OPTIMAL DESIGN, ANALYSIS, POSITIONING OF DGS AND ENERGY MANAGEMENT OF MICROGRIDS

Thesis submitted by

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"Statement of Originality"

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All information in this thesis have been obtained and presented in accordance with existing academic rules and ethical conduct. I declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work.
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Dedicated to my Family

ABSTRACT

The research introduces an innovative method for determining the most advantageous location and capacity of Distributed Generation (DG) units in a microgrid, with the main aim of reducing active power loss and overall expenditure. The presented work tackles the crucial problem of finding the best possible trade-off between system effectiveness and financial concerns. The suggested approach makes use of sophisticated optimization techniques to account for the intricate interactions between several elements, including DG unit characteristics, load demand profiles, and network topology. This technique dramatically lowers active power losses while also lowering the total cost of the system by carefully selecting the best locations and DG unit sizes in the microgrid. The present study advances sustainable energy systems by offering a holistic approach that strikes a balance between operational efficiency and economic feasibility, thereby improving microgrid performance.

Further to the above, another research that involves a novel approach to multi-party energy management of microgrids by integrating demand response mechanisms for both heat and electricity is investigated here. To meet the needs for heat and power simultaneously, the research takes a cooperative and coordinated strategy to maximize the use of energy resources in a microgrid context. Effective balancing between the production and consumption of heat and power by various microgrid participants is a feature of the suggested energy management system. Demand response techniques allow the microgrid to adjust to changing energy circumstances, improve total energy efficiency, and support sustainable energy methods.

In addition to the above, a concept of community microgrid has been investigated to optimize the cost of energy for the microgrid participants. A priority-based mutual power sharing between microgrids is investigated. The project aims to create a novel strategy that will enable microgrids in a community to share electricity more effectively. To dynamically distribute and share electric power among interlinked microgrids, the suggested system uses a

priority-based framework that takes into account variables including load demand, system reliability, and emergency/ importance of the load. The community microgrid may thus improve overall resilience by prioritizing electricity distribution based on the criticality of the demand in real time.

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List of Abbreviation

Distributed Energy Resources	DER
Renewable Energy Sources	RES
Microturbines	MT
Fuel Cells	FC
Photovoltaic	PV
Energy Storage Systems	ESS
Distributed Energy Resource	DER
Combined Heat and Power	CHP
Following Thermal Load	FTL
Following Electric Load	FEL
Following Hybrid Load	FHL
Microgrid Operator	MGO
Community Microgrid	CMG
Energy Management System	EMS
Community Microgrid Controller	CMGC
Smart Metering	SM
Interface Controllers	IC
Microgrid Controller	MC
Pulse Width Modulator	PWM
Power System	PS
DG Placement	DGP
Load Models	LMs
Radial DN	RDN
Optimal Power Flow	OPF

Distributed Renewable Generation	DRG
Metaheuristic Algorithms	MAs
Genetic Algorithm	GA
Particle Swarm Optimization	PSO
Grey Wolf Optimization	GWO
Gravitational Search Algorithm	GSA
Bat Algorithm	BA
Whale Optimization Algorithm	WOA
Harris Hawk Optimization	HHO
Cat Swarm Optimization	CSO
Artificial Bee Colony Optimization	ABCO
Teaching-Learning based ABCO	TLABCO
Cuckoo Search Algorithm	CSA
Antlion Optimization Algorithm	AOA
Shuffled Frog-Leaping Algorithm	SFLA
Salp Swarm Algorithm	SSA
Multi Agent System	MAS
Quantum Particle Swarm Optimization	QPSO
Modified Bat Algorithm	MBA
Peer-to-Peer	P2P
Microgrid-to-Microgrid	M2M
Bill-Sharing	BS
Mid-Market Rate	MMR
Demand Response Management	DRM
Enhanced BAT Algorithm	EBAT

Cost Factor Index	CFI
Objective Functions	OF
Multi Objective Functions	MOF
Simulated Annealing	SA
Firefly Algorithm	FA
PSO with Constriction Factor	PSOCFA
Phasor PSO	PPSO
Shuffled BAT Algorithm	ShBAT
Multi Objective PSO	MOPSO
Basic Open Source MINLP	BONMIN

Chapter
1
Introduction

1. Introduction

The traditional methods used to generate energy on a big scale are referred to as conventional power generation. The main sources of energy used in these techniques are nuclear power and fossil fuels, which include coal, natural gas, and oil. Typically, coal, natural gas, or oil are burned in fossil fuel-based power plants to heat water and create steam. After that, the steam is used to power turbines that are attached to generators, transforming the thermal energy into electrical energy.

Similarly, using a similar turbine-driven process, nuclear power plants use the heat produced by nuclear fission reactions to create steam that is used to generate electricity. Because of these techniques' dependability, scalability, and steady output, they have been the mainstay of the world's energy supply for many years.

The reliability and consistency of their electrical supply, which is essential for all industries, infrastructure, and daily living, is a well-known attribute of conventional power plants. These plants provide power to homes, industries, educational institutions, hospitals, and manufacturing facilities and have significantly contributed to meeting the ever-increasing global demand for electricity.

Despite their pervasive application and dependability, conventional methods of power generation have some obstacles and disadvantages.

- First off, a lot of greenhouse gasses which includes carbon dioxide, are discharged into the atmosphere during the fossil fuel combustion in power plants. These emissions fuel climate change, which raises sea levels, causes global warming, and increases the frequency of extreme weather events. In addition, the extraction and transportation of fossil fuels can harm the ecosystem by destroying habitats and contaminating water supplies.

- Furthermore, conventional power plants frequently need large volumes of water for cooling. Particularly in areas already experiencing drought or water shortage, this excessive water use may put a burden on the region's water supplies. There have been instances where power plants have contaminated or depleted water supplies, impacting aquatic ecosystems and the communities that depend on them.
- Thirdly, a big worry is how to get rid of the garbage that conventional power plants produce. Large volumes of ash and other byproducts, some of which may contain potentially harmful substances, such as heavy metals, are produced by coal-fired power plants. Similar to this, radioactive waste produced by nuclear power plants is dangerous and needs to be handled and stored carefully to avoid contaminating the environment for thousands of years.
- Moreover, conventional electricity generation may be harmful to people's health. The emissions produced by burning fossil fuels add to air pollution, which raises the risk of cardiovascular issues, respiratory ailments, and early death. As the Chornobyl disaster and other similar instances have shown, nuclear accidents are uncommon but can have disastrous effects on the environment and public health.
- Subsequently, as conventional power generation is frequently concentrated, extensive infrastructure and long-distance transmission lines are needed. Widespread power outages and financial losses may result from disruptions to this centralized arrangement, such as natural catastrophes or cyberattacks.

To surmount the obstacles linked to traditional power generation—such as depletion of resources, environmental repercussions, and public health issues—a combination of approaches is necessary. These approaches should strive to decrease dependence on non-renewable resources while also limiting the adverse consequences of current power generation techniques.

Utilization of fossil fuels and nuclear energy can be decreased by raising the proportion of renewable energy sources i.e. solar, wind, hydroelectric, and geothermal power. Infrastructure and technology for renewable energy can be purchased by corporations and individuals, with the help of incentives designed to encourage the creation and implementation of renewable energy projects.

The concept of microgrid comes into existence to provide the owners of renewable generating resources with the features of a grid. The connection of the microgrid to the distribution system of the utility grid marks a paradigm shift toward the generation and utilization of electric power. Microgrids are small-scale energy systems that can operate both individually and in tandem with the larger power grid. They can use a variety of energy sources, including energy storage, renewable energy, and occasionally traditional generators.

1.1. Renewable Energy Sources

Natural resources replenished constantly or at a pace higher than human usage are considered renewable energy sources. These energy resources are practically limitless and are naturally regenerated on a human timeline. These include sunshine, wind, water (hydroelectric), biomass, and geothermal heat. They are referred to as renewable sources. Fig. 1.1 shows different renewable energy sources. Renewable energy sources provide a sustainable and ecologically beneficial alternative to fossil fuels. They are a major focus on the efforts to transition to a future with more sustainable energy as they allow electricity to be generated without depleting finite resources or significantly increasing greenhouse gas emissions.

