [26].

$$P_{wt}(v) = \begin{cases} 0 & if v < V_{ci} \\ P_R(A + Bv + Cv^2) & if\ V_{ci} < v < V_r \\ P_R & if\ V_r < v < V_{co} \\ 0 & if\ V_{co} < v \end{cases} \quad (3.3)$$

$$C_{wt} = C_{inv} + (C_{pkWh} \times P_{wt}) \quad (3.4)$$

In which P_{wt} is output power, P_R is rated power, v is wind speed, V_{ci} is cut-in wind speed, V_{co} is cut-off wind speed, V_r is rated wind speed, C_{inv} is the investment cost, C_{pkWh} is the generation cost per kWh and C_{wt} is WT generation cost and A, B and C are the generation cost coefficients. Characterization of a WT's generation is shown in Figure 3.1.

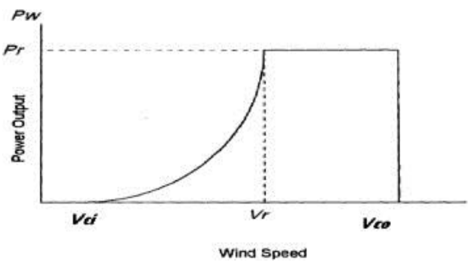

Figure 3.1: Characterization of a WT's generation [26]

3.1.1.3 Diesel Engine Generation

Although the main purpose of employing MGs is to focus more on managing RESs, in some conditions it is more reliable and economic to generate power using fossil fuel. In this study, the cost of releasing greenhouse emissions into the atmosphere is considered in addition to the fuel consumption cost of fossil fuel generation.

$$C_{fuel} = A + B \times P_{ffg} + C \times P_{ffg}^{2} \quad (3.5)$$

$$P_{ffg}^{min} \leq P_{ffg} \leq P_{ffg}^{max} \quad (3.6)$$

$$C_{em} = (C_{co2} + C_{so2} + C_{no2}) \times P_{ffg} \quad (3.7)$$

$$C_{ffg} = C_{fuel} + C_{em} \quad (3.8)$$

In which P_{ffg} is output power, A, B, and C, are cost coefficients, C_{fuel} is the generation fuel cost, C_{co2}, C_{so2}, and C_{no2} are greenhouse emissions costs, C_{em} is total greenhouse emissions cost, and C_{ffg} is fossil fuel generation total cost and A, B and C are the generation cost coefficients.

3.1.1.4 ESS

The concept of the ESS is to operate as a load when there is excess energy and inject the stored energy into the system whenever it is needed. The charge and discharge cost formula are mentioned below. C_{ch} and C_{dch} are charge and discharge costs of ESS respectively, P_{ess} is the power that is consumed as a load in charging mode, or generated as a power generator in discharging mode. C_{inv} and C_{conn} are investment costs of buying and connecting the ESS to the grid. $C_{ess,ch}$ and $C_{ess,dch}$ are the total costs of ESSs in charging or discharging modes respectively.

$$C_{ess,ch} = C_{inv} + C_{conn} + \frac{P_{ess}}{\eta} \times C_{ch} \quad (3.9)$$

$$C_{ess,dch} = C_{inv} + C_{conn} + \frac{P_{ess}}{\eta} \times C_{dch} \quad (3.10)$$

3.1.1.5 DR Program

The DR program is also employed to make the system more reliable and economic. In the high demand time intervals, an incentive payment is considered for consumers who reduce their adjustable load or transfer it to low demand periods. The amount of money that is paid to consumers for the reduced energy consumption is considered as the cost of applying the DR program in the MG.

$$C_{DR} = C_i \times P_{DR} \tag{3.11}$$

In which C_i is the incentive payment for load reduction per kWh, P_{DR} is the reduced power by DR program, and C_{DR} is the DR program total cost.

3.1.1.6 Utility Purchase

Depending on the amount and the cost of produced energy by DERs inside the MG, in some periods purchasing power from the main grid leads the system to be more economic and reliable. The cost of the main grid purchase is calculated considering the price of energy per hour and the abonnement cost.

$$C_{up} = C_{ab} + (C_{pkWh} \times P_{up}) \tag{3.12}$$

In which C_{ab} is the abonnement cost, C_{pkWh} is the electrical energy price per kWh, P_{up} is the purchased power from the utility, C_{up} is the utility purchase total cost.

3.1.2 Constraint

The main goal of this study is to generate as same amount as demanded load in all-time intervals, considering the different behaviors of ESS, therefore the calculations must be categorized in two different types, whenever the ESS is in charging mode equation (3.13) and when it is in discharging equation (3.14) must be used:

$$\sum P_{ffg} + \sum P_{wt} + \sum P_{pv} - \sum P_{ess} + \sum P_{dr} + P_{gp} = \sum P_{load} \tag{3.13}$$

$$\sum P_{ffg} + \sum P_{wt} + \sum P_{pv} + \sum P_{ess} + \sum P_{dr} + P_{gp} = \sum P_{load} \tag{3.14}$$

In which P_{dr} is the amount of reduced power by DR program and P_{gp} is the purchased power from main grid and P_{load} is the demanded load of the MG. Whenever the ESS is in charging mode the equation (10) and when it is in discharging mode the equation (11) must be satisfied.

3.1.3 Optimization

In order to obtain the optimum generation cost which satisfies the demanded load two different optimization methods are employed in this research GA and PSO.

3.1.3.1 GA

The GA is employed as the optimization tool in this thesis. This approach routinely yields outstanding results and is simple to apply from a computational standpoint. The first population, or group of likely solutions discovered at random in a search area and recorded in a proper coding, is where GA begins. Every solution is a unique entity with chromosome-like properties. In GA, chromosomes are composed of a string of genes, each of which is represented by a binary value (0s and 1s). Given a spower electronic converterified objective function, (J_{obj}), GA is used to reduce it such that each person undergoes a fitness evaluation, (J_i), which is a measurement of each person's performance. Following the distribution of each person's fitness, the population is exposed to three fundamental operations: crossover, mutation, and selection [77].

Selection is the operator in charge of determining convergence, thus by using the right selection approach, you may prevent premature convergence to a load optimum. Depending on the appraisal of a person's fitness for reproduction, there are several ways available. There are many distinct kinds of selection, including elitist selection, scaling selection, ranking selection, roulette wheel selection, fitness proportionate selection, and tournament selection [78].

During the selection process two of individuals will be selected for regeneration, and new offspring are produced via crossover and mutation. Progress is made at this time because low achievers are eliminated. In the scenario of a crossover with a crossing site, as shown in Figure 3.3, a cross point *k* is chosen randomly from the intervalwhere *l* is the individual's string length [78].

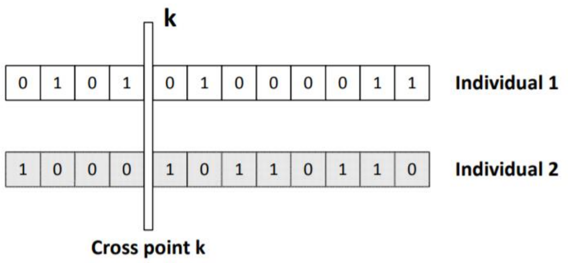

Figure 3.2: The cross-postion of two individuals

As shown in Figure 3.3, the new sets are generated by exchanging all binary codes between *k + 1* and l.

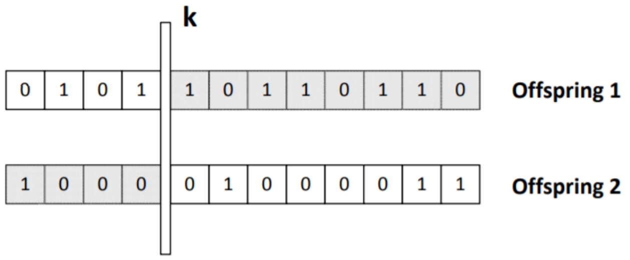

Figure 3.3: New generated strings by two individuals

In first two places of crossover, the elements of parents' strings are switched. The mutation operator is therefore recorded to each member of the current offspring with a probability, in order to ensure genetic diversity (p_{mut}). The ideal probability value changes depending on the circumstance. As illustrated in Figure 3.4, binary genes can be modified by converting a 0 to 1 or a 1 to 0, depending on the individual.

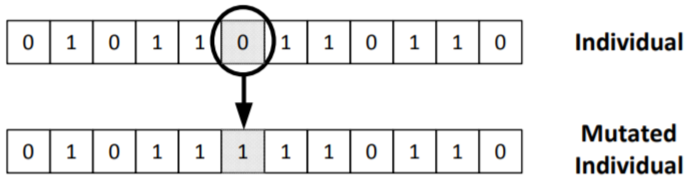

Figure 3.4: An individual gene mutation

The new population is produced when the three operators are used. In order to select the best candidate, the initial individuals and the next generation are considered. An individual from the first generation is replaced by an individual from the second generation if the value of the function of progenitor fitness is greater than the value of the fitness function of the offspring. Once the first generation is finished, the formed population goes through the same evaluation, selection, and mutation procedures as the prior one. A stop condition might be the highest generation or a specific objective function value assessment.

3.1.3.2 PSO

The PSO uses a population-based selection process as an optimization technique, in which particles change their position (state) over time. In a PSO system, particles move about in a multidimensional search space. Using the best position that it and its neighbor have encountered, each particle modifies its location throughout flight using its own (Pbest) and its neighbor's (Gbest) experiences Figure 3.5.

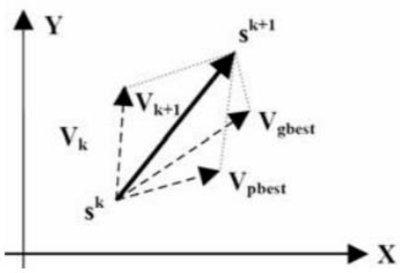

Figure 3.5: Representation of multidimentional position changing in (PSO)

This change may be demonstrated using the idea of velocity. To alter each agent's velocity, apply the equation shown below:

$$v_i^{k+1} = \omega v_i^k + C_1 rand \times \left(pbest_i - x_i^k\right) + C_2 rand \times \left(gbest_d - x_i^k\right) \quad (3.15)$$

Where v_i^k is the velocity of i_{th} particle at k_{th} iteration, C_1, C_2 are the positive costants, $rand$ is Uniformly distributed random number between 0–1, x_i^k is position of i_{th} particle at k_{th} iteration $pbest_i$ is the personal best of i_{th} particle at k_{th} iteration $gbest_d$ is the global best at k_{th} iteration in a group. Some of developed PSO methods by other researchers are mentioned below:

Dynamic adaptive dissipative PSO (ADPSO)

In this algorithm, the PSO is given a dissipative that introduces negative entropy, and when the swarm finds an equilibrium state in later runs, a mutation operator is used to enhance the diversity in the swarm. To maintain a balance between local and global optimality, it produces an adaptive approach for inertia weight [79].

Dynamic and Adjustable PSO (DAPSO)

The DAPSO method, which calculates the distance of each particle to the ideal place to alter the velocity of particles in each step, has been developed to strike a balance between discovery and extraction in the PSO as well as to maintain and safeguard the variety of the particles [80].

Dynamic Double Particle Swarm Optimizer (DDPSO)

This approach ensures convergence to the overall ideal solution by employing a convergence analysis. In this technique, particle position limitations are established dynamically [81].

Dual Layered PSO (DLPSO)

To construct a neural network, the DLPSO algorithm was created. An architectural layer of the network is optimized using this algorithm. It is employed for joint weights in neural networks. Testing neural network controllers is done using a traditional boost power transformer [82].

Dynamic neighborhood PSO (DNPSO)

The traditional PSO technique has certain changes made by the DNPSO approach. In this technique, a different parameter named Nbest is used instead of the PSO's current Gbest. The best particle in the present particle's neighborhood is referred to by this word. This approach explains the multi-objective nature of the neighborhood selection for the present particle. Additionally, choosing their best is another goal [83].

Estimation of Distribution PSO (EDPSO)

The PSO and Estimation of Distribution Algorithm (EDA) were combined to create this algorithm. In fact, the ED algorithms attempt to locate better regions utilizing the data produced from stochastic models, upon which good solution areas on distribution are formed throughout the optimization process. Utilizing this aspect of the algorithm helps PSO perform better [84].

Multi Objective PSO (MOPSO)

The particle velocity and position are updated in a similar manner by the MOPSO and PSO algorithms. The two "guides" that the PSO algorithm uses to update a particle's velocity and position are the best solution the particle has discovered (i.e., the individual guide $pbest_i$) and the best solution the population as a whole has found so far (i.e., the global guide $gbest_d$). The MOPSO and PSO algorithms are also distinct in a number of ways. To start, the individual and global guides have different updating and selection processes. Additionally, the MOPSO algorithm's result is a set of Pareto-optimal solutions. Additionally, a storage set must be created for the MOPSO algorithm in order to save the population's noninferior solutions. The formation of a storage set, the choice of individual and global guides, and the parameter settings for the MOPSO algorithm have all been thoroughly studied by a number of researchers, and some results have been produced. The MOPSO method still struggles to efficiently search for the global optimal solution to large-scale problems and is still prone to premature convergence [85]. In this research MOPSO variant is used to obtain the ED in the MG.

3.2 Power Flow Analysis

Power flow analysis is employed to investigate the operating conditions of a power system in steady state situation, which can be done using different approaches such as Newton Raphson, Gauss Seidel or backward forward sweep methods depending on the characteristics of the power system.

One of the most effective load flow techniques is the backward/forward sweep (BFS), however it can only be used with radial distribution systems. BFS is the best load flow method for radial distribution networks since it doesn't require complex calculations like the Jacobian matrix or the creation of nonlinear equations [86].

In this work, a backward/forward sweep technique is suggested to handle the radial distribution system. The suggested technique is examined on 33bus radial distribution networks. A recursive connection between voltage values is resolved using the backward/forward sweeping approach. To solve the equations, the load flow will be simulated in MATLAB. The equations of the suggested load flow technique is explained in the next section.

3.2.1 Backward/Forward Sweeping Method

In order to do the power flow calculations in a distribution system, Figure 3.6 presents single-line model which is used to generated simplified recursive equations. The power flow analysis may be used to evaluate the 33 bus system's voltage magnitude and the losses of power. The purpose of the function is to determine the power flow [87].

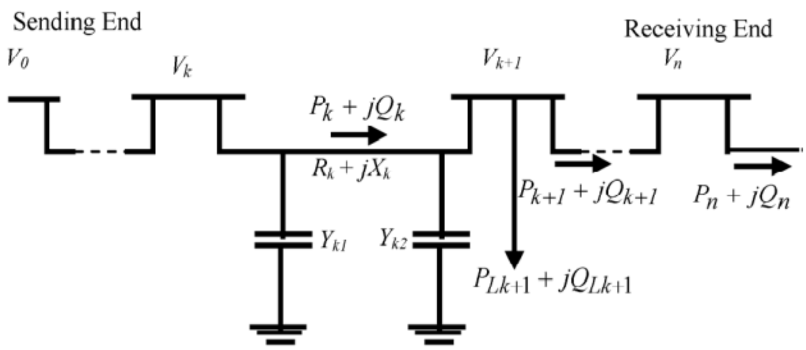

Figure 3.6: Single Line Diagram of backward/forward sweeping method

$$P_{k+1} = P_k - P_{Loss,k} - P_{Lk+1} \tag{3.16}$$

$$Q_{k+1} = Q_k - Q_{Loss,k} - Q_{Lk+1} \tag{3.17}$$

Where;

P_k Active power emitted from the bus k ;

P_Q Reactive energy emitted from the bus k ;

$P_{Loss,k}$ Active power Loss between buses k ;

$Q_{Loss,k}$ Reactive power Loss between buses k ;

P_{Lk+1} Active load power in bus $k+1$;

Q_{Lk+1} Reactive load power in bus $k+1$;

The following formula can be used to compute the power loss in the line segment linking buses k and $k+1$:

$$P_{loss}\,(k, k+1) = R_k\,\frac{P_k^2 + Q_k^2}{V_k^2} \tag{3.18}$$

$$Q_{loss}\,(k, k+1) = X_k\,\frac{P_k^2 + Q_k^2}{V_k^2} \tag{3.19}$$

Where;

$P_{loss}\,(k,k+1)$ Active power Loss between buses k and $k+1$

$Q_{loss}\,(k,k+1)$ Reactive power Loss between buses k and $k+1$

After then, the feeder's overall power loss, P, is computed by summing the losses of all feeder line sections, which is expressed as

$$P_{Total,loss}\,(k, k+1) = \sum_{k=1}^{n} P_{loss}\,(k, k+1) \tag{3.20}$$

$$Q_{Total,loss}\,(k, k+1) = \sum_{k=1}^{n} Q_{loss}\,(k, k+1) \tag{3.21}$$

Where;

$P_{Total,loss}\,(k,k+1)$ is the Total Active Power Loss;

$Q_{Total,loss}\,(k,k+1)$ is the Total Reactive Power Loss;

The backward/forward sweeping method has been changed to make it possible to look at the convergence of the iterative process. Think about the branch that joins the nodes "k" and "k+1" in Figure 3.1. The active power (P_K) and reactive power (Q_K) of flowing via branch from node 'k' to node 'k+1' may be computed and are presented as moving backwards from the last node.

$$P_k = P'_{k+1} + r_k \frac{(P^2_{k+1} + Q^2_{K+1})}{V^2_{k+1}} \tag{3.22}$$

$$Q_k = Q'_{k+1} + X_k \frac{(P^2_{k+1} + Q^2_{K+1})}{V^2_{k+1}} \tag{3.23}$$

Where;

$$P'_{k+1} = P_{k+1} + P_{Lk+1} \tag{3.24}$$

$$Q'_{k+1} = Q_{k+1} + Q_{Lk+1} \tag{3.25}$$

P_{LK+1} and Q_{LK+1} are loads of bus ‘k+1’,

P_{K+1} and Q_{K+1} are the active real and reactive power flows of bus ‘k+1’.

The voltage characteristics at each bus are calculated in forward direction.

$$I_k = \frac{V_k < \delta_k - V_{k+1} < \delta_{k+1}}{r_k + jx_k} \tag{3.26}$$

Use the magnitude and phase angle equations iteratively and forward to get the angle and voltage of each node in a distribution system.

Flat or 1.0 p.u. is considered as the initial voltage level of each node. The updated voltages at each node are used to continually calculate the branch powers. In the recommended load flow approach, voltages are acquired during the forward walk while power summing is performed during the backward walk . Figure 3.7 illustrates the actual steps for computing the power flow using the back/forward sweeping approach. The suggested backward Forward sweep method is used on the IEEE 33-bus power system.

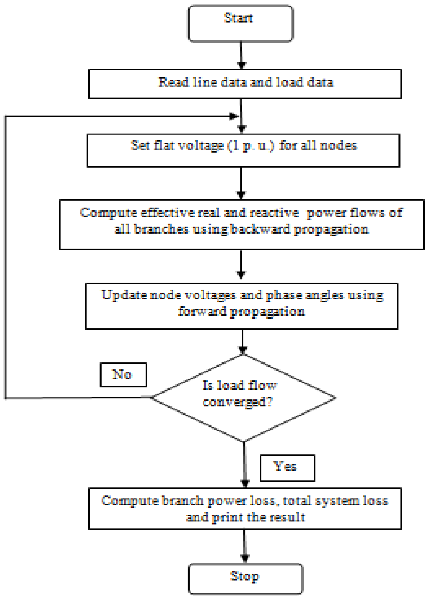

Figure 3.7: The flowchart of backward / forward sweeping method [88]

3.2.2 Voltage Deviation

Voltage deviation is necessary for the computation of the objective function to evaluate the system's response to the DGs. Since it is assumed that the voltage of the slack bus is constant at all times, it is not taken into consideration while calculating voltage deviation. Multiply the overall difference in bus voltages (excluding slack bus) by one less than the total number of buses to determine the voltage variation (p.u). (removing the slack bus) [89]. The final voltage deviation value will be largely independent of network size using this method:

$$V_{dev} = \frac{\sum_{i=2}^{Bus\ No} |1 - V_i|}{BusNo - 1} \tag{3.27}$$

where: V_{dev} explains the overall voltage deviation in the system buses.

3.3 Research Topology

In order to obtain the optimal ED of MG generation while it is equal to demanded load in all-time series two different optimization algorithms using MATLAB software are employed, GA and PSO. In both of the algorithms the generation cost functions of all components of the MG are considered and the ESS state of charge is determined, then the equations (3.13) or (3.14) will be solved until it reaches to specified number of iterations or less than amount of defined error. After finding the optimum value of ED the voltage level will be calculated using Backward/Forward sweep method, to check the voltage deviation. The flowchart of discussed program is shown in Figure 3.8. The related MATLAB codes of this program can be seen in the Appendix.

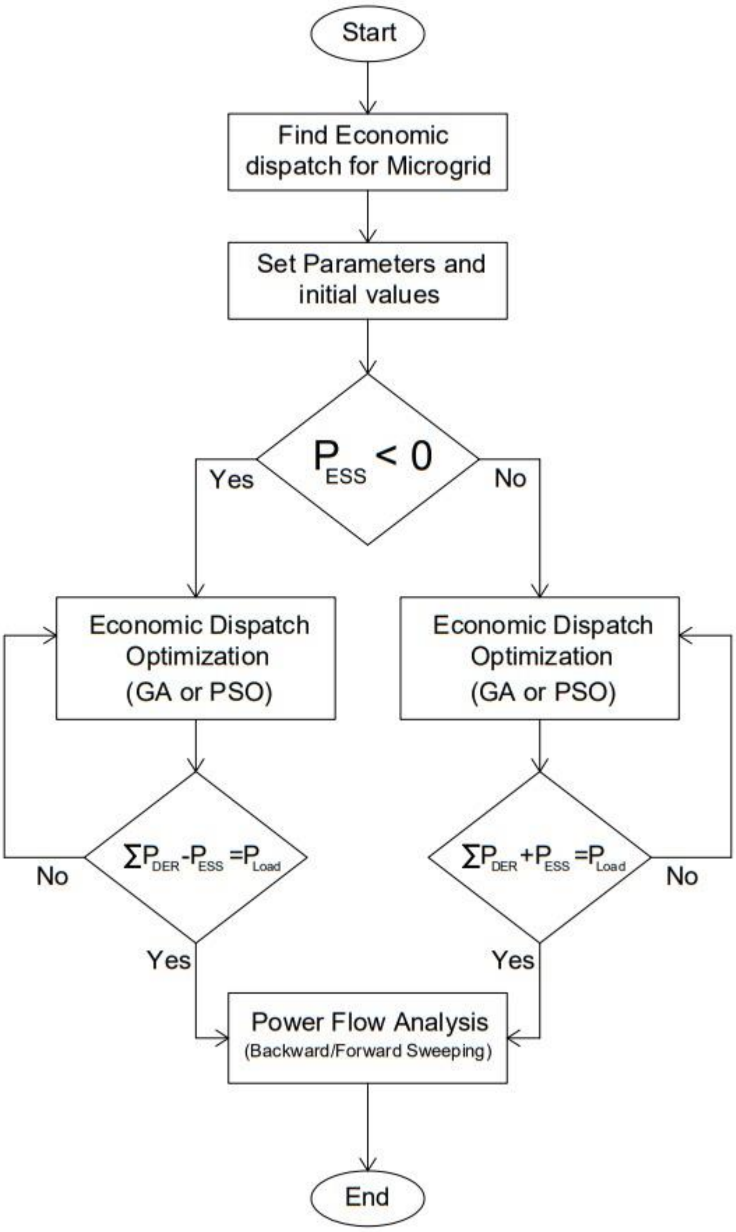

Figure 3.8: The flowchart of the proposed method

Chapter 4

CASE STUDY AND RESULTS

4.1 System Data

In this thesis IEEE 33-bus power grid is considered as the MG which is consisting, PV panels, WT, fossil fuel generation, and ESS which is connected to the main grid in PCC, and DR program is employed to have the contribution of consumers for applying the energy management system. Employing dual solving method and using MATLAB software for this problem allows to compare the difference in their results in obtained outputs. The most crucial ED of GA and PSO methods and also power flow analysis outputs are discussed in this research.

4.1.1 MG Structure

The proposed MG structure can be seen in Figure 4.1 and the data of each line is shown in Table 4.1. The PCC of the MG is at bus 1.

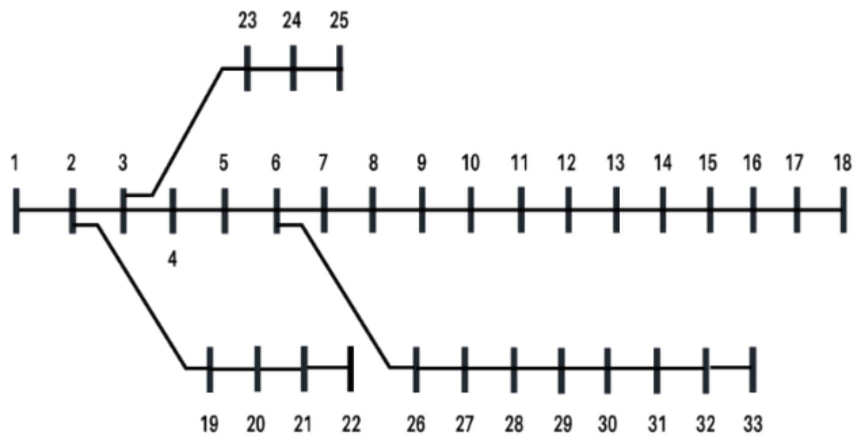

Figure 4.1: IEEE 33-Bus single line diagram

Table 4.1: Line data

Line No.	In Bus	Out Bus	Resistance (Ω)	Reactance (Ω)
1	1	2	0.0922	0.0470
2	2	3	0.4930	0.2511
3	3	4	0.3660	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	0.7114	0.2351
8	8	9	1.0300	0.7400
9	9	10	1.0440	0.7400
10	10	11	0.1966	0.0650
11	11	12	0.3744	0.1238
12	12	13	1.4680	1.1550
13	13	14	0.5416	0.7129
14	14	15	0.5910	0.5260
15	15	16	0.7463	0.5450
16	16	17	1.2890	1.7290
17	17	18	0.7320	0.5740
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.8980	0.7091
24	24	25	0.8960	0.7011
25	6	26	0.2030	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0590	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.9630
31	31	32	0.3105	0.3619
32	32	33	0.3410	0.5302

4.1.2 Load

The information of the total hourly load of a complete day is shown in Figure 4.2 and the amount of demanded load on each bus is mentioned in Table 4.2.