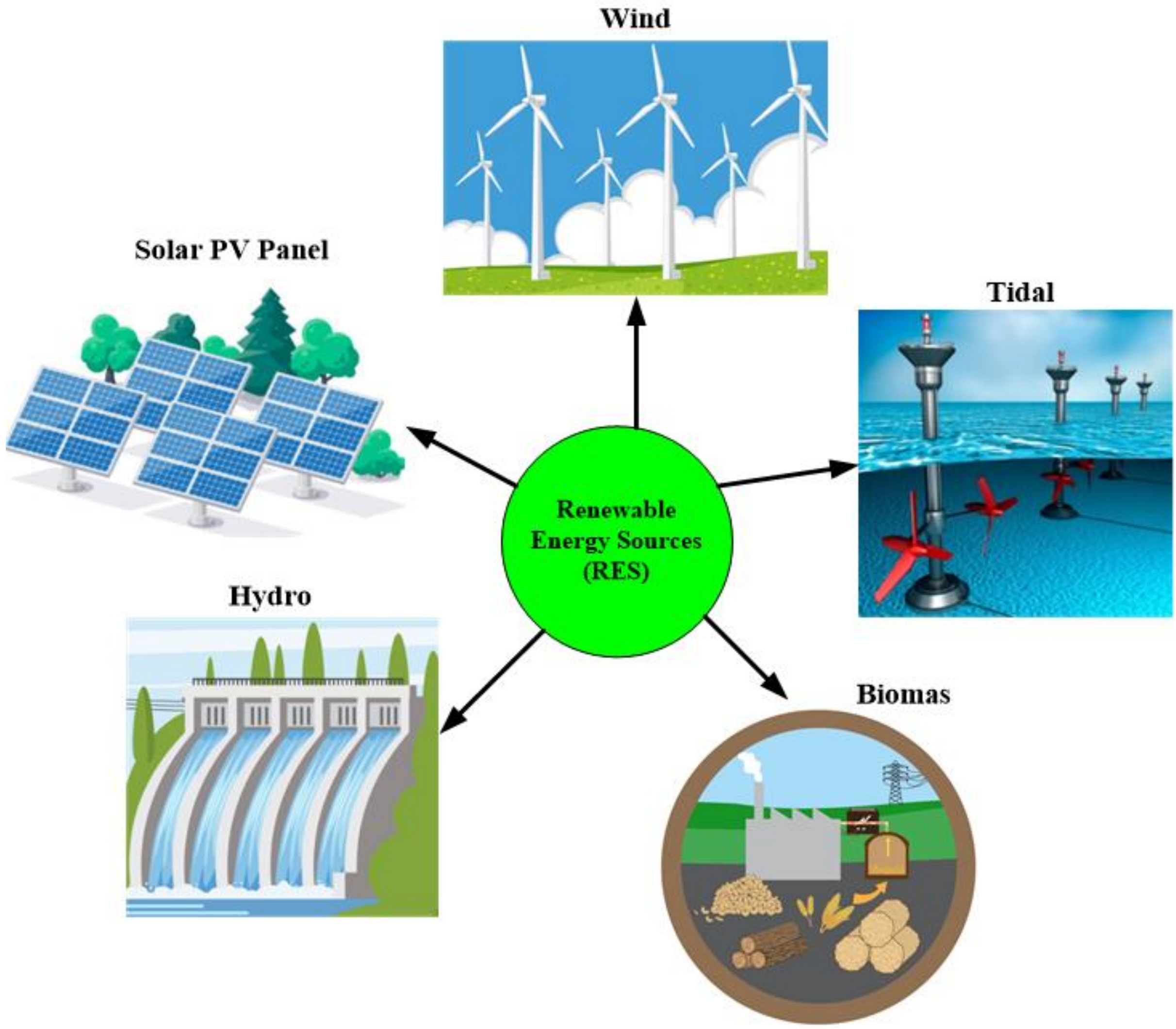

Fig. 1.1. Different Renewable Energy Sources

The following main renewable energy sources are employed in the production of electricity:

- The most tapped renewable energy is solar energy which is produced by photovoltaic cells or by solar thermal systems. It is abundant and easily accessible.
- Wind energy is another source that is expanding quickly. It is harnessed by wind turbines, which turn kinetic energy into electricity. This is especially true in regions with strong and regular wind patterns.

- Large-scale electricity production frequently uses hydropower, a dependable and well-established renewable energy source produced by using the force of flowing water through turbines.
- Biomass energy is produced by burning organic materials such as wood, agricultural waste, and municipal solid waste, or it can be processed into biofuels and burned directly to produce power.
- Geothermal power plants generate electricity by using the ambient heat that exists beneath the Earth’s surface. This renewable energy source (RES) is reliable and long-lasting.
- Still not largely harnessed is the tidal and wave energy which shows promise for coastal areas since it harnesses the movement of the tides and waves to produce electricity.

When combined, these renewable energy sources help create a more sustainable, affordable, and cleaner environment for the production of power.

1.2. Microgrid

A small collection of electrical sources and loads that may function both independently and in tandem with the main grid is known as a microgrid. Microgrids can operate in both grid-connected and island mode. While in islanded mode of operation, if faces a power shortage problem it can connect with the main grid, and after resolving the problem it can disconnect from the main grid. Microgrids are frequently used to supply electricity to isolated places, islands, or towns that are difficult for the main grid to reach. In addition, they can be applied in cities to boost energy resilience, boost productivity, and include renewable energy sources.

One of a microgrid's most important characteristics is its capacity to balance local supply and demand. To do this, it frequently combines devices that can store energy like batteries with renewable energy sources i.e. wind turbines, solar panels, or small-scale hydropower generators. This makes it possible for microgrids to maximize energy use, lessen dependency on the main grid, and in certain situations, even sell extra power back to it.

Because they can keep providing electricity to vital infrastructure like medical facilities, emergency services, and networks of communication, microgrids can be especially helpful in times of crisis or grid failure. By including renewable energy sources in the local energy mix, they can also assist in lowering the overall environmental effect of producing electricity and increase energy access in developing areas.

Distributed generators (DG) are of paramount importance in microgrids as they supply localized power generation which can be seamlessly incorporated into the overarching grid infrastructure. Usually smaller in size, these generators can be placed near the location where electricity is consumed, negating the requirement for a large transmission network and distribution network. In microgrids, the following are the frequently used categories of distributed generators: Solar photovoltaic (PV) panels, Wind turbine (WT), Microturbine (MT), Fuel Cell (FC), Diesel Generators, Combine Heat Power (CHP) systems, etc. Fig. 1.2 shows an example of microgrid.

For microgrids to work and operate, distributed generators (DGs) are essential components of the system. These generators offer localized power generation that can be integrated into the microgrid infrastructure as they are situated near the point of electricity consumption. DGs' main function is to diversify the microgrid's electricity sources, frequently by combining RES like solar, wind, or hydropower. By diversifying its sources of energy, the microgrid becomes less dependent on fossil fuels and centralized power plants, increasing its resilience and sustainability.

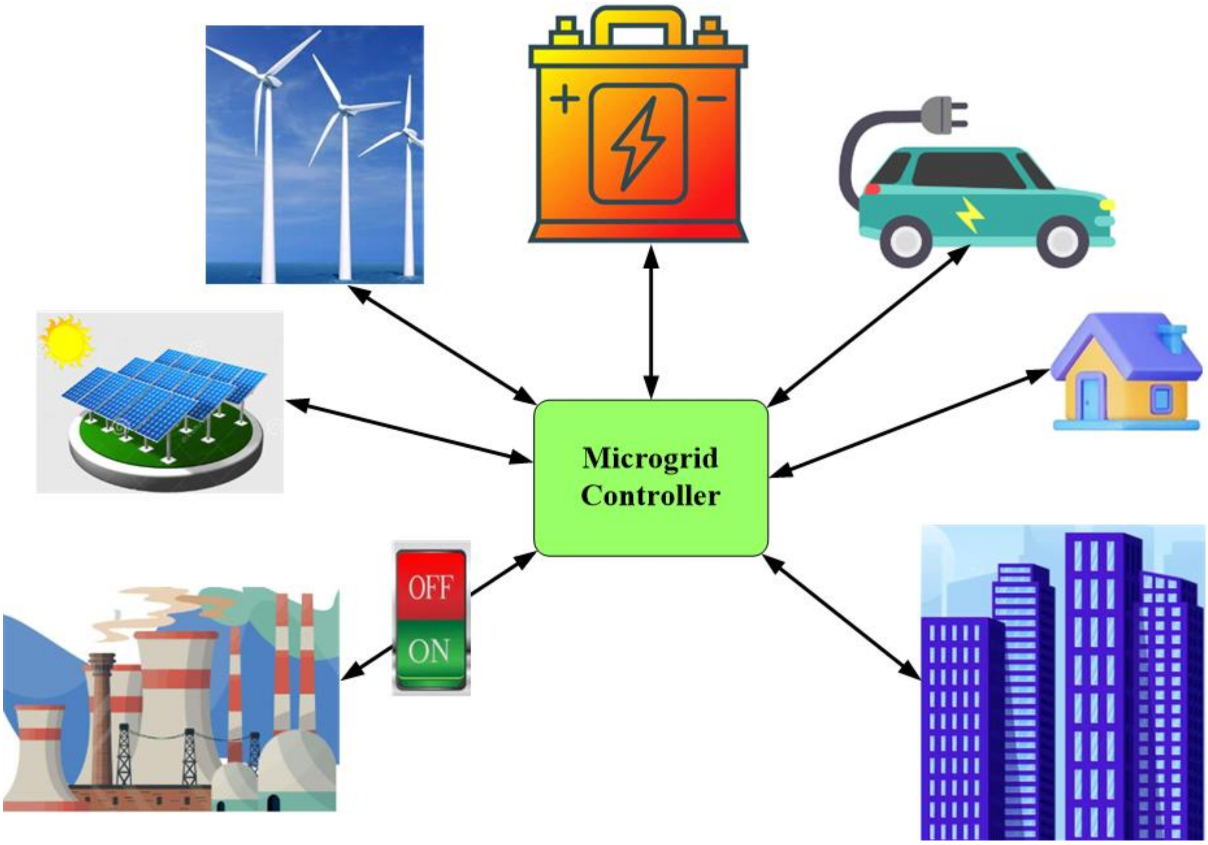

Fig. 1.2. Example of Microgrid

Enhancing energy efficiency and lowering transmission losses are two other important functions of DGs in microgrids. DG reduces the need for long-distance power transmission, which can lead to large energy losses, by producing electricity locally. Because it lessens the effect of outside variables like transmission line failures or grid disturbances, this concentrated generation also improves the microgrid's overall stability.

When the microgrid functions independently of the main grid in an islanded mode, or when it is operating independently, distributed generators (DGs) guarantee that vital loads, such as hospitals, emergency response centers, and communication networks, are powered. The microgrid's resilience and dependability are increased by its autonomous operation, particularly in locations vulnerable to power outages.

1.3. Placement and Sizing of DG Sources

To maximize the benefits of distributed energy resources and ensure effective and dependable operation, distributed generation (DG) sources must be sized and placed optimally inside microgrids. The location of DG sources within the microgrid is an important factor to be considered. The microgrid can maximize its capacity and lessen its dependency on non-renewable sources by installing DG sources strategically in regions with high availability of renewable resources.

Furthermore, the energy demand characteristics of the microgrid should be carefully considered while sizing the DG sources. This entails looking at the microgrid's load profile, any seasonal variations in energy consumption as well as the average and peak demand. To fulfill the requirements of the energy requirements of the microgrid, DG sources must be sized taking into consideration variables like load variety and future load growth potential.

Energy storage system integration should also be taken into account while placing and sizing distributed generation (DG) sources. Energy storage can be used in conjunction with distributed generation (DG) sources by storing extra energy during times of high generation or low demand and releasing it at times of low generation or peak demand. The microgrid can optimize the usage of renewable energy resources, balance supply and demand, and increase grid stability by combining the placement and sizing of DG sources with energy storage.

Finally, considering the unique goals of the microgrid, including improving energy resiliency, cutting carbon emissions, or making cost savings, will help determine the best location and size of DG sources. The microgrid can be designed to effectively accomplish its aims while functioning efficiently and sustainably by matching the location and sizing decisions with these objectives. To determine the best location and size of distributed generation (DG) sources in a microgrid, a holistic approach that considers technical, economic, geographical, and environmental variables is necessary.

1.4. Energy Management of Microgrid with Heat & Electricity Coupled Demand Response

When it comes to managing the needs for both heat and electricity, microgrid energy management systems, or EMS, are crucial for integrating and maximizing the various energy resources found within a microgrid. These systems can increase resilience and efficiency even further when combined with demand response (DR) programs that control both the amount of electricity and heat used.

The necessity of real-time energy supply and demand balancing is the heart of microgrid energy management. Demand response techniques for both heat and electricity allow microgrid energy management systems (EMS) to dynamically adjust energy usage patterns in response to changing conditions. For instance, the system can prioritize using thermal energy stored in the battery for heating during times of high electrical demand, thereby lowering the amount of electricity required from the grid. Likewise, surplus power produced during off-peak hours can be saved for future use or used to generate heat, maximizing the microgrid's overall energy consumption.

The efficient use of fuel resources by CHP systems is one of their main benefits. CHP systems are capable of attaining fuel efficiencies of 80% or higher by capturing and using waste heat that could have been discarded in traditional power generation. CHP systems are a good fit for microgrids looking to maximize their energy use and lessen their need for outside energy sources because of their high efficiency.

CHP systems enhance their versatility when incorporated into a microgrid that possesses linked heat and power demand response capabilities. Microgrids can adapt dynamically to changing grid circumstances, energy pricing, and user requirements by adjusting their operation to satisfy the fluctuating demand for heat and power.

Microgrids' economic viability is further improved by combining the utilization of CHP with demand response capabilities. Microgrids equipped with CHP systems can optimize their energy usage patterns and lower their energy costs by taking part in demand response programs. To further strengthen their value proposition in the microgrid ecosystem, CHP systems may also be able to make money by offering grid services like capacity assistance or frequency regulation.

As far as the environment is concerned, CHP systems help cut down on the release of greenhouse gases by consuming less fuel overall for the production of heat and electricity. This is in line with the increased focus in energy systems on sustainability and decarbonization. In addition, CHP systems increase the general durability of microgrids by offering a dependable and steady source of heat and power. This increases their capacity to tolerate disturbances and guarantees a continuous supply of energy to vital operations.

Microgrid energy management yields multiple advantages when demand response for both electricity and heat is included. Optimizing the utilization of existing energy resources can result in lower energy expenditures while boosting the usage of renewable energy can boost sustainability and increase resilience by offering backup power during grid failures. Moreover, microgrids can take a more active position in the wider energy ecosystem and improve grid stability and dependability by taking part in demand response programs.

1.5. Power Sharing in a Community Microgrid

A community microgrid is a self-sufficient energy system that is specifically designed to serve a particular community or region. It can operate autonomously or in tandem with the main power grid. Within its limits, a community microgrid incorporates many distributed energy resources (DERs), in contrast to standard centralized power systems. These could include combined heat and power plants, solar panels, and wind turbines, among other renewable energy sources. Energy storage devices, like batteries, are added to the microgrid to store extra energy during times of low demand or high production of renewable energy.

To implement sophisticated control mechanisms and communication channels for effective energy management, smart grid technologies are essential to community microgrids. These technologies provide grid stability, load balancing, and optimal energy distribution. Enhancing local energy sustainability, dependability, and resilience is the main goal of a community microgrid.

Community microgrids stand out due to their ability to function independently during main grid disruptions or power outages. Because towns, municipalities, or cooperatives frequently own and run these microgrids, this resilience is attained via local control and ownership. Local authority not only guarantees response to community demands but also encourages resident engagement and ownership.

Furthermore, community microgrids can be linked to the main electrical grid to enable bidirectional energy exchange. Because of this connection, the neighborhood microgrid can draw electricity when needed or give surplus power to the main grid, giving it flexibility and assistance. Community microgrids are linked, which improves grid reliability overall and helps achieve more general goals related to energy resilience.

The optimization of energy distribution and maintenance of the local energy supply depends heavily on the sharing of power across individual microgrids within a community microgrid. A decentralized network is created inside a community by these microgrids, which are frequently outfitted with energy from renewable sources like wind turbines and solar panels. The ability to smoothly move extra energy produced in one microgrid to locations with higher demand is one of the main goals of power-sharing, also known as load balancing. By preventing outages and improving overall energy efficiency, this dynamic redistribution aids in maintaining a steady and uniform power supply across the neighborhood.