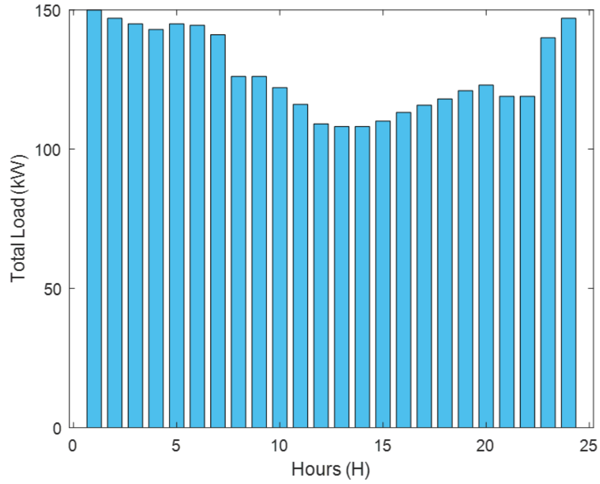

Figure 4.2: Total hourly demanded load of a specific day

Table 4.2: Load data

Bus No.	P_D (KW)	Q_D (KVar)	Bus No.	P_D (KW)	Q_D (KVar)
1	0	0	**18**	90	40
2	100	60	**19**	90	40
3	90	40	**20**	90	40
4	120	80	**21**	90	40
5	60	30	**22**	90	40
6	60	20	**23**	90	50
7	200	100	**24**	420	200
8	200	100	**25**	420	200
9	60	20	**26**	60	25
10	60	20	**27**	60	25
11	45	30	**28**	60	20
12	60	35	**29**	120	70
13	60	35	**30**	200	600
14	120	80	**31**	150	70
15	60	10	**32**	210	100
16	60	20	**33**	60	40
17	60	20			

4.1.2 Solar Irradiance

The PV solar generation calculations input values are the daily solar irradiance and the weather temperature which were characterized using different subsets of irradiance and temperature data from Montana having latitude $46^{\circ}\ 57'\ 54.9360''$ N and longitude $109^{\circ}\ 32'\ 1.2876''$ W in 20th of June, obtained by National Renewable Energy Laboratory (NREL) that are presented in Figure 4.3 and Figure 4.4 respectively. The PV panel module which is considered for this study is SR-M672280 manufactured by

Sunrise Solar Tech with the technology of Mono-C-Si and with the maximum output power of 280.14 W and the total number of panels are 450 [90].

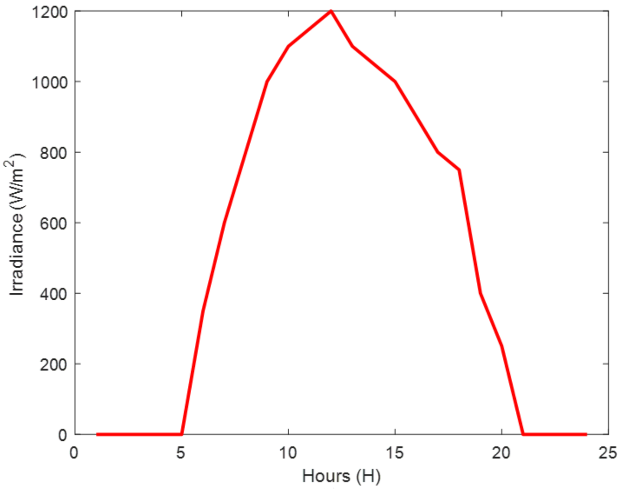

Figure 4.3: Hourly solar irradiance of a specific day

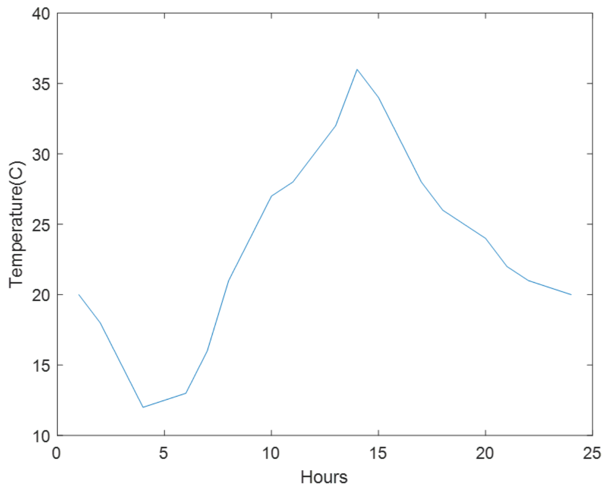

Figure 4.4: Hourly weather temperature of a specific day

4.1.2 Wind Speed

WT generation is compeletly dependent on the wind speed, the hourly wimd speed of a specific day which were characterized using different subsets of wind data from Montana having latitude 46◦ 57′ 54.9360″ N and longitude 109◦ 32′ 1.2876″ W in 20th of June obtained by National Renewable Energy Laboratory (NREL) is illustrated in Fugre 4.5 [90].

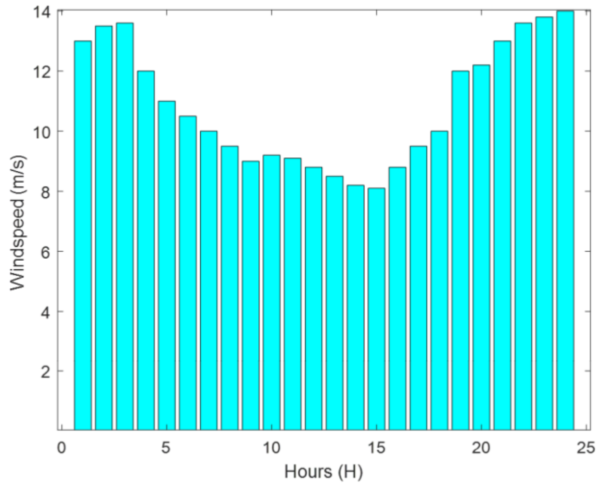

Figure 4.5: Hourly wind speed of a specific day

4.2 Energy Management Results

Energy management program has applied using both methods and resulted in satisfying the equations (3.13) and (3.14) in order to supply energy to the MG's loads in 24 hours-time series in an economic approach. The results of each MG components for each method (GA and PSO) are mentioned below.

4.2.1 PV Generation

The generated power of PV solar panels is shown in Figure 4.6 and Figure 4.7 for GA and PSO method respectively. As it is clear in time intervals with more solar radiation the amount of generated power is larger. A comparison between the results of PV generation declares that from 17:00 to 18:00 GA method relies on solar generation more than PSO, which means that in this time interval PSO uses another generator that will be shown in the next results.

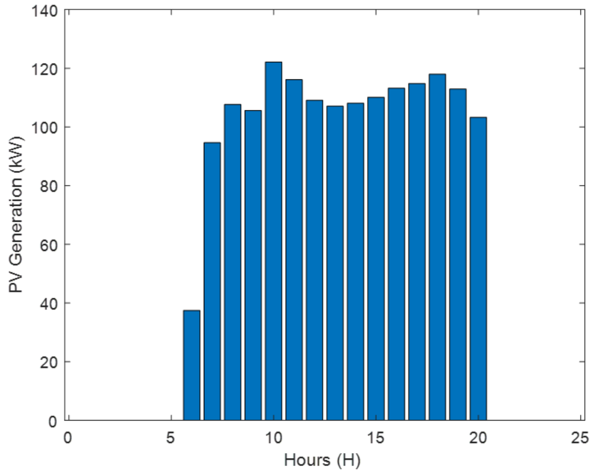

Figure 4.6: PV solar generation using GA method

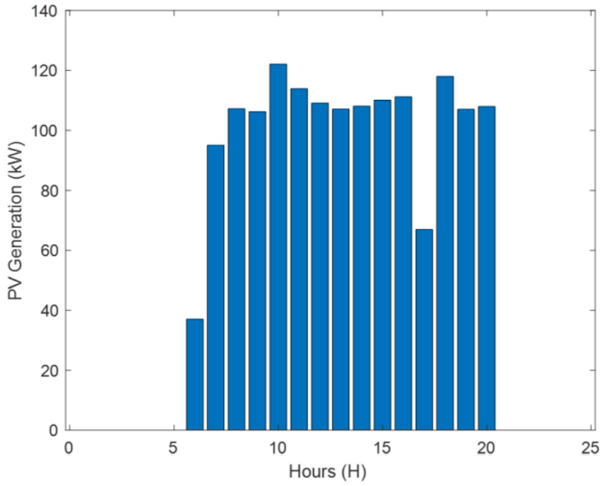

Figure 4.7: PV solar generation using PSO method

4.2.2 WT Generation

The WT generation using both GA and PSO method are shown in Figures 4.8 and 4.9 respectively.

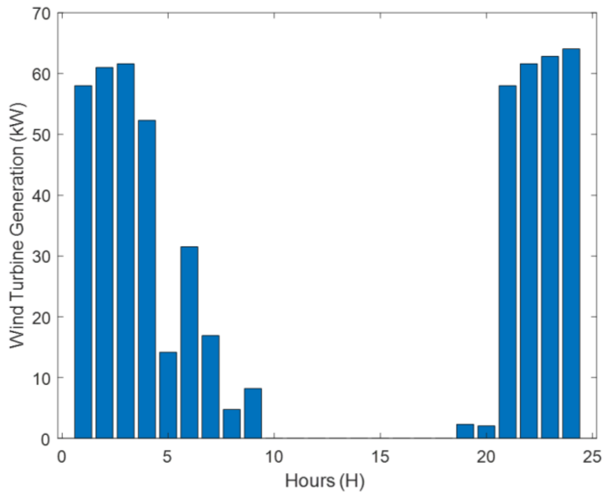

Figure 4.8: WT generation using GA method

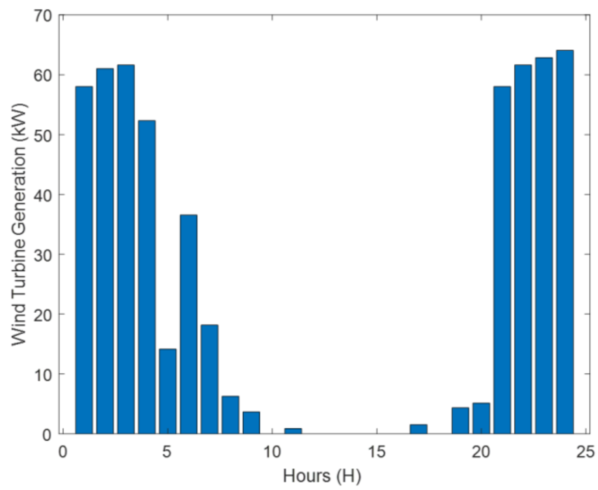

Figure 4.9: WT generation using PSO method

4.2.3 ESS

As it is clear in Figure 4.10 the results of both methods show that in the low demand time intervals mostly during the night the produced power by ESS is negative which means that it is in charging mode and behaves as a load in the MG, on the other hand in peak hours the stored energy will be released to supply MG's loads, the comparison of two methods shows that using PSO leads the MG to relies on ESS more than using GA. In GA method this lack of energy is supplied using solar radiation which can be seen by comparing the Figure 4.6 and Figure 4.7. The total remaining stored energy in th ESS after a complete day in GA and PSO methods are 255.05 kWh and 184.30 kWh respectively.

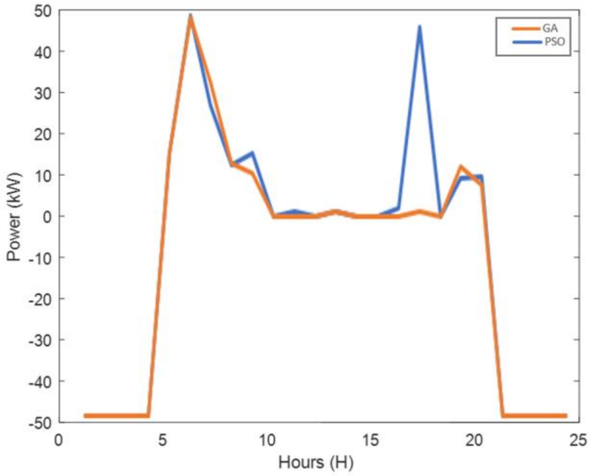

Figure 4.10: Comparison of ESS behavior in GA and PSO method

4.2.4 DR Program

The reduced amount of the demanded load by consumers which is called as DR program is shown in Figure 4.11 and Figure 4.12 for both methods.

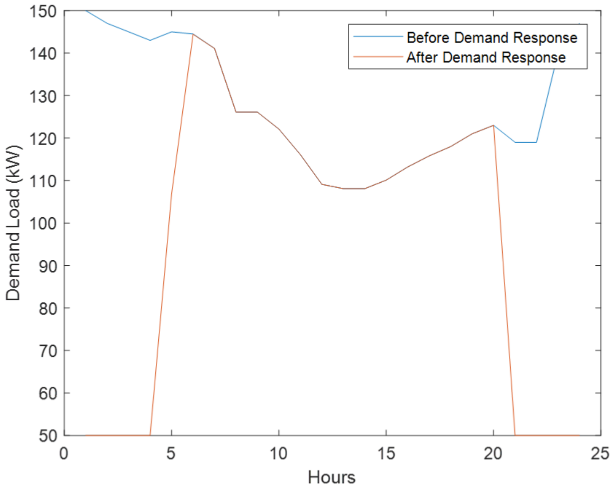

Figure 4.11: DR program results using GA method

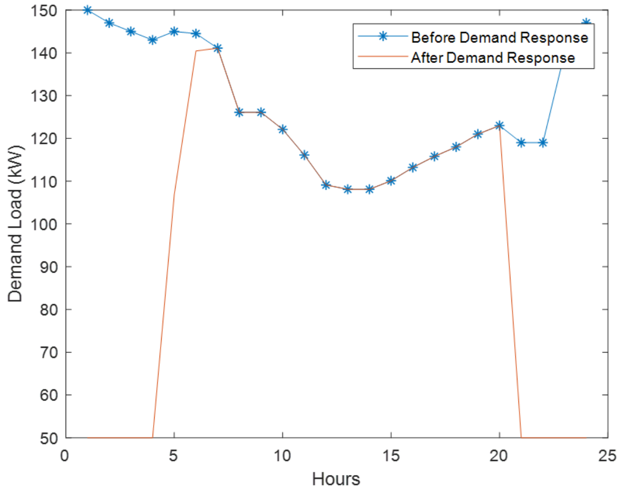

Figure 4.12: DR program results using PSO method

4.2.5 Utility Purchase

The total amount of electricity which is purchased during a specific day from the main grid using both GA and PSO algorithms is shown in Table 4.3. As it is clear in the table in both algorithms the total utility purchase is almost same.

Table 4.3: Utility purchase results

Method	Utility Purchase (kWh)
GA	30.75
PSO	30.74

4.2.6 Fossil Fuel Generation

Fossil fuel generation helps the MG stays reliable in some time series. The total amount of generated energy by fossil fuel generators (MT and Diesel generator) in a specific day using both methods can be seen in Table 4.4.

Table 4.4: Fossil fuel generation results

Method	MT (kWh)	Diesel Generator (kWh)
GA	370.75	20.70
PSO	363.49	20.73

4.2.7 Combined Results of Energy Management System

It is obvious that the results of GA and PSO methods that are shown in Figure 4.13 and Figure 4.14 respectively differ slightly. The comparison between Figure 4.2 and the result of energy management in both methods declares that the DR program has reduced the MG's load in some time intervals. This reduction of load provides a situation in MG to have excess energy production by WT and MT which is stored by ESS to be used in peak load period. Between 7:00 – 20:00 that there is enough solar radiation, therefore most of the energy consumption has supplied by PV panels. Diesel generator production and utility purchased has a small share in some short time intervals which there is not enough solar radiation or wind speed.

Figure 4.15 presents an economical comparison of GA and PSO methods. As it is clear both of the methods provide almost same economical results in most of the time series, and it can be seen that in the hours that there is sufficient solar radiation the generation cost has been dropped up to 40% which means that PV solar generation plays a major role in minimizing the generation cost. A closer look at the Figure 4.15 declares that PSO provides less generation cost in some time intervals. The comparison of hourly generation cost in GA and PSO methods in a specific day is shown in Table 4.3.

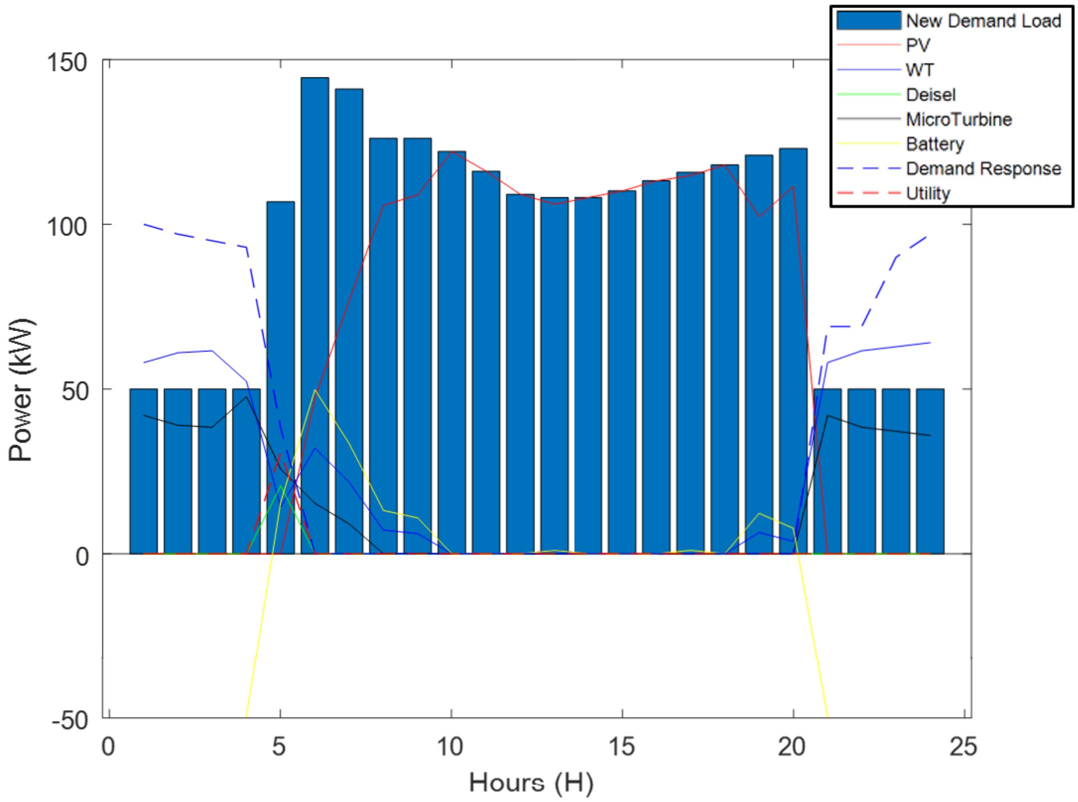

Figure 4.13: Optimized power generation using GA method

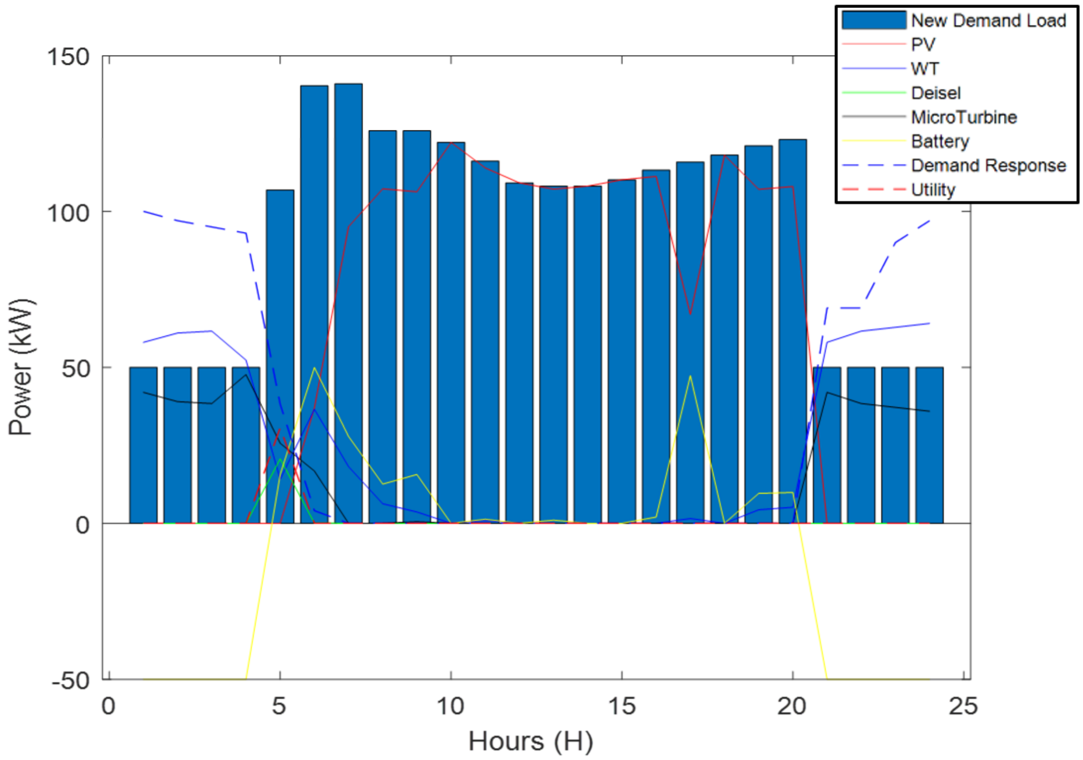

Figure 4.14: Optimized power generation using PSO method

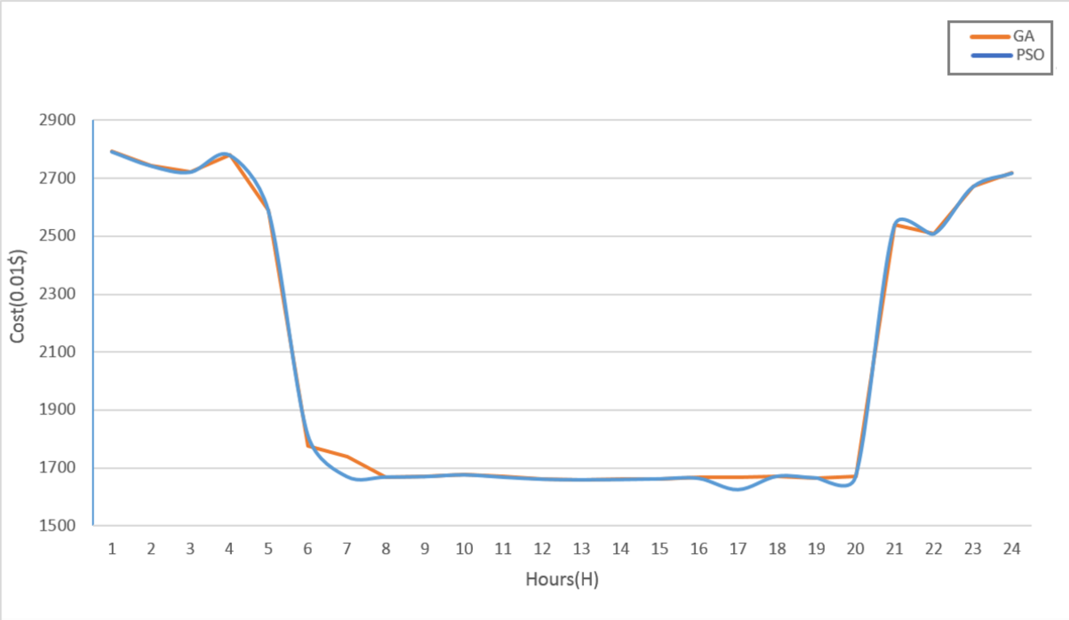

Figure 4.15: Comparison of optimum generation cost using GA and PSO methods

Table 4.5: Hourly generation cost comparison of two methods for a specific day

Hour	Generation cost (0.01$)	
	GA	*PSO*
1	2792	2792
2	2743	2743
3	2722	2722
4	2781	2781
5	2589	2589
6	1777	1818
7	1740	1672
8	1669	1670
9	1673	1671
10	1677	1677
11	1670	1669
12	1662	1662
13	1660	1660
14	1661	1661
15	1663	1663
16	1667	1665
17	1669	1626
18	1672	1672
19	1664	1667

20	1671	1669
21	2538	2538
22	2509	2509
23	2671	2671
24	2718	2718
Total Generation cost of a specific day	49260	49187

4.3 Power Flow Analysis

The voltage magnitude deviation is shown in Figure 4.16 and Figure 4.17 for GA and PSO methods respectively and compared with the voltage level of before applying ED, although in PSO method there is more fluctuations in voltage deviation, in both methods the voltage magnitude remains in the standard range.