A community microgrid that allows microgrids to share electricity has many benefits that make the energy infrastructure more durable, effective, and sustainable. An important benefit is that load balancing can be used to improve overall grid stability. A more equitable distribution of power throughout the community can be ensured by microgrids that are producing excess energy and can easily share it with other microgrids that are facing higher demand. This load balancing increases the overall system resilience while also preventing localized grid imbalances.

Chapter
2
Literature Review

2. Literature Review

2.1. Optimal placement and Sizing of DG sources in Microgrid

There are serious environmental problems associated with the traditional methods of producing electricity, especially when fossil fuels are burned. Climate change is exacerbated by the massive volumes of greenhouse gases released by the burning of petroleum, natural gas, and coal. Furthermore, the collection, transportation, and burning of these fuels pollute the air and water, which hurts human health and ecosystems. Distributed generation (DG), in contrast to traditional centralized generation, refers to the utilization of one's generation or neighboring small generating units to meet the power demands of consumers [1]. The technical, financial, and environmental power systems can all benefit from the ideal selection, sizing, and positioning of DGs [2]. Alternative energy sources like wind, solar, biomass, hydrogen, and waves are becoming more and more popular as a result of these advantages [3–4]. It is anticipated that as the idea of the smart grid has quickly developed in recent years, the incidence of DG will rise even further [5-7]. This research proposes a new optimization technique for optimal allocation and sizing of DG sources in microgrids.

2.1.1. Requirement of DG Insertion & Allocation

To improve the reliability, sustainability, and efficiency of the power system (PS), optimal DG placement [DGP] combines DG and RES [8]. Voltage stability [9], dependability [10], and distribution network (DN) loading capabilities [11] may all be enhanced by optimal DGP, which can also lower losses in power and harmonic distortion [12]. Furthermore, distribution growth [13], infrastructure improvement expenditure [14], and peak loading [15] can all be postponed using optimal DGP. However, because of the rise in short circuit current, incorrect DG allocation can lead to malfunctioning protective equipment and the opposite of the intended effects [16, 17].

In addition to offering the chance to generate energy from a variety of ecologically beneficial sources, distributed generation (DG) may successfully improve energy quality and stability [11]. DG sizes range from a few kW to several hundred megawatts. Additionally, DG allows for bidirectional power flow across the grid and DG, meeting the power demands of different consumer types like residential, commercial, and industrial. As a result, for the commercial, residential, and industrial load models (LMs) listed in Table 2.1, many optimal DGP studies have identified the ideal DG location, size, and unit amount, taking into account the power loss, voltage profile, and short circuit level [18, 19]. Different conventional and renewable energy sources are depicted in Fig. 2.1 and 2.2.

Table. 2.1. Capacities of different types of DGs

Sl. No.	Size of DG	End-user	Capacity
1	Large	Industry	50 – 300 MW
2	Medium	Industry	5 – 50MW
3	Small	Residential, Commercial	5 – 5000kW
4	Micro	Residential, Commercial	1 – 5000W

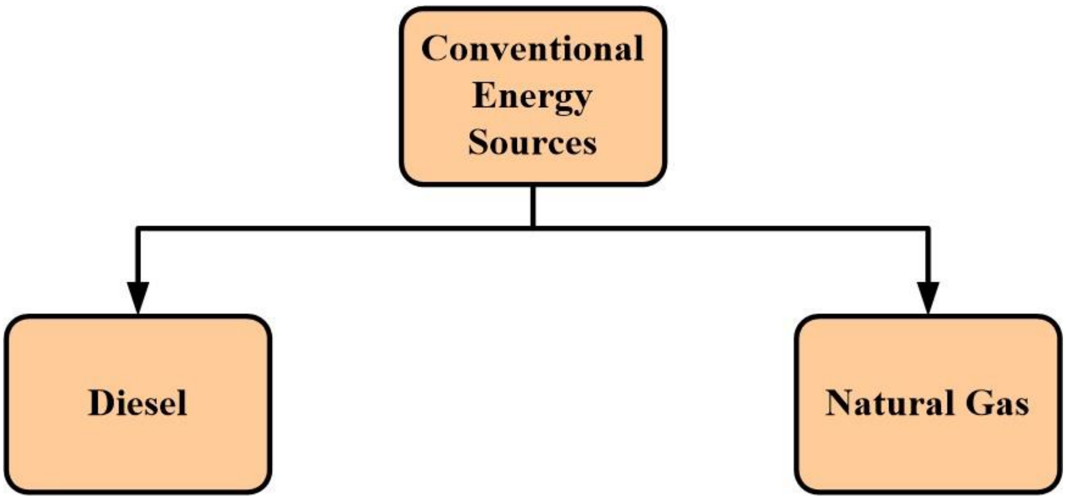

Fig. 2.1. Conventional energy sources

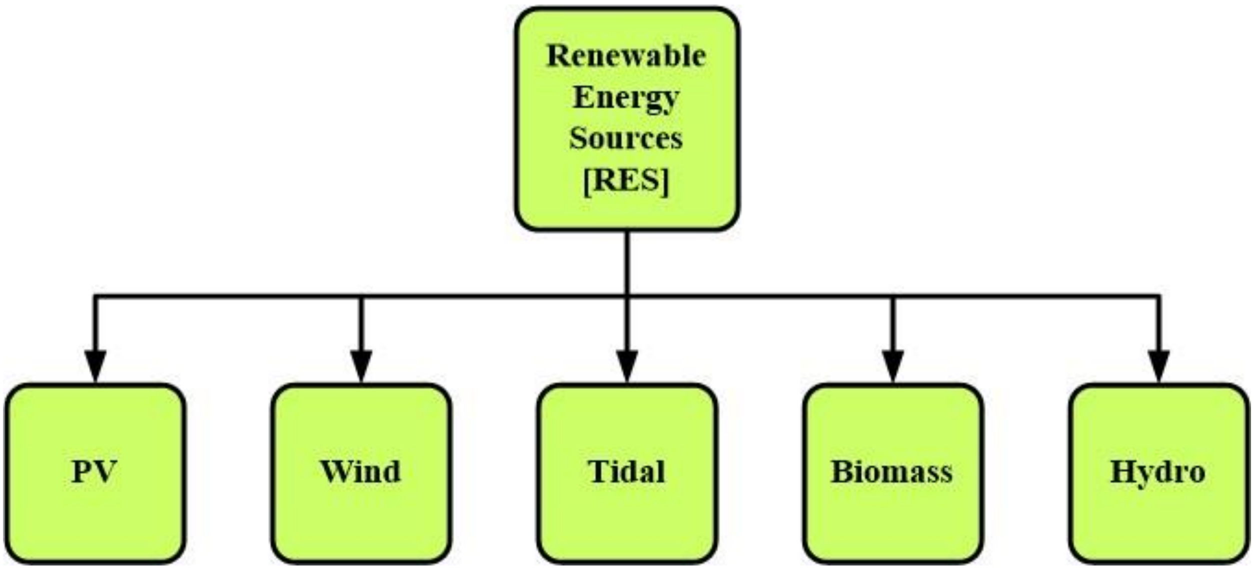

Fig. 2.2. Different Renewable energy sources

2.1.2. Optimal Power Flow for Optimal DG Placement

The following factors should be taken into account while integrating DG: penetration rate, ownership, technology, location, rating, electricity delivery area, purpose, and environmental impact [20]. Exams administered by the optimal DGP employ multi-purpose functions with varying objectives and limitations [21]. The computation of optimal DGP takes into account variations in voltage, particularly radial DN (RDN), as well as variations in load and power factor [22]. An ideal DG size lowers the prosumer's energy costs while simultaneously improving power quality. Multi-purpose optimal DGP techniques are used to examine the effects of various load types [23, 24].

Optimization strategies for microgrid planning have the potential to improve PS's overall performance [25], including optimal power flow (OPF) [26] and dependability [27]. It is possible to think of optimal DGP as an OPF issue with non-linear constraints and operation variables. To establish the economic operating conditions of PS without compromising system safety, the OPF may take into account generating costs, system models, and load patterns [28]. By optimizing the energy losses, it also decides how to allocate distributed renewable generation (DRG). By controlling reactive power, it could also reduce the overall loss of active power [29].