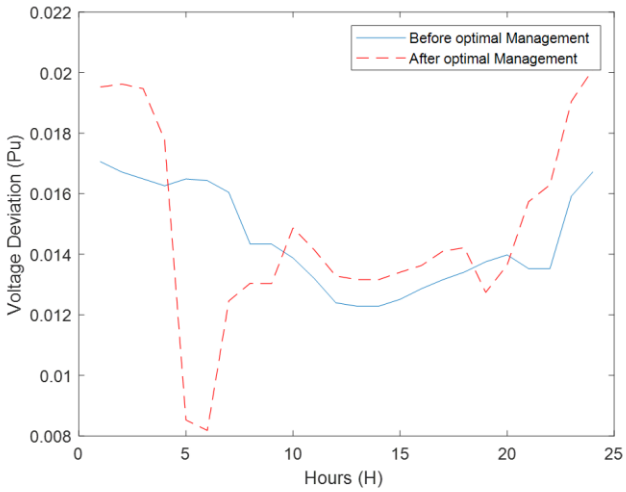

Figure 4.16: The voltage magnitude deviation in GA method

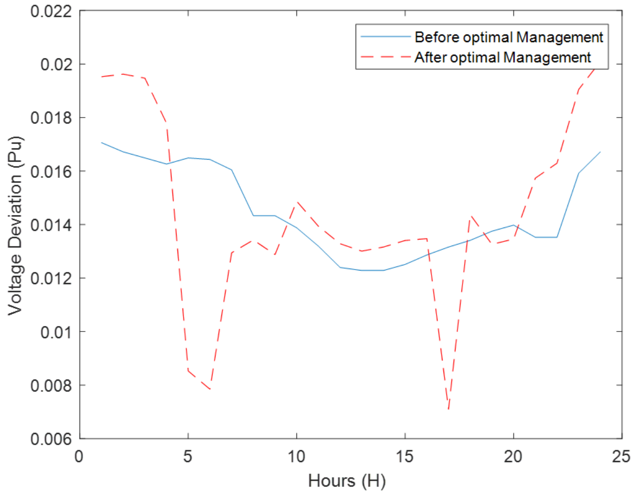

Figure 4.17: The voltage magnitude deviation in PSO method

Chapter 5

CONCLUSION AND FUTURE STUDY

In this thesis an energy management system which offers optimum generation cost of a grid-connected MG consist of PV solar panels, WT, fossil fuel generation, ESS, and employs DR program and the main grid purchase, considering voltage deviation before and after applying the optimal management is investigated.

This research presents a comparison between two optimization methods, GA and PSO for minimizing the generation cost. The results show that the generation cost in PSO method is more economic and it employs ESS more than GA method and the PV solar generation takes the lead in generation cost minimization.

Power flow analysis is also calculated using backward/forward sweeping method to check and compare the output voltage level before and after applying energy management system. Voltage deviation outputs show that in both algorithms the voltage fluctuations are increased after applying management program specially in PSO method but still it is in the standard range.

Some of the possible future works of this thesis are mentioned below:

- MG components can be replaced or added for example combined cooling and heating systems, concentrated solar generation, biomass power generation and so on.

- ESS cost function can be defined according to existing technologies such as battery energy storage, hydrogen energy storage, pumped hydro energy storage, compressed air energy storage, molten salt in combination with concentrated solar generation and so on.
- The employed optimization method can be changed or improved as well, for instance, combined GA/PSO method, grey wolf optimization, dynamic programing, linear programing and so on.

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APPENDIX

Fitness function of energy management system in charging mode of ESS MATLAB code:

```
function Y=fitf_DRB(x1)
%%%
global m1


%  line No. sending  recieving   resistance(ohm)     reactance(ohm)
%            node     node
l=[        1     1      2           0.0922              0.0470
           2     2      3           0.4930              0.2511
           3     3      4           0.3660              0.1864
           4     4      5           0.3811              0.1941
           4     5      6           0.8190              0.7070
           6     6      7           0.1872              0.6188
           7     7      8           0.7114              0.2351
           8     8      9           1.0300              0.7400
           9     9      10          1.0440              0.7400
          10    10      11          0.1966              0.0650
          11    11      12          0.3744              0.1238
          12    12      13          1.4680              1.1550
          13    13      14          0.5416              0.7129
          14    14      15          0.5910              0.5260
          15    15      16          0.7463              0.5450
          16    16      17          1.2890              1.7210
          17    17      18          0.7320              0.5740
          18     2      19          0.1640              0.1565
          19    19      20          1.5042              1.3554
          20    20      21          0.4095              0.4784
          21    21      22          0.7089              0.9373
          22     3      23          0.4512              0.3083
          23    23      24          0.8980              0.7091
          24    24      25          0.8960              0.7011
          25     6      26          0.2030              0.1034
          26    26      27          0.2842              0.1447
          27    27      28          1.0590              0.9337
          28    28      29          0.8042              0.7006
          29    29      30          0.5075              0.2585
          30    30      31          0.9744              0.9630
          31    31      32          0.3105              0.3619
          32    32      33          0.3410              0.5302];
     %-----------------------------------------------------------------

%%%--------------- this program release by Alireza Kermani----------------
-
%---------- PV Cost -----------------------
Ppv=x1(1);
Cpv=29.55+1.15*Ppv;
%%-----------Wind Turbine Cost------------------
Pwt=x1(7);
Cwt=85+1.05*Pwt;
%------------Deisel Generator Cost ------------------------------
Pdg=x1(3);
%----
a1=(1.04*1e-4);
b1=6.53;
c1=431;
```

```
Cfuel_dg=c1+b1*Pdg+a1*Pdg.^2;
%-------
Cco2=1.24;
Cso2=2.41;
Cno2=1.28;
CEMI_dg=(Cco2+Cso2+Cno2)*Pdg;
Cdg=Cfuel_dg+CEMI_dg;
%----------------------- Microturbine Cost -------------------------------
Pmt=x1(4);
%----
a2=(0.94*1e-4);
b2=4.26;
c2=551.21;
Cfuel_mt=c2+b2*Pdg+a2*Pmt.^2;
%-------
Cco2=1.24;
Cso2=2.41;
Cno2=1.28;
CEMI_mt=(Cco2+Cso2+Cno2)*Pmt;
Cmt=Cfuel_mt+CEMI_mt;
%----------------------- Battery Cost -------------------------------
Pbattery=x1(5);
eta=0.92;
Cinvest=184;
Cconnection=156;
Cch=0.21;
Cenrgy=Cinvest+Cconnection+(Pbattery/eta)*Cch;
%----------------------- Demand Response Cost ----------------------------
---
Pdr=x1(6);
Cdr=8.2*Pdr;
%----------------------- Electrical Utility Cost -------------------------
------
Putility=x1(2);
Cutility=100+8.1*Putility;
%%  --------------------defination of first objective function------------
--------------

%%  --------------------defination of first objective function------------
--------------
[Plosskw,Qlosskw,Voltage_Mag,Voltage_Angle,Ibrp]=LoadFlowAnalysis(m1,l,Ppv
,Pwt,Pdg,Pmt,Pbattery,Pdr,Putility);

Plosskw_normal=(sum(Plosskw)/sum(m1(:,2)));
Qlosskw_normal=(sum(Qlosskw)/sum(m1(:,2)));
VD=sqrt(sum((1-Voltage_Mag).^2));
UtilityCost=sum(m1(:,2))*8.1+100;

totalcost_normal=(Cpv+Cwt+Cdg+Cmt-Cenrgy+Cdr+Cutility)/UtilityCost;

 Y=totalcost_normal+Plosskw_normal+Qlosskw_normal+VD;
```

Fitness function of energy management system in discharging mode of ESS MATLAB code:

```
function Y=fitf_DR(x1)
%%%
```

```
global m1
% BUs No. load at BUS
%       P(KW)    Q(KVAR)


%  line No. sending  recieving   resistance(ohm)     reactance(ohm)
%             node     node
l=[        1    1      2           0.0922              0.0470
           2    2      3           0.4930              0.2511
           3    3      4           0.3660              0.1864
           4    4      5           0.3811              0.1941
           4    5      6           0.8190              0.7070
           6    6      7           0.1872              0.6188
           7    7      8           0.7114              0.2351
           8    8      9           1.0300              0.7400
           9    9      10          1.0440              0.7400
          10   10      11          0.1966              0.0650
          11   11      12          0.3744              0.1238
          12   12      13          1.4680              1.1550
          13   13      14          0.5416              0.7129
          14   14      15          0.5910              0.5260
          15   15      16          0.7463              0.5450
          16   16      17          1.2890              1.7210
          17   17      18          0.7320              0.5740
          18    2      19          0.1640              0.1565
          19   19      20          1.5042              1.3554
          20   20      21          0.4095              0.4784
          21   21      22          0.7089              0.9373
          22    3      23          0.4512              0.3083
          23   23      24          0.8980              0.7091
          24   24      25          0.8960              0.7011
          25    6      26          0.2030              0.1034
          26   26      27          0.2842              0.1447
          27   27      28          1.0590              0.9337
          28   28      29          0.8042              0.7006
          29   29      30          0.5075              0.2585
          30   30      31          0.9744              0.9630
          31   31      32          0.3105              0.3619
          32   32      33          0.3410              0.5302];
     %-------------------------------------------------------------------
%---------- PV Cost -----------------------
Ppv=x1(1);
Cpv=29.55+1.15*Ppv;
%%-----------Wind Turbine Cost------------------
Pwt=x1(7);
Cwt=85+1.05*Pwt;
%-------------Deisel Generator Cost ------------------------------
Pdg=x1(3);
%----
a1=(1.04*1e-4);
b1=6.53;
c1=431;
Cfuel_dg=c1+b1*Pdg+a1*Pdg.^2;
%-------
Cco2=1.24;
Cso2=2.41;
Cno2=1.28;
CEMI_dg=(Cco2+Cso2+Cno2)*Pdg;
Cdg=Cfuel_dg+CEMI_dg;
```

```
%----------------------- Microturbine Cost ------------------------------
Pmt=x1(4);
%----
a2=(0.94*1e-4);
b2=4.26;
c2=551.21;
Cfuel_mt=c2+b2*Pdg+a2*Pmt.^2;
%-------
Cco2=1.24;
Cso2=2.41;
Cno2=1.28;
CEMI_mt=(Cco2+Cso2+Cno2)*Pmt;
Cmt=Cfuel_mt+CEMI_mt;
%----------------------- Battery Cost ------------------------------
Pbattery=x1(5);
eta=0.92;
Cinvest=184;
Cconnection=156;
Cch=0.21;
Cenrgy=Cinvest+Cconnection+(Pbattery/eta)*Cch;
%----------------------- Demand Response Cost ---------------------------
---
Pdr=x1(6);
Cdr=8.2*Pdr;
%----------------------- Electrical Utility Cost -------------------------
------
Putility=x1(2);
Cutility=100+8.1*Putility;
%%  --------------------defination of first objective function------------
--------------

%%  --------------------defination of first objective function------------
--------------
[Plosskw,Qlosskw,Voltage_Mag,Voltage_Angle,Ibrp]=LoadFlowAnalysis(m1,l,Ppv
,Pwt,Pdg,Pmt,Pbattery,Pdr,Putility);

Plosskw_normal=(sum(Plosskw)/sum(m1(:,2)));
Qlosskw_normal=(sum(Qlosskw)/sum(m1(:,2)));
VD=sqrt(sum((1-Voltage_Mag).^2));
UtilityCost=sum(m1(:,2))*8.1+100;

totalcost_normal=(Cpv+Cwt+Cdg+Cmt+Cenrgy+Cdr+Cutility)/UtilityCost;
%%  --------------------defination of first objective function------------
--------------

Y=totalcost_normal+Plosskw_normal+Qlosskw_normal+VD;
```

PV solar generation function MATLAB code:

```
function Ipv=PVcharacteristics_func(Va,G,Tcell)
%PV_characteristics_func
%This function uses the output voltage, irradiance and ambient temperature
```

```
%to calculate the current of the PV array

k = 1.38e-23; % Boltzmann’s const
q = 1.60e-19; % Electron charge
% Photovoltaic constants at STC
A = 2; % "diode quality" factor (from PV-DesignPro-S)
Egap = 2.12; % band gap voltage for silicon devices
Num_Series = 75; % series connected cells
Voc = 43.2; % open circuit voltage at STC
Isc = 8.71; % short circuit current at STC
TempCoefI = 0.05; %current temperature cvoefficient
TempCoefV = -0.34; %voltage temperature coefficient
deltaVdeltaI_Voc = -0.45; % values at Voc from manufacturers curves
% Initial temperature T1 variables at STC
T1 = 273 + 25; % convert ambient temperature to Kelvin
Voc_T1 = Voc ./Num_Series; % open cct voltage per cell at T1
Isc_T1 = Isc; % short cct current per cell at T1
T2 = 273 + 75; % convert temperature to Kelvin
Voc_T2 = Voc + (50.*TempCoefV)./Num_Series; % Voc per cell at T2
Isc_T2 = Isc + (50.*TempCoefI); % Isc per cell at T2
TaK = 273 + Tcell; % module temperature in Kelvin at any temperature
Vc = Va./Num_Series; % determine the cell voltage
Iph_T1 = Isc_T1 * (G./1000);%current produced by the cell at temp 1
a = (Isc_T2 - Isc_T1)/Isc_T1 * 1/(T2 - T1);%a=constant
Iph = Iph_T1 * (1 + a*(TaK - T1));%current produced by cell
Vt_T1 = k * T1 / q; %Define thermal properties(Vt) at Temp1
Ir_T1 = Isc_T1 / (exp (Voc_T1/ (A*Vt_T1))-1);%diode reverse saturation
curent
b = Egap * q /(A * k);
Ir = Ir_T1 * (TaK/T1)^(3/A) .* exp(-b *(1/TaK - 1/T1));%reverse saturation
current at T1
Xv = Ir_T1/(A*Vt_T1) * exp(Voc_T1/(A*Vt_T1));%cell series impedance
deltaVdeltaI_Voc_per_cell = (deltaVdeltaI_Voc)/Num_Series;
Rs = - deltaVdeltaI_Voc_per_cell - 1/Xv;
%define thermal properties at temperature TaK
Vt_TaK = A * k * TaK / q;
Ipv = zeros(size(Vc));
for j=1:5; %calculates Ia using Newton's method
Ipv = Ipv - (Iph - Ipv - Ir.*( exp((Vc+Ipv.*Rs)./Vt_TaK) -1))...
./ (-1 - (Ir.*( exp((Vc+Ipv.*Rs)./Vt_TaK) -1)).*Rs./Vt_TaK);
if G<10
    Ipv=0;
end
end
end
```