For example, a novel OPF approach to calculate DG size was proposed [30] by incorporating voltage limitations into the load flow solution to ascertain the impact of the level of voltage and network connectivity capacity. Utilizing embedded smart grid-based techniques and OPF, solutions are provided to reduce power and energy losses [31]. Energy storage system (ESS)-related equations for three-phase AC power flow are provided in Equations 2.1 – 2.6.

$$P_{Git} - P_{Dit} - P_{ESSbt}^{ch} = \sum_{j=1}^{N} V_{it}.V_{jt}.Y_{ij}.\cos(\theta_{ij} + \delta_{jt} - \delta_{it}) \quad (2.1)$$

$$P_{Git} - P_{Dit} - P_{ESSbt}^{dch} = \sum_{j=1}^{N} V_{it}.V_{jt}.Y_{ij}.\cos(\theta_{ij} + \delta_{jt} - \delta_{it}) \quad (2.2)$$

$$Q_{Git} - Q_{Dit} = -\sum_{j=1}^{N} V_{it}.V_{jt}.Y_{ij}.\sin(\theta_{ij} + \delta_{jt} - \delta_{it}) \quad (2.3)$$

$$I_{ijt} = |Y_{ij}|.\left[V_{it}^2 + V_{jt}^2 - 2V_{it}.V_{jt}.\cos(\delta_{jt} - \delta_{it})\right]^{1/2} \quad (2.4)$$

$$P_{loss} = \sum_{j=1}^{N} I_{ij}^2.r_{ij} \quad (2.5)$$

$$V_{min} \leq V_{it} \leq V_{max} \quad (2.6)$$

Equations 2.1 and 2.2 represent the active power flow when ESS is charging and discharging respectively where P_{Git} is the generated active power and $P_{Dit}$is the demand active power at time t bus i. Equation 2.3 shows the reactive balance of power where $Q_{Git}$is the generated and P_{Dit} is the desired generated reactive power at time t bus i. Current can be calculated using equation 2.4 where current is flowing from bus i to bus j. Magnitude and angle of voltage denoted by V_{it} and δ_{it} for bus i at time t. Admittance magnitude and angle are represented by Y_{ij} and θ_{ij}. Total active power loss can be calculated using equation 2.5 and equation 2.6 represents the voltage constraints.

2.1.3. Optimization Technique for DG placement & Sizing

The ideal placement and size of DG modules in an electrical network depend on a number of important variables. To find the best configuration, these elements are taken into account during the optimal DGP process. To lower losses, enhance voltage profiles, and boost system efficiency overall, optimal DGP usually locates DG units next to buses that have large distribution system losses. The availability of renewable energy sources (RES) like wind, solar power, or hydropower influences the appropriate size and location of the optimal DGP based on the area width required to support the DG.

Figure 2.3 illustrates how several approaches to solving optimal DGP problems have been documented in several reviews, classifying analytical techniques, and metaheuristic algorithms (MAs). The reduction of power losses [32], generation costs [33], and greenhouse gas emissions [34] is the primary goal of optimization algorithms in power systems. Analytical techniques claim that, particularly for complicated issues, heuristic and metaheuristic strategies offer more appropriate and straightforward answers [35]. Heuristic algorithms, however, are limited in their ability to guarantee the global optimal solution in optimization issues because of the high number of iterations and algorithm variables [36, 37].

2.1.3.1. Analytical Methods

In analytical methods, a numerical equation typically represents the problem being studied. The engineered model determines how accurate the optimization process is. Using additional models, theoretical computations, and mathematical analyses, analytical solutions can be produced [38]. Comparing the analytical methods concerning optimization criteria allows for an analysis of the suitability of DRG planning [39]. Analytical tools for optimum DRG planning have been enhanced; comprehensive studies have evaluated this [40].

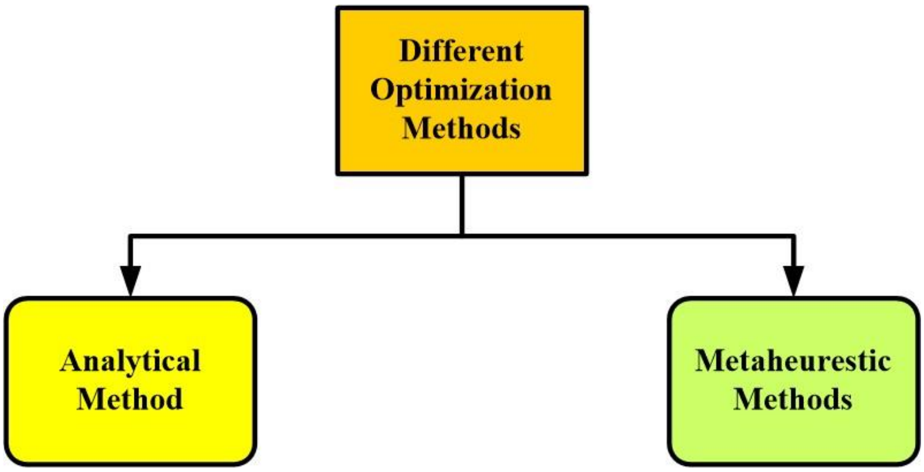

Fig. 2.3. Different Optimization Methods

2.1.3.2. Metaheuristic Methods

Heuristic refers to learning by experimentation or direct observation; meta denotes anything beyond or at a higher level. By combining many principles, the metaheuristic technique is an iterative method that directs information toward a heuristic search that ultimately leads to an ideal solution. The PS optimization process models and involves complicated and divided technical and non-technical concerns [41]. Using the fewest number of calculations, heuristic approaches determine the best answer. Evolutionary and swarm algorithms, for example, are widely used in bio-inspired metaheuristic classifications [42].

The most popular meta-heuristic techniques are Genetic Algorithm (GA) [43] and particle swarm optimization (PSO) [44, 45]. Exploration of the search space is encouraged by the randomness introduced by the stochastic nature of GA. Artificial intelligence, finance, engineering, and other fields are among the issues that GA and PSO can use to solve.

Grey wolf optimization (GWO) was motivated by Mirjalili and Lewis's [46] observations of the social leadership and hunting strategies of grey wolves. Multi-purpose optimal DGP uses GWO-based optimizations to reduce reactive power loss and enhance the voltage profile, among other things. According to numerical findings, GWO outperforms the gravitational search algorithm (GSA) and the bat algorithm (BA) over the characteristic convergence curves and voltage profile [47].

A metaheuristic optimization method called the whale optimization algorithm (WOA) was proposed by Mirjalili and Lewis in 2016, demonstrating the way whales hunt [48]. Multi-purpose optimal DGP benefits from its effectiveness, including reduced power loss and expenses [49], as well as enhanced voltage profile [50].

The Harris Hawk Optimization (HHO) algorithm is a novel metaheuristic technique that can be utilized for various optimization issues. It can arrive at the solution more quickly and effectively than many MAs [51]. Proposed algorithms for single and multi-purpose optimal DGP include parallel and cat swarm optimization (CSO) [52].

The artificial bee colony optimization (ABCO) [53], teaching-learning based ABCO (TLABCO) [4], cuckoo search algorithm (CSA) [54], antlion optimization algorithm (AOA) [55, 56], shuffled frog-leaping algorithm (SFLA) [57], GSA [58], and salp swarm algorithm (SSA) [59, 60] are some of the preferred MAs for optimal DGP, despite what has already been mentioned.

2.2. Energy management of Microgrid

For microgrids to meet stability requirements and other requirements, real-time control and optimal functioning of distributed energy resources (DERs) must be taken into account, which calls for sophisticated energy management systems (EMS). The last ten years have seen a lot of interest in energy management (EM) optimization for microgrids, with numerous suggestions ranging from sophisticated learning algorithms to mathematical methods. Furthermore, metaheuristic techniques have been widely used to optimize DER dispatching in order to lower total operating costs. Real-time control methods have been thoroughly studied in this context as well. Numerous studies have been carried out in this field, according to a review of the literature on the subject. Combining research on thermal energy supply and electrical power generation, EMS for MG is covered for building applications [66].