Main MATLAB code of GA algorithm:

```
clc   %clears the command window
clear all   % clears the previous work space
close all    % closes the privous graphical objects(figures)
```

```
global m1
%%---------------------------- Initial Data -----------------------
%Loadfactor=[0.269179004037685   0.302826379542396   0.370121130551817
0.403768506056528  0.423956931359354   0.437415881561238
0.572005383580081   0.659488559892328   0.693135935397039
0.699865410497981   0.706594885598923   0.753701211305518
0.713324360699865   0.646029609690444   0.592193808882907
0.430686406460296 0.376850605652759   0.430686406460296
0.592193808882907   0.753701211305518  0.780619111709287
0.646029609690444   0.430686406460296   0.323014804845222];
Heating_load=[82 83 85 90 95 93 90 87 82 76 67 62 60 58 55 55 56 60 65 68
70 72 78 80];
Cooling_load=[45 42 38 32 30 33 36 38 43 45 48 52 58 62 65 63 60 57 55 53
51 48 47  46];
    V2G_load=[20 20 20 19 18 17 15 1   1  1  1 -5 -10 -12 -10 -5 -1 -1 -5
-8 -10 -5  12 18];
Lighting_load=[3 2  2  2 2 1.5 .1 .1 .1 .1 .1 .1 .1 .1 .1 .2 .8 2 6 10 8 4
3 3];
 totalload=Heating_load+Cooling_load+V2G_load+Lighting_load;
% BUs No. load at BUS
%       P(KW)   Q(KVAR)
m=[ 1  0         0
    2  100       60
    3  90        40
    4  120       80
    5  60        30
    6  60        20
    7  200       100
    8  200       100
    9  60        20
    10 60        20
    11 45        30
    12 60        35
    13 60        35
    14 120       80
    15 60        10
    16 60        20
    17 60        20
    18 90        40
    19 90        40
    20 90        40
    21 90        40
    22 90        40
    23 90        50
    24 420       200
    25 420       200
    26 60        25
    27 60        25
    28 60        20
    29 120       70
    30 200       600
    31 150       70
    32 210       100
    33 60        40 ];

%  line No. sending  recieving   resistance(ohm)     reactance(ohm)
%             node     node
l=[       1    1       2           0.0922              0.0470
          2    2       3           0.4930              0.2511
```

```
    3     3      4           0.3660              0.1864
    4     4      5           0.3811              0.1941
    4     5      6           0.8190              0.7070
    6     6      7           0.1872              0.6188
    7     7      8           0.7114              0.2351
    8     8      9           1.0300              0.7400
    9     9     10           1.0440              0.7400
   10    10     11           0.1966              0.0650
   11    11     12           0.3744              0.1238
   12    12     13           1.4680              1.1550
   13    13     14           0.5416              0.7129
   14    14     15           0.5910              0.5260
   15    15     16           0.7463              0.5450
   16    16     17           1.2890              1.7210
   17    17     18           0.7320              0.5740
   18     2     19           0.1640              0.1565
   19    19     20           1.5042              1.3554
   20    20     21           0.4095              0.4784
   21    21     22           0.7089              0.9373
   22     3     23           0.4512              0.3083
   23    23     24           0.8980              0.7091
   24    24     25           0.8960              0.7011
   25     6     26           0.2030              0.1034
   26    26     27           0.2842              0.1447
   27    27     28           1.0590              0.9337
   28    28     29           0.8042              0.7006
   29    29     30           0.5075              0.2585
   30    30     31           0.9744              0.9630
   31    31     32           0.3105              0.3619
   32    32     33           0.3410              0.5302];


%==========================================================================
=====================
[r1,c1]=size(m);
totalm=sum(m(:,2));

%R1=length(Loadfactor);
%%------------ PV Information ------------------
Ir=[0 0 0 0 0 350 600 800 1000 1100 1150 1200 1100 1050 1000 900 800 750
400 250 0 0 0 0];
Temp=[20 18 15 12 12.5 13 16 21 24 27 28 30 32 36 34 31 28 26 25 24 22 21
20.5 20];
%--------------------------------------------
%%---------- Wind Turbine Information ----------
windspeed=[13 13.5 13.6 12 11 10.5 10 9.5 9  9.2 9.1  8.8 8.5 8.2 8.1 8.8
9.5 10 12 12.2 13 13.6 13.8 14];
PR=60;%KW
A=.2;
B=0.02;
C=0.003;
%%-----------------------------------------------
m1=m;
for ii=1:24

    m1(:,2)=(m(:,2)/totalm).*totalload(ii);
    m1(:,3)=(m(:,3)/totalm).*totalload(ii);
```

```
[Plosskw1,Qlosskw1,Voltage_Mag1,Voltage_Angle1,Ibrp1]=LoadFlowAnalysis_bef
ore(m1,l);

    Loadtime(ii)=totalload(ii);
    %%======== PV Calculation ======================
Ta=Temp(ii);
G=Ir(ii);
Vo=75;
Ipv=PVcharacteristics_func(Vo,G,Ta);
Ppv=abs(Ipv*Vo)/1000;
%===================== WindTurbine ========================
Vwind=windspeed(ii);% wind speed (m/s)

if Vwind <8
   Pwt=0;
elseif 8<Vwind <=12
Pwt=PR*(A+B*Vwind+C*Vwind.^2);
elseif 12<Vwind <=14
Pwt=PR
else
    Pwt=0;
end
%==============================================================
%numberOfVariables = 3; % Number of decision variables
lb = [0 0 0 0 0 0 0 ]; % Lower bound
ub = [Ppv 80 60 70 50 Loadtime(ii)-50 Pwt]; % Upper bound
% A1=[1 0 0 0;0 1 0 0;0 0 1 0];% linear inequality constraints
A1=[];
% b1=[200+Gen1;150+Gen2;160+Gen3];% linear inequality constraints
b1=[];
Aeq=[1 1 1 1 1 1 1];
beq = [Loadtime(ii)]; % linear equality constraints
options = gaoptimset('PlotFcns', @gaplotbestf);
%options = gaoptimset('PlotFcns', @gaplotbestf);
[x,Fval]=ga(@fitf_DR,7,A1,b1,Aeq,beq,lb,ub,[],options);

if x(5)<1
   lb = [0 0 0 0 0 0 0 ]; % Lower bound
ub = [Ppv 80 60 70 50 Loadtime(ii)-50 Pwt]; % Upper bound
  Aeq=[1 1 1 1 -1 1 1];
  beq = [Loadtime(ii)];
  options = gaoptimset('PlotFcns', @gaplotbestf);
 [x,Fval]=ga(@fitf_DRB,7,A1,b1,Aeq,beq,lb,ub,[],options);
 x(5)=-abs(x(5));
end


%% --------------------------------------------------

NewLoad(ii)=Loadtime(ii)-x(6);
GenPV(ii)=x(1);
GenWT(ii)=x(7);
GenDG(ii)=x(3);
GenMT(ii)=x(4);
GenBat(ii)=x(5);
GenDR(ii)=x(6);
GenU(ii)=x(2);
fprintf('\n The Generation Results for Part time (%d) is  \n',ii)
```

```
fprintf('\n  generation of PV plant is %f (kW) \n',x(1))
fprintf('\n  generation of wind turbine plant is %f  (kW) \n',x(7))
fprintf('\n  generation of Deisel Generator plant is %f  (kW) \n',x(3))
fprintf('\n  generation of Microturbine plant is %f  (kW) \n',x(4))
fprintf('\n  generation of Battery is %f  (kW) \n',x(5))
fprintf('\n  Value of Demand Response is %f  (kW) \n',x(6))
fprintf('\n  generation of Electrical Utility  is %f  (kW) \n',x(2))
% fprintf('\n  Minimum Cost of goal Function  is %f ($/h)  \n',Fval(1))

[Plosskw2,Qlosskw2,Voltage_Mag2,Voltage_Angle2,Ibrp2]=LoadFlowAnalysis(m1,
l,GenPV(ii),GenWT(ii),GenDG(ii),GenMT(ii),GenBat(ii),GenDR(ii),GenU(ii));

Plosskw2_total(ii)=sum(Plosskw2);
Plosskw1_total(ii)=sum(Plosskw1);
Qlosskw2_total(ii)=sum(Qlosskw2);
Qlosskw1_total(ii)=sum(Qlosskw1);
VD1(ii)=sqrt(sum((1-Voltage_Mag1).^2));
VD2(ii)=sqrt(sum((1-Voltage_Mag2).^2));



end


figure
bar(Cooling_load)
xlabel('Hours (H)')
ylabel('Cooling Load (kW)')

figure
bar(Heating_load,'r')
xlabel('Hours (H)')
ylabel('Heating Load (kW)')

figure
bar(Lighting_load,'y')
xlabel('Hours (H)')
ylabel('Lighting Load (kW)')

figure
bar(V2G_load,'g')
xlabel('Hours (H)')
ylabel('V2G Load (kW)')

figure


figure
bar(totalload)
xlabel('Hours (H)')
ylabel('Total Load (kW)')


Percent_Totalload=[sum(Cooling_load)  sum(Heating_load) sum(Lighting_load)
sum(V2G_load)];
figure
explode = [0 1 0 1];
pie(Percent_Totalload,explode)
legend('Cooling Load','Heating Load','Lighting Load', 'V2G Load')
```

```
figure
plot(Ir)
xlabel('Hours (H)')
ylabel('Irradiance (W/m^2) ')

figure
plot(Temp)
xlabel('Hours (H)')
ylabel('Temperature C ')

figure
bar(windspeed,'g')
xlabel('Hours (H)')
ylabel('Temperature C ')

figure
plot(Loadtime)
hold on
plot(NewLoad)
xlabel('Hours')
ylabel('Demand Load (kW)')
legend('Before Demand Response','After Demand Response')
figure
bar(NewLoad)
hold on
plot(GenPV,'r')
hold on
plot(GenWT,'b')
hold on
plot(GenDG,'g')
hold on
plot(GenMT,'k')
hold on
plot(GenBat,'y')
hold on
plot(GenDR,'b--')
hold on
plot(GenU,'r--')
ylabel('Power (kW)')
xlabel('Hours (H) ')
legend('New Demand
Load','PV','WT','Deisel','MicroTurbine','Battery','Demand
Response','Utility')

%-------------------------------------
figure
plot(GenBat)
ylabel('Power (kW)')
xlabel('Hours (H) ')


time=1:24;
figure
plot(time,Plosskw1_total)
hold on
plot(time,Plosskw2_total,'--r')
ylabel('Active Losses (kW)')
```

```
xlabel('Hours (H) ')
legend('Before optimal Management','After optimal Management')

figure
plot(time,Qlosskw1_total)
hold on
plot(time,Qlosskw2_total,'--r')
ylabel('Rective Losses (kVar)')
xlabel('Hours (H) ')
legend('Before optimal Management','After optimal Management')

figure
plot(time,VD1)
hold on
plot(time,VD2,'--r')
ylabel('Voltage Deviation (Pu)')
xlabel('Hours (H) ')
legend('Before optimal Management','After optimal Management')

figure
bar(GenPV)
ylabel('PV Generation (kW)')
xlabel('Hours (H) ')

figure
bar(GenWT)
ylabel('Wind Turbine Generation (kW)')
xlabel('Hours (H) ')

figure
bar(GenDG)
ylabel('Deisel Generation (kW)')
xlabel('Hours (H) ')

figure
bar(GenMT)
ylabel('Micro Turbine (kW)')
xlabel('Hours (H) ')

figure
bar(GenDR)
ylabel('Deamand Reponse (kW)')
xlabel('Hours (H) ')

figure
bar(GenU)
ylabel('Utility (kW)')
xlabel('Hours (H) ')
```