The exhaust gas from the MT can be used to generate heat and electricity. The MT-based combined heat power (CHP) system is one of the DERs in the MG. The two operational methods that CHP systems can operate under are generation following thermal load (FTL) and generation following electric load (FEL) [67, 68]. Additionally, the loads associated with electric appliances are typically divided into two categories: the base load, which is constant and cannot be scheduled, and the variable load, which is flexible and is scheduled as such. Several research, such as the control model [69], optimal scheduling [70 – 73], feasibility analysis [74 – 76], etc., have focused on the functioning of CHP-MG. A CHP system's overall profit from selling power to the end user is described in [73]. The total operating expenses of CHP system is given in [78]. The main energy savings and utilization [77] are used to illustrate how cost-effective the CHP system is.

Nonetheless, mathematical techniques and metaheuristics constitute the majority of optimization methods. With a greater emphasis on MG control techniques, MG EMS is examined critically in [79]. [80, 81] evaluate EMS for DC MGs. While Al-Ismail [80] provides a critical critique of the EMS approaches. [81] provides a more thorough discussion of optimization techniques. EMS for MGs with various categories and contents was covered by the writers of [82], [83], [84], [85], and [86].

[87] proposed a system for energy management control that uses a multi-agent system (MAS) to monitor and manage microgrid operations in real-time according to predetermined standards. The recommended strategy, according to the results, minimizes energy expenses while meeting customer demand at unpredictable times, thereby guaranteeing optimal

microgrid performance. By taking into account a DC microgrid with integrated RES and ESS, [88] presented a control technique for energy management. The integration of renewable energy sources (RES) with energy storage systems (ESS) is dependable when it satisfies load demand under transient conditions. These conditions include swings in RES power supply and sudden changes in load demand. In order to guarantee real-time control and monitoring of microgrid operations, [89] suggested a Fuzzy Q-Learning energy management control technique. A microgrid with PV and ESS was examined by [90] and its use for smart homes was suggested.

To create a Quantum Particle Swarm Optimisation (QPSO) that maximizes the power-sharing with the utility grid, Kumar et al. [91] took into consideration a RES-based grid-connected microgrid and developed an optimal power dispatch strategy for the Distributed Generation (DG) units. The findings show that total energy prices have significantly decreased, and they offer a way to analyze load participation patterns and give the utility grid operational flexibility. A grid-connected microgrid's Energy Management Strategy (EMS) was created by Luo et al. [92] by adding sufficient real-time data. The Modified Bat Algorithm (MBA) is applied to address the microgrid's uncertainties, and the outcomes are contrasted with those of other algorithms. [93] suggested using PSO and artificial neural networks in an islanded microgrid's EMS strategy to guarantee optimal microgrid operation.

2.3. Priority based power sharing in a community microgrid

A community microgrid (CMG) is formed when a community interface controller connects a collection of neighboring microgrids. To achieve the intended goals, which are made possible by the MG and CMG concepts, an energy management system (EMS) must be applied [94]. A basic explanation of the community microgrid idea is given [95]. It involves the direct communication of microgrid regions with their neighboring territories through regulated interconnecting lines. The benefits and structure of a community microgrid, where each microgrid is connected by a common AC bus to other microgrids in the community and the main grid, have been described [96].

Numerous studies have been done regarding MG and CMG applications regarding the CMG architecture [97], control approaches [98], computational optimization [99], and communication methods [100]. Concepts of virtual power plants and MG were extensively examined [101], and scheduling problems concerning objective functions, unpredictability, credibility, problem-solving strategies, reactive power, and demand response were looked into. Samir et al. [102] reviewed hybrid renewable MG optimization solutions, using AI, probabilistic, iterative, and predictable approaches. Carlos et al. looked at the computational techniques utilized in MG planning [103]. Distributed communication network features, communication reliability issues, and distributed control technique classification were covered [104]. Regarding the incorporation of RES into MGs, Hannan et al. thoroughly investigated the traditionalization of optimized controller approaches and looked at both complex and conventional optimization algorithms in MG implementations [105]. In [106], a summary of the primary benefits and challenges related to the management and operation of the CMG is provided.

The implementation of a community microgrid, in particular, requires a well-thought-out plan to manage the exchange of power among participating microgrids, especially when the community is operating independently. Computers at the network's edge, known as peers, store and distribute resource information on peer-to-peer (P2P) networks, which are an accepted resource sharing paradigm in the field of computer science [107]. A community-model graph (CMG) is a P2P or microgrid-to-microgrid (M2M) network because it consists of numerous prosumers, or microgrids, each with its own generation and demand, that are located in close proximity to one another. P2P (peer-to-peer) energy trading is the local exchange of excess energy from several small-scale distributed energy resources [108]. Under the P2P paradigm, local energy trading and demand response (DR) to available resources within a community are promoted [109].

A P2P energy swap idea has been proposed for smart houses by Alam et al. [110]. The P2P energy transmission method presented by [111] in a smart grid scenario is efficient and privacy-preserving, thanks to its special optimization strategy that encourages optimal energy transfer without disclosing data. A multi-index performance assessment approach is presented in [112] to appraise the economic viability of peer-to-peer energy sharing programs. Nevertheless, Long et al. [113] did not account for DR when they presented different P2P market norms through the use of bill-sharing (BS), mid-market rate (MMR), and auction-based pricing methods. A market-based distributed system for competitive energy trading across microgrids was created in [114] and is known as the multi-leader-multi-follower Stackelberg game.

Stackelberg game theory is used in [115] to investigate demand response management (DRM) from several perspectives. To study DRM, real-time pricing, and energy sharing management, many academics have employed a range of game theoretic techniques [116]. Performing the trading of energy in these projects was the responsibility of a different organization that serves as a coordinator for energy trading [117].

2.4. Motivation of the Work

The global movement towards more sustainable and clean energy systems serves as the driving force behind the work. Microgrids that incorporate renewable energy sources are getting increasingly important as worries about climate change and requirements to reduce dependency on fossil fuels grow. Distributed generation (DG) provides a decentralized and environmentally sustainable method of producing energy, especially when it comes from sources of renewable energy like solar and wind. To maximize their effectiveness, minimize energy losses, and guarantee a steady supply of power, these generators' layout and positioning must be optimized.

Additionally, the necessity for sophisticated energy management strategies is highlighted by the growing complexity of energy systems brought about by the introduction of variable renewable energy sources. In a microgrid, good management and synchronization of distributed generation (DGs) can boost resilience to power outages, stabilize the grid, and offer affordable energy options.

The main goal is to provide techniques and approaches that improve the sustainability, dependability, and efficiency of microgrids by emphasizing the best possible DG position, design, and energy management.

2.5. Research Gap

The research gaps are in several important areas where previous studies haven't yet offered thorough answers or techniques. Even though DG integration in microgrids has been the subject of extensive research, there are still gaps in the development of comprehensive frameworks that optimize DG placement in terms of both their physical location and their operational control under various scenarios, including load fluctuations, renewable intermittency, and grid connection/disconnection.

All-inclusive Optimization Frameworks

Most current research focuses on energy management techniques or optimizing the positioning and size of distributed solar PV generation. To maintain overall system efficiency, dependability, and cost-effectiveness, models that simultaneously optimize distributed generation location, sizing, and real-time energy management are required. This is where the gap exists.

Configurations and Modes of Operation of Microgrids

The intricacy of distributed generation placement and control during these transitions is frequently overlooked in research on microgrid operation. There is a need to develop optimization models that can manage these shifts and guarantee a continuous, reliable power supply under both regular and emergency circumstances.

Economic Trade-offs

Although DG and microgrid technical performance has been thoroughly investigated, little research has been done on how to reconcile the economic trade-offs when placing DGs and managing energy. This gap can be bridged by creating models that consider environmental effects like emissions reduction and sustainability measures in addition to economic factors like capital and operating costs.

By filling in these research gaps, microgrid design and operation could be greatly advanced, leading to more sustainable, resilient, and efficient energy systems that can be tailored to a variety of situations and energy sources.

2.6. Scope of the Work

The research would focus on developing techniques to install Distributed Generators (DGs) in microgrids in the best possible locations and sizes to maximize efficiency, performance, and dependability. Along with the consideration of technical and financial aspects into account, it would also incorporate energy management techniques to guarantee the best possible power flow, reduce losses, and incorporate renewable energy sources. The modeling and simulation of isolated and grid-connected microgrids are likely to be the main topics of the thesis.

2.7. Objective

Developing all-encompassing techniques and strategies for the effective layout, positioning, and functioning of DGs in microgrids is the main goal of the research. By identifying the best sites and DG unit sizes while considering both technical and financial issues into account, the goal is to maximize the performance, dependability, and cost-effectiveness of microgrids.

Another key objective is to create a coordinated energy management scheme for microgrids that incorporates electricity and heat systems. To increase energy efficiency, cost-effectiveness, and system reliability, it focuses on optimizing demand response for multiple parties while taking the interdependence of heat and electrical demands into consideration.

Another major goal is to create a power-sharing system that gives priority to energy exchange across networked microgrids inside a community. Its main goal is to maximize the allocation of extra power according to predetermined priorities, guaranteeing that key loads are satisfied first and fostering efficiency and stability throughout the power-sharing process. The community energy systems are made more reliable and resilient by this method.

2.8. Contribution and organization

Chapter 3: A novel optimization technique is proposed in this chapter for optimal placement and sizing of DG sources in an energy efficient microgrid. The main objective of the research is to reduce the active power loss and overall cost of DGs of the microgrid by optimally placing and sizing the DG units. A comparative study with some existing optimization methods such as PSOCFA [61], PPSO [62], ShBAT [63], MOPSO [64], and BONMIL [65] is provided.

Chapter 4: An energy management system that involves multiple parties is suggested in this chapter to facilitate the financial operation of MG. In addition to a base generation capacity supplied by PV sources throughout the day, the MG's generation comes from a CHP system that operates in the following electric load (FEL), following thermal load (FTL), and following hybrid load (FHL) modes. PV- Users that have a PV system installed are called prosumers. The prosumers can provide and load energy to the MG simultaneously. On the other hand, depending on the situation and required net power, a prosumer can switch between being a buyer and a seller at different points in time.

Chapter 5: The primary goal of the chapter is to feed any microgrid's extra power to the neighborhood's main AC bus so that other microgrids can use it to fill in their power shortages when needed. By adopting a priority-based distribution algorithm, the community microgrid controller (CMGC) that is being discussed here will determine how excess power is sent to the microgrids that are facing power shortage problems on a priority basis. The production of extra power has a limit. This extra power could compete with quite a few microgrids. The microgrids (one or more) that will receive this electricity, along with the amount and duration of operation, are prioritized.

Chapter 6: This chapter concludes the thesis

Chapter 3

Optimal DG Placement & Sizing

3. A Novel Algorithm for Optimization of DG Placement and Sizing in an Energy-Efficient Microgrid

To transform various energy sources into electricity, numerous technologies are usually used in conventional electric power generation. Fossil fuels (coal, oil, and natural gas), nuclear energy, and hydropower are the main energy sources used to produce conventional power. For many years, the generation of electric power by conventional methods has been the mainstay of the world's electricity production. However, to address environmental concerns and battle climate change, there is an increasing emphasis on switching to cleaner and more sustainable energy sources. One significant development in the continuing evolution of the power generation environment is the move toward renewable energy. Here comes the idea of microgrids.

The idea of microgrids signifies a paradigm change in the way we view and organize electrical power networks. A small-scale, localized energy system known as a microgrid can function both independently and in tandem with the main power grid. Microgrids provide a more resilient, sustainable, and locally regulated method of energy generation and distribution, which has numerous benefits across multiple industries. The concept of microgrids offers several benefits, including enhanced resilience and dependability, energy security, the addition of renewable energy sources (RES), energy storage, mitigation of emissions of greenhouse gas, cost savings and efficiency, community empowerment, adaptability, and scalability, digitalization and technologies for smart grid, mitigation of distribution & transmission losses, assistance in electrifying remote areas, ease of energy access. Because of their benefits, microgrids are a desirable solution for problems with the current energy system and provide a route forward for a more locally controlled, sustainable, and resilient energy future.

The flexibility and sustainability of microgrids are greatly enhanced by the presence of Distributed Generation (DG) sources. Distributed generation describes small-scale generating systems that generate electricity in close accessibility regions to the final consumers. These sources can be both conventional, like natural gas generators and combined heat power (CHP) systems, and renewable, like solar PV panels, biomass generators, and wind turbines.

A microgrid's total performance and efficiency are greatly influenced by the positioning of its Distributed Generation (DG) sources [8]. To increase the microgrid's resilience, dependability [10], and financial sustainability [9], DG sources are to be positioned strategically inside it. During this placement procedure, a number of things must be considered: the location of the DG within the microgrid, the load distribution, and demand. Planning and engineering professionals can identify the best sites for distributed generation (DG) installation by carefully examining these variables. With this meticulous planning, transmission losses and costs are reduced, and the microgrid's capacity to manage variations in power output and demand is enhanced.

A novel optimization technique is investigated in this research considering active power loss and cost minimization of the microgrid for placement and sizing the DG sources. Enhanced BAT algorithm (EBAT) which is an improved version of the conventional BAT algorithm and can be applicable for multi objective identification.

3.1. Problem Formulation

This research's primary goal is to determine the best location and size for distributed generation while taking multi-objective functions into account. In this part, the objective function is modeled mathematically.

3.1.1. Objective function

Minimizing real power loss and the cost factor index (CFI) are the objective functions (OF). Multi multi-objective function (MOF) is formulated by using weight factor.

$$\mathcal{MOF} = x_1 PL + x_2 CFI \tag{3.1}$$

Where the weight coefficients are denoted by the letters x_1 and x_2 and $\mathcal{MOF}$ is the minimization objective which includes all objective functions. The weight coefficients indicate how essential the objective functions are. Weight coefficients are typically regarded as follows for simplicity:

$$\sum_{i=1}^{n} x_i,\ 0 < x_i < 1 \tag{3.2}$$

Based on the condition of utility, appropriate weighting factor values can be chosen. According to the objective function's overall importance, the utility typically assigns it a greater weighting factor. Typically, it is determined by the price of fuel, the technology being employed, environmental concerns, and consumer demand. The cost of power loss is usually much more than the cost of the DER. Hence the weightage in the optimization of the cost of power loss is usually more than the cost of DER. Active power losses in this instance are taken with a weightage value of 0.7, while the DER cost is given a weightage factor of 0.3.

3.1.1.1.Real power loss

Calculations are made to determine the total active power losses at each node due to current flowing across the network from the MG and DGs. This objective function can be expressed as follows:

$$PL = \sum_{i=1}^{n} (Pg_i - Pl_i) \tag{3.3}$$

Where,

$$Pg_i = \sum_{k=1}^{n} V_i V_k Y_{ik} \cos(\delta_i - \delta_k - \theta_{ik}) \tag{3.4}$$

$Pl_i = Real\ Power\ load$

3.1.1.2.Overall cost of DG unit

Operational and maintenance costs, also the initial investment cost, determine the total cost of DG. The overall cost of installing DG for a particular period might be expressed as follows:

$$Cost_{DG} = (P_{DG} * 40000) - (P_{DG} * 40000 * d) + (R_1 * 16000) + (R_T * 700) + Cost_{au} \quad (3.5)$$

Where P_{DG} = Solar panel rating (kW)

R1 = Inverter rating (V/A/kW)

RT = Transformer Rating (kVA)

$$Cost_{au} = 0.02 * [(P_{DG} * 40000) - (P_{DG} * 40000 * d) + (R_1 * 16000) + (R_T * 700)] \quad (3.6)$$

d = Discount rate

3.1.1.3.Cost Facto Index (CFI)

The index used to describe the overall cost of allocating DG in a distribution network is,

$$CFI = \frac{Cost_{DG}}{Cost_{DG}^{max}} \quad (3.7)$$

$Cost_{DG}$ = The price of the optimally-chosen DG.

$Cost_{DG}^{max}$ = Provides the entire cost associated with the largest possible DG size.

3.1.2. Constraints

Several restrictions are placed on the DG units' capacity in this study. For simulations, the following real power restrictions of DGs are taken into account:

$$P_{DG}^{min} < P_{DG} < P_{DG}^{max} \quad ; \quad 500kW < P_{DG} < 1100kW \quad (3.8)$$

3.2. Different Algorithms

The best location for Distributed Generation (DG) units in a microgrid is one of many complicated problems that can be solved with the help of metaheuristic algorithms, a popular optimization technique. These algorithms are made to effectively search across solution spaces and identify nearly ideal solutions. Several metaheuristic algorithms, including Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), PSO with constriction Factor (PSOCFA), Phasor PSO (PPSO), Shuffled BAT algorithm (ShBAT), Multi Objective PSO (MOPSO), Basic Open Source MINLP (BONMIN) etc., are frequently utilized to optimize the placement of distributed generation (DG) in microgrid structures.