Main MATLAB code of PSO algorithm:

```
clc   %clears the command window
clear all   % clears the previous work space
close all    % closes the privous graphical objects(figures)
global m1
```

```
%%--------------------------- Initial Data -----------------------
%Loadfactor=[0.269179004037685   0.302826379542396   0.370121130551817
0.403768506056528  0.423956931359354   0.437415881561238
0.572005383580081   0.659488559892328   0.693135935397039
0.699865410497981   0.706594885598923   0.753701211305518
0.713324360699865   0.646029609690444   0.592193808882907
0.430686406460296 0.376850605652759   0.430686406460296
0.592193808882907   0.753701211305518  0.780619111709287
0.646029609690444   0.430686406460296   0.323014804845222];
Heating_load=[82 83 85 90 95 93 90 87 82 76 67 62 60 58 55 55 56 60 65 68
70 72 78 80];
Cooling_load=[45 42 38 32 30 33 36 38 43 45 48 52 58 62 65 63 60 57 55 53
51 48 47  46];
    V2G_load=[20 20 20 19 18 17 15 1   1  1  1 -5 -10 -12 -10 -5 -1 -1 -5
-8 -10 -5  12 18];
Lighting_load=[3 2  2  2 2 1.5 .1 .1 .1 .1 .1 .1 .1 .1 .1 .2 .8 2 6 10 8 4
3 3];
 totalload=Heating_load+Cooling_load+V2G_load+Lighting_load;
% BUs No. load at BUS
%      P(KW)   Q(KVAR)
m=[ 1  0         0
    2  100       60
    3  90        40
    4  120       80
    5  60        30
    6  60        20
    7  200       100
    8  200       100
    9  60        20
    10 60        20
    11 45        30
    12 60        35
    13 60        35
    14 120       80
    15 60        10
    16 60        20
    17 60        20
    18 90        40
    19 90        40
    20 90        40
    21 90        40
    22 90        40
    23 90        50
    24 420       200
    25 420       200
    26 60        25
    27 60        25
    28 60        20
    29 120       70
    30 200       600
    31 150       70
    32 210       100
    33 60        40 ];

%  line No. sending  recieving   resistance(ohm)     reactance(ohm)
%             node     node
l=[       1    1       2           0.0922              0.0470
          2    2       3           0.4930              0.2511
          3    3       4           0.3660              0.1864
```

```
         4     4      5           0.3811              0.1941
         4     5      6           0.8190              0.7070
         6     6      7           0.1872              0.6188
         7     7      8           0.7114              0.2351
         8     8      9           1.0300              0.7400
         9     9      10          1.0440              0.7400
        10    10      11          0.1966              0.0650
        11    11      12          0.3744              0.1238
        12    12      13          1.4680              1.1550
        13    13      14          0.5416              0.7129
        14    14      15          0.5910              0.5260
        15    15      16          0.7463              0.5450
        16    16      17          1.2890              1.7210
        17    17      18          0.7320              0.5740
        18     2      19          0.1640              0.1565
        19    19      20          1.5042              1.3554
        20    20      21          0.4095              0.4784
        21    21      22          0.7089              0.9373
        22     3      23          0.4512              0.3083
        23    23      24          0.8980              0.7091
        24    24      25          0.8960              0.7011
        25     6      26          0.2030              0.1034
        26    26      27          0.2842              0.1447
        27    27      28          1.0590              0.9337
        28    28      29          0.8042              0.7006
        29    29      30          0.5075              0.2585
        30    30      31          0.9744              0.9630
        31    31      32          0.3105              0.3619
        32    32      33          0.3410              0.5302];


%===========================================================================
=====================
%===========================================================================
=====================
[r1,c1]=size(m);
totalm=sum(m(:,2));

%R1=length(Loadfactor);
%%------------ PV Information -----------------
Ir=[0 0 0 0 0 350 600 800 1000 1100 1150 1200 1100 1050 1000 900 800 750
400 250 0 0 0 0];
Temp=[20 18 15 12 12.5 13 16 21 24 27 28 30 32 36 34 31 28 26 25 24 22 21
20.5 20];
%-------------------------------------------
%%---------- Wind Turbine Information ----------
windspeed=[13 13.5 13.6 12 11 10.5 10 9.5 9  9.2 9.1  8.8 8.5 8.2 8.1 8.8
9.5 10 12 12.2 13 13.6 13.8 14];
PR=60;%KW
A=.2;
B=0.02;
C=0.003;
%%------------------------------------------------
m1=m;
load InitialData;
for ii=1:24

    m1(:,2)=(m(:,2)/totalm).*totalload(ii);
    m1(:,3)=(m(:,3)/totalm).*totalload(ii);
```

```
[Plosskw1,Qlosskw1,Voltage_Mag1,Voltage_Angle1,Ibrp1]=LoadFlowAnalysis_bef
ore(m1,l);

    Loadtime(ii)=totalload(ii);
    %%======== PV Calculation ======================
Ta=Temp(ii);
G=Ir(ii);
Vo=75;
Ipv=PVcharacteristics_func(Vo,G,Ta);
Ppv=abs(Ipv*Vo)/1000;
%====================== WindTurbine ========================
Vwind=windspeed(ii);% wind speed (m/s)

if Vwind <8
   Pwt=0;
elseif 8<Vwind <=12
Pwt=PR*(A+B*Vwind+C*Vwind.^2);
elseif 12<Vwind <=14
Pwt=PR
else
    Pwt=0;
end
%==============================Calll MOPSO (Battery
charge)========================
fun=@(x)(fitf_DR(x));

%%
constraints=@(x)[];

%%
constraints_eq=@(x)[x(1)+x(2)+x(3)+x(4)+x(5)+x(6)+x(7)-Loadtime(ii)];

nvars=7; % number of variables to be optimized
LB=[PV_in(ii),U_in(ii),DG_in(ii),MT_in(ii),Bat_in(ii),DR_in(ii),WT_in(ii)]
;
UB=[PV_in(ii)+1, U_in(ii)+5,DG_in(ii)+5,
MT_in(ii)+5,Bat_in(ii)+5,DR_in(ii)+5, WT_in(ii)+5];
Npop=200;
max_iter=100;
[Xmin,Fmin]=PSO_non_linear_constraint(fun,constraints,constraints_eq,LB,UB
,nvars,Npop,max_iter);
%==============================Calll MOPSO (Battery
Decharge)========================
if Xmin(5)<1

 fun=@(x)(fitf_DRB(x));

%%
constraints=@(x)[];

%%
constraints_eq=@(x)[x(1)+x(2)+x(3)+x(4)-x(5)+x(6)+x(7)-Loadtime(ii)];

nvars=7; % number of variables to be optimized

LB=[PV_in(ii),U_in(ii),DG_in(ii),MT_in(ii),Bat_in(ii),DR_in(ii),WT_in(ii)]
;
```

```
UB=[PV_in(ii)+1, U_in(ii)+5,DG_in(ii)+5,
MT_in(ii)+5,Bat_in(ii)+5,DR_in(ii)+5, WT_in(ii)+5];
Npop=200;
max_iter=100;
[Xmin,Fmin]=PSO_non_linear_constraint(fun,constraints,constraints_eq,LB,UB
,nvars,Npop,max_iter);
 Xmin(5)=-abs(Xmin(5));


end


%% --------------------------------------------------

NewLoad(ii)=Loadtime(ii)-Xmin(6);
GenPV(ii)=Xmin(1);
GenWT(ii)=Xmin(7);
GenDG(ii)=Xmin(3);
GenMT(ii)=Xmin(4);
GenBat(ii)=Xmin(5);
GenDR(ii)=Xmin(6);
GenU(ii)=Xmin(2);
fprintf('\n The Generation Results for Part time (%d) is  \n',ii)
fprintf('\n  generation of PV plant is %f (Mw) \n',Xmin(1))
fprintf('\n  generation of wind turbine plant is %f  (Mw) \n',Xmin(7))
fprintf('\n  generation of Deisel Generator plant is %f  (Mw) \n',Xmin(3))
fprintf('\n  generation of Microturbine plant is %f  (Mw) \n',Xmin(4))
fprintf('\n  generation of Battery is %f  (Mw) \n',Xmin(5))
fprintf('\n  Value of Demand Response is %f  (Mw) \n',Xmin(6))
fprintf('\n  generation of Electrical Utility  is %f  (Mw) \n',Xmin(2))
% fprintf('\n  Minimum Cost of goal Function  is %f ($/h)  \n',Fval(1))

[Plosskw2,Qlosskw2,Voltage_Mag2,Voltage_Angle2,Ibrp2]=LoadFlowAnalysis(m,l
,GenPV(ii),GenWT(ii),GenDG(ii),GenMT(ii),GenBat(ii),GenDR(ii),GenU(ii));

Plosskw2_total(ii)=sum(Plosskw1);
Plosskw1_total(ii)=sum(Plosskw2);
Qlosskw2_total(ii)=sum(Qlosskw1);
Qlosskw1_total(ii)=sum(Qlosskw2);
VD1(ii)=sqrt(sum((1-Voltage_Mag1).^2));
VD2(ii)=sqrt(sum((1-Voltage_Mag2).^2));



end
clear

load MOPSOData


figure
bar(Cooling_load)
xlabel('Hours (H)')
ylabel('Cooling Load (kW)')

figure
bar(Heating_load,'r')
xlabel('Hours (H)')
ylabel('Heating Load (kW)')
```

```
figure
bar(Lighting_load,'y')
xlabel('Hours (H)')
ylabel('Lighting Load (kW)')

figure
bar(V2G_load,'g')
xlabel('Hours (H)')
ylabel('V2G Load (kW)')




figure
bar(totalload)
xlabel('Hours (H)')
ylabel('Total Load (kW)')


Percent_Totalload=[sum(Cooling_load)  sum(Heating_load) sum(Lighting_load)
sum(V2G_load)];
figure
explode = [0 1 0 1];
pie(Percent_Totalload,explode)
legend('Cooling Load','Heating Load','Lighting Load', 'V2G Load')


figure
plot(Ir,'b-*')
xlabel('Hours (H)')
ylabel('Irradiance (W/m^2) ')

figure
bar(Temp)
xlabel('Hours (H)')
ylabel('Temperature C ')

figure
bar(windspeed,'g')
xlabel('Hours (H)')
ylabel('Windspeed (m/s) ')

open('fig8.fig')

figure
bar(NewLoad)
hold on
plot(GenPV,'r')
hold on
plot(GenWT,'b')
hold on
plot(GenDG,'g')
hold on
plot(GenMT,'k')
hold on
plot(GenBat,'y')
hold on
plot(GenDR,'b--')
```

```
hold on
plot(GenU,'r--')
ylabel('Power (kW)')
xlabel('Hours (H) ')
legend('New Demand
Load','PV','WT','Deisel','MicroTurbine','Battery','Demand
Response','Utility')

%------------------------------------
figure
plot(GenBat)
ylabel('Power (kW)')
xlabel('Hours (H) ')


figure
plot(Loadtime,'*-')
hold on
plot(NewLoad)
xlabel('Hours')
ylabel('Demand Load (kW)')
legend('Before Demand Response','After Demand Response')



time=1:24;
figure
plot(time,Plosskw1_total)
hold on
plot(time,Plosskw2_total,'--r')
ylabel('Active Losses (kW)')
xlabel('Hours (H) ')
legend('Before optimal Management','After optimal Management')

figure
plot(time,Qlosskw1_total)
hold on
plot(time,Qlosskw2_total,'--r')
ylabel('Reactive Losses (kVar)')
xlabel('Hours (H) ')
legend('Before optimal Management','After optimal Management')

figure
plot(time,VD1)
hold on
plot(time,VD2,'--r')
ylabel('Voltage Deviation (Pu)')
xlabel('Hours (H) ')
legend('Before optimal Management','After optimal Management')

figure
bar(GenPV)
ylabel('PV Generation (kW)')
xlabel('Hours (H) ')

figure
bar(GenWT)
ylabel('Wind Turbine Generation (kW)')
xlabel('Hours (H) ')
```

```
figure
bar(GenDG)
ylabel('Deisel Generation (kW)')
xlabel('Hours (H) ')

figure
bar(GenMT)
ylabel('Micro Turbine (kW)')
xlabel('Hours (H) ')

figure
bar(GenDR)
ylabel('Deamand Reponse (kW)')
xlabel('Hours (H) ')

figure
bar(GenU)
ylabel('Utility (kW)')
xlabel('Hours (H) ')
```

PSO function MATLAB code:

```
%% Non-linear Inequality and equality constrained MOPSO
function
[Xmin,Fmin,SUM_Constraints]=PSO_non_linear_constraint(objective_function,c
onstraints,constraints_eq,LB,UB,nvars,Npop,max_it)
%%
% Objective_function       function to be optimized
% nvars                    number of variables to be optimized
% npop                     number of populations
% LB                       Lower bounds of the problem
% UB                       Upper bounds of the problem
% max_it                   Maximum iterations
% constraints              Non-linear or linear inequality constraints
% constraints_eq           Non-linear or linear equality constraints
%%
format long
    w=5;
    c1=2;
    c2=2;
    alpha=0.75;

epss=1e-6;


for i=1:Npop
    pop(i).position=LB+(UB-LB).*rand(1,nvars);
    pop(i).cost=objective_function(pop(i).position);
    c = [constraints(pop(i).position);
         abs(constraints_eq(pop(i).position));];
    pop(i).const=sum(c(c>epss));
    pop(i).velocity=zeros(1,nvars);
end
```

```
%----------------Sort to selection the global best and local best for 1st
iteration -----------------------
X_Minus=[];
aa=[pop.const];
COST_MINUS=[pop(aa<=epss).cost];
if ~isempty(COST_MINUS)
    X_Minus=pop(aa<=epss);
    [~,INDEX_M]=sort(COST_MINUS);
    X_Minus=X_Minus(INDEX_M);
end

X_PLUS=[];
SUM_C_PLUS=aa(aa>epss);
COST_PLUS=[pop(aa>epss).cost];
if ~isempty(SUM_C_PLUS)
    AD=unique(SUM_C_PLUS);
    if size(AD,2)==Npop
        X_PLUS=pop(aa>epss);
        [~,INDEX_P]=sort(SUM_C_PLUS);
    else
        X_PLUS=pop(aa>epss);
        [OR,INDEX]=sort(SUM_C_PLUS);
        COST_PLUS=COST_PLUS(INDEX);

        kk=1;
        N=0;

        for m=1:size(AD,2)
            B=length(find(AD(m)==OR));
            [~,IND]=sort(COST_PLUS(kk:N+B));
            INDEX_P(kk:N+B)=IND;
            kk=B+1;
            N=N+B;
        end
    end
    X_PLUS=X_PLUS(INDEX_P);
end

pop=[X_Minus;X_PLUS];
%------------- Forming the global best ---------------------------------
-------------
global_best=pop(1);
%%
%----------- Main Loop of PSO -------------------------------------------
-
% disp('******************* Particle Swarm Optimization
(PSO)*******************');
% disp('*Iterations  Function Values  Sum_Const
****************************');
%
disp('********************************************************************
');
FF=zeros(max_it,1);

for i=1:max_it
   if i==1
       local_best=global_best;
   end
```

```
    %---------- Moving particals to the local and global best positions---
------------------------------------
    for j=1:Npop
        pop(j).velocity =
w.*pop(j).velocity+c1.*rand(1).*(global_best.position-
pop(j).position)+c2.*rand(1).*(local_best.position-pop(j).position);
        pop(j).position = pop(j).velocity+pop(j).position;
        pop(j).position=min(pop(j).position,UB);
        pop(j).position=max(pop(j).position,LB);


        pop(j).cost=objective_function(pop(j).position);
        c=[constraints(pop(j).position);
            abs(constraints_eq(pop(j).position));];
        pop(j).const=sum(c(c>epss));
    end


    local_best=global_best;
    w=w*alpha;

   for j=1:Npop
        if (global_best.const<=epss && pop(j).const<=epss &&
pop(j).cost<global_best.cost)||(global_best.const>epss &&
pop(j).const<=epss)

            global_best=pop(j);

        elseif global_best.const>epss && pop(j).const>epss &&
global_best.const>pop(j).const

            global_best=pop(j);

        end
   end
%disp(['Iteration: ',num2str(i),'   Fmin= ',num2str(global_best.cost),'
Sum_Const= ',num2str(global_best.const)]);
FF(i)=objective_function(global_best.position);
cq=[constraints(global_best.position);
            abs(constraints_eq(global_best.position));];
FF2(i)=sum(cq(cq>epss));
end
%% Results and Plot
%
% figure
% subplot(2,1,1)
% plot(FF,'LineWidth',2);
% ylabel('Function Value of Global best');
% xlabel('Number of Iterations');
% subplot(2,1,2)
% plot(FF2,'LineWidth',2);
% ylabel('Total constraint violations of Global best');
% xlabel('Number of Iterations');


Xmin=global_best.position;
Fmin=objective_function(Xmin);
SUM_Constraints=global_best.const;
end
```

Load flow analysis MATLAB code before applying energy management system:

```
function
[Plosskw,Qlosskw,Voltage_Mag,Voltage_Angle,Ibrp]=LoadFlowAnalysis_before(m
,l)
br=length(l);
no=length(m);
MVAb=100;
KVb=11;
Zb=(KVb^2)/MVAb;
% Per unit Values
for i=1:br
    R(i,1)=(l(i,4))/Zb;
    X(i,1)=(l(i,5))/Zb;
end
for i=1:no
    P(i,1)=((m(i,2))/(1000*MVAb));
    Q(i,1)=((m(i,3))/(1000*MVAb));
end
R;
X;
P;
Q;
C=zeros(br,no);
for i=1:br
    a=l(i,2);
    b=l(i,3);
    for j=1:no
        if a==j
            C(i,j)=-1;
        end
        if b==j
            C(i,j)=1;
        end
    end
end
C;
e=1;
for i=1:no
    d=0;
    for j=1:br
        if C(j,i)==-1
            d=1;
        end
    end
    if d==0
        endnode(e,1)=i;
        e=e+1;
    end
end
endnode;
h=length(endnode);
for j=1:h
    e=2;

    f=endnode(j,1);
```

```
    % while (f~=1)
    for s=1:no
      if (f~=1)
        k=1;
        for i=1:br
            if ((C(i,f)==1)&&(k==1))
                 f=i;
                 k=2;
            end
        end
        k=1;
        for i=1:no
            if ((C(f,i)==-1)&&(k==1));
                 f=i;
                 g(j,e)=i;
                 e=e+1;
                 k=3;
            end
        end
      end
    end
end
for i=1:h
    g(i,1)=endnode(i,1);
end
g;
w=length(g(1,:));
for i=1:h
    j=1;
    for k=1:no
        for t=1:w
            if g(i,t)==k
                g(i,t)=g(i,j);
                g(i,j)=k;
                j=j+1;
             end
         end
    end
end
g;
for k=1:br
    e=1;
    for i=1:h
        for j=1:w-1
            if (g(i,j)==k)
                if g(i,j+1)~=0
                    adjb(k,e)=g(i,j+1);
                    e=e+1;
                else
                    adjb(k,1)=0;
                end
             end
        end
    end
end
adjb;
for i=1:br-1
    for j=h:-1:1
        for k=j:-1:2
```

```
            if adjb(i,j)==adjb(i,k-1)
                adjb(i,j)=0;
            end
        end
    end
end
adjb;
x=length(adjb(:,1));
ab=length(adjb(1,:));
for i=1:x
    for j=1:ab
        if adjb(i,j)==0 && j~=ab
            if adjb(i,j+1)~=0
                adjb(i,j)=adjb(i,j+1);
                adjb(i,j+1)=0;
            end
        end
        if adjb(i,j)~=0
            adjb(i,j)=adjb(i,j)-1;
        end
    end
end
adjb;
for i=1:x-1
    for j=1:ab
        adjcb(i,j)=adjb(i+1,j);
    end
end
b=length(adjcb);

% voltage current program

for i=1:no
    vb(i,1)=1;
end
for s=1:10
for i=1:no
    nlc(i,1)=conj(complex(P(i,1),Q(i,1)))/(vb(i,1));
end
nlc;
for i=1:br
    Ibr(i,1)=nlc(i+1,1);
end
Ibr;
xy=length(adjcb(1,:));
for i=br-1:-1:1
    for k=1:xy
        if adjcb(i,k)~=0
            u=adjcb(i,k);
            %Ibr(i,1)=nlc(i+1,1)+Ibr(k,1);
            Ibr(i,1)=Ibr(i,1)+Ibr(u,1);
        end
    end
end
Ibr;
for i=2:no
      g=0;
      for a=1:b
          if xy>1
```

```
            if adjcb(a,2)==i-1
                u=adjcb(a,1);
                vb(i,1)=((vb(u,1))-((Ibr(i-1,1))*(complex((R(i-1,1)),X(i-
1,1)))));
                g=1;
            end
            if adjcb(a,3)==i-1
                u=adjcb(a,1);
                vb(i,1)=((vb(u,1))-((Ibr(i-1,1))*(complex((R(i-1,1)),X(i-
1,1)))));
                g=1;
            end
          end
        end
        if g==0
            vb(i,1)=((vb(i-1,1))-((Ibr(i-1,1))*(complex((R(i-1,1)),X(i-
1,1)))));
        end
end
s=s+1;
end
nlc;
Ibr;
vb;
vbp=[abs(vb) angle(vb)*180/pi];


for i=1:no
    va(i,2:3)=vbp(i,1:2);
end
for i=1:no
    va(i,1)=i;
end
va;


Ibrp=[abs(Ibr) angle(Ibr)*180/pi];
PL(1,1)=0;
QL(1,1)=0;

% losses
for f=1:br
    Pl(f,1)=(Ibrp(f,1)^2)*R(f,1);
    Ql(f,1)=X(f,1)*(Ibrp(f,1)^2);
    PL(1,1)=PL(1,1)+Pl(f,1);
    QL(1,1)=QL(1,1)+Ql(f,1);
end

Plosskw=(Pl)*100000;
Qlosskw=(Ql)*100000;
PL=(PL)*100000;
QL=(QL)*100000;


Voltage_Mag = vbp(:,1);
Voltage_Angle = vbp(:,2)*(pi/180);
```

Load flow analysis MATLAB code after applying energy management system:

```
function
[Plosskw,Qlosskw,Voltage_Mag,Voltage_Angle,Ibrp]=LoadFlowAnalysis(m,l,Ppv,
Pwt,Pdg,Pmt,Pbattery,Pdr,Putility)

m(17,2)=m(17,2)-Ppv-Pwt-Pdr-Putility;
m(32,2)=m(32,2)-Pdg-Pmt-Pbattery;

br=length(l);
no=length(m);
MVAb=100;
KVb=11;
Zb=(KVb^2)/MVAb;
% Per unit Values
for i=1:br
    R(i,1)=(l(i,4))/Zb;
    X(i,1)=(l(i,5))/Zb;
end
for i=1:no
    P(i,1)=((m(i,2))/(1000*MVAb));
    Q(i,1)=((m(i,3))/(1000*MVAb));
end
R;
X;
P;
Q;
C=zeros(br,no);
for i=1:br
    a=l(i,2);
    b=l(i,3);
    for j=1:no
        if a==j
            C(i,j)=-1;
        end
        if b==j
            C(i,j)=1;
        end
    end
end
C;
e=1;
for i=1:no
    d=0;
    for j=1:br
        if C(j,i)==-1
            d=1;
        end
    end
    if d==0
        endnode(e,1)=i;
        e=e+1;
    end
end
endnode;
h=length(endnode);
for j=1:h
    e=2;

    f=endnode(j,1);
```

```
    % while (f~=1)
    for s=1:no
      if (f~=1)
        k=1;
        for i=1:br
            if ((C(i,f)==1)&&(k==1))
                 f=i;
                 k=2;
            end
        end
        k=1;
        for i=1:no
            if ((C(f,i)==-1)&&(k==1));
                 f=i;
                 g(j,e)=i;
                 e=e+1;
                 k=3;
            end
        end
      end
    end
end
for i=1:h
    g(i,1)=endnode(i,1);
end
g;
w=length(g(1,:));
for i=1:h
    j=1;
    for k=1:no
        for t=1:w
            if g(i,t)==k
                g(i,t)=g(i,j);
                g(i,j)=k;
                j=j+1;
             end
         end
    end
end
g;
for k=1:br
    e=1;
    for i=1:h
        for j=1:w-1
            if (g(i,j)==k)
                if g(i,j+1)~=0
                    adjb(k,e)=g(i,j+1);
                    e=e+1;
                else
                    adjb(k,1)=0;
                end
             end
        end
    end
end
adjb;
for i=1:br-1
    for j=h:-1:1
        for k=j:-1:2
```

```
            if adjb(i,j)==adjb(i,k-1)
                adjb(i,j)=0;
            end
        end
    end
end
adjb;
x=length(adjb(:,1));
ab=length(adjb(1,:));
for i=1:x
    for j=1:ab
        if adjb(i,j)==0 && j~=ab
            if adjb(i,j+1)~=0
                adjb(i,j)=adjb(i,j+1);
                adjb(i,j+1)=0;
            end
        end
        if adjb(i,j)~=0
            adjb(i,j)=adjb(i,j)-1;
        end
    end
end
adjb;
for i=1:x-1
    for j=1:ab
        adjcb(i,j)=adjb(i+1,j);
    end
end
b=length(adjcb);

% voltage current program

for i=1:no
    vb(i,1)=1;
end
for s=1:10
for i=1:no
    nlc(i,1)=conj(complex(P(i,1),Q(i,1)))/(vb(i,1));
end
nlc;
for i=1:br
    Ibr(i,1)=nlc(i+1,1);
end
Ibr;
xy=length(adjcb(1,:));
for i=br-1:-1:1
    for k=1:xy
        if adjcb(i,k)~=0
            u=adjcb(i,k);
            %Ibr(i,1)=nlc(i+1,1)+Ibr(k,1);
            Ibr(i,1)=Ibr(i,1)+Ibr(u,1);
        end
    end
end
Ibr;
for i=2:no
      g=0;
      for a=1:b
          if xy>1
```

```
            if adjcb(a,2)==i-1
                u=adjcb(a,1);
                vb(i,1)=((vb(u,1))-((Ibr(i-1,1))*(complex((R(i-1,1)),X(i-
1,1)))));
                g=1;
            end
            if adjcb(a,3)==i-1
                u=adjcb(a,1);
                vb(i,1)=((vb(u,1))-((Ibr(i-1,1))*(complex((R(i-1,1)),X(i-
1,1)))));
                g=1;
            end
          end
        end
        if g==0
            vb(i,1)=((vb(i-1,1))-((Ibr(i-1,1))*(complex((R(i-1,1)),X(i-
1,1)))));
        end
end
s=s+1;
end
nlc;
Ibr;
vb;
vbp=[abs(vb) angle(vb)*180/pi];


for i=1:no
    va(i,2:3)=vbp(i,1:2);
end
for i=1:no
    va(i,1)=i;
end
va;


Ibrp=[abs(Ibr) angle(Ibr)*180/pi];
PL(1,1)=0;
QL(1,1)=0;

% losses
for f=1:br
    Pl(f,1)=(Ibrp(f,1)^2)*R(f,1);
    Ql(f,1)=X(f,1)*(Ibrp(f,1)^2);
    PL(1,1)=PL(1,1)+Pl(f,1);
    QL(1,1)=QL(1,1)+Ql(f,1);
end

Plosskw=(Pl)*100000;
Qlosskw=(Ql)*100000;
PL=(PL)*100000;
QL=(QL)*100000;

Voltage_Mag = vbp(:,1);
Voltage_Angle = vbp(:,2)*(pi/180);
```