3.2.1. Particle Swarm Optimization (PSO)

Created in 1995 by James Kennedy and Russell Eberhart [118], Particle Swarm Optimization (PSO) is an optimization technique inspired by nature. Inspired by the social behavior of fish schools or flocks of birds, it is a population-based stochastic optimization technique. Finding optimal or nearly optimal solutions to optimization issues is the goal of the algorithm. Below is a step-by-step breakdown of how PSO is implemented.

1. Identify the Issue: Describe the microgrid optimization problem, considering the limitations, the objective function that has to be minimized, the placement of the DG units as decision variables, and any other pertinent aspects.

2. PSO Parameters Initialization: Configure the maximum iterations (iter max), initialize the swarm positions (swarm) and velocities (velocity) at random.

3. In order to meet fitness criteria, each particle, i, is represented by a vector $Position_i$ with n locations and a velocity vector, $Velocity_i$, which is used for the position update

of particles that move based on experience, data from the social environment, and the particle's current position.

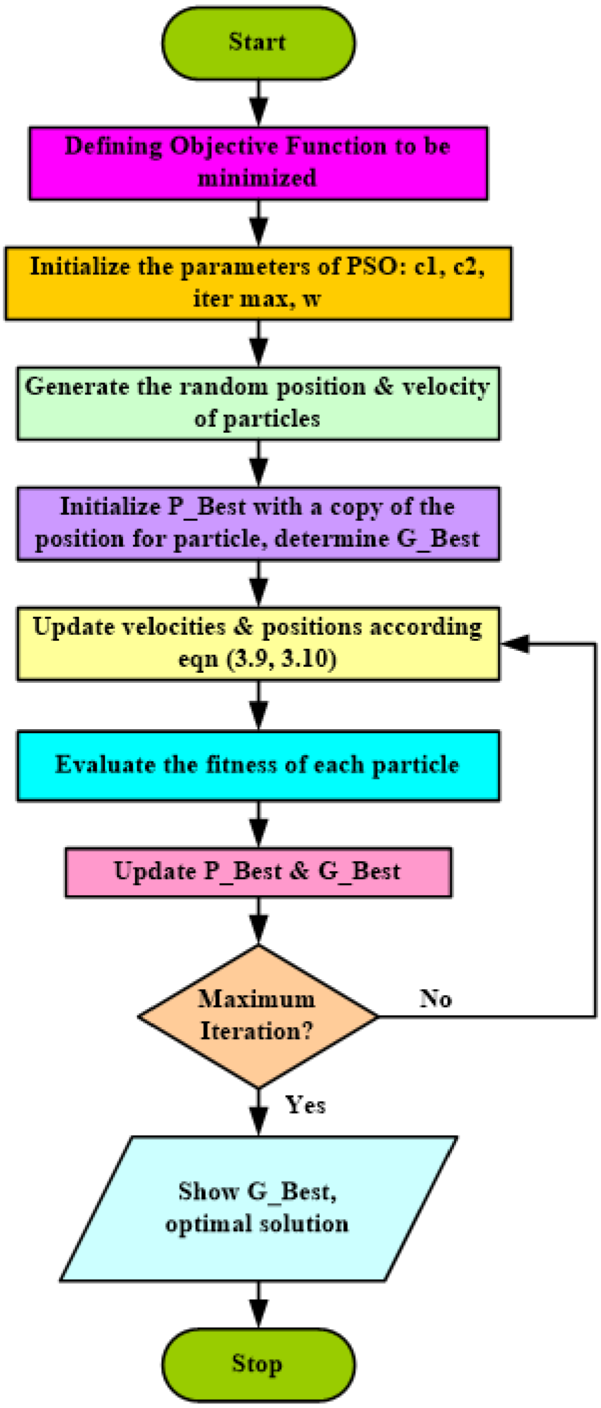

Fig. 3.1. PSO Algorithm Flowchart

4. Find the swarm's most suitable particle. The local fitness (P) value surpasses the current or running best fitness (P_Best) value, set current fitness (P_Best) = P.

5. If current fitness surpasses global best (G_Best) fitness, set P_Best = G_Best.

6. To get the best solution, update the particle's position and velocity utilizing equ. (3.9) and (3.10) until the stopping requirement is satisfied.

$$Position_i^{T+1} = Position_i^T + Velocity_i^{T+1} \quad (3.9)$$

$$Velocity_i^{T+1} = \omega * Velocity_i^T + C_1 * Rand * \left[P_{Best_i} - Position_i^T\right] + C_2 * Rand * \left[G_{Best_i} - Position_i^T\right] \quad (3.10)$$

In this research $C_1 = 2.5, C_2 = 1.5, \omega = 0.99$

In Fig. 3.1, a flowchart depicts the PSO algorithm's step-by-step procedure

3.2.2. PSO with Constriction factor (PSOCFA)

A natural selection process, which is often employed by evolutionary computations like genetic algorithms, is combined with the PSO mechanism in hybrid particle swarm optimization [119, 120]. For example, in every iteration, the total amount of highly regarded agents rises while the quantity of weakly evaluated agents falls. Since pbesti and gbest are the primary factors that determine the search procedure using PSO, pbesti and gbest limit the search criteria, conversely, PSOCFA can use the selection mechanism to immediately move the current search points into the attractive and effective area. Position of agents with poor evaluation scores should be replaced with those with high scores for evaluation by employing the selection process.

Selection rate (sr) is another name for the replacement rate. It is noted that even if one agent's role is changed by another, each agent's Pbesti information remains intact. As a result, reliance on the prior position with high evaluation and realization of the required area by extensive search.

$$V_i^{K+1} = CFA \times [V_i^K + C_1 \times rand_1 \times (pbest_i - S_i^K) + C_2 \times rand_2^* \times (gbest - S_i^K)] \quad (3.11)$$

Where,

$$CFA = \frac{2}{\left|2\emptyset - \sqrt{\emptyset^2 - 4\emptyset}\right|} \quad (3.12)$$

$$\emptyset = C_1 + C_2 \quad (3.13)$$

3.2.3. Phasor PSO (PPSO)

A nonparametric PSO is obtained by modeling the particle acceleration coefficients (C1 and C2) while taking phase angle (θ) into consideration. This new simple adaptive PSO is called PPSO. Utilizing periodic trigonometric equations of the phase angle (θ), the authors [121] proposed an efficient and useful function for PSO accelerating coefficients. To show the ith particle through a magnitude xi and phase angle θi, the phase angle of each particle is recognized.

The weight of inertia in the suggested PPSO is fixed to w = 0. The following Equation is used to update the velocity in each iteration:

$$V_i(t+1) = |\cos\theta_i(t)|^{2\sin\theta_i(t)}.\left(pbest_i(t) - X_i(t)\right) + |\sin\theta_i(t)|^{2\cos\theta_i(t)}.\left(gbest(t) - X_i(t)\right) \quad (3.14)$$

The location of the particle is altered as

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad (3.15)$$

The equation following is used to update the phase angle (θ) in each iteration:

$$\theta_i(t+1) = \theta_i(t) + |\cos\theta_i(t) + \sin\theta_i(t)|.2\pi \quad (3.16)$$

3.2.4. Shuffled BAT Algorithm (ShBAT)

Another genuine coded population-based meta-heuristic optimization technique that was created by fusing the characteristics of BAT [122] and SFLA [123] is called ShBAT. A new optimization algorithm is created by combining the BAT's investigation and the SFLA's utilization property.

Frequency, $F(i) = F_{min} + (F_{max} - F_{min}) * \beta$ (3.17)

Velocity, $V(i) = V(i) + (Sol(i) - best) * F(i)$ (3.18)

Where, F is the frequency and V is considered as velocity

3.2.5. Multi Objective PSO (MOPSO)

The multi-objective particle swarm optimization (MOPSO) algorithm updates the position of particle and velocity while taking several objectives into account. Particles are guided towards a set of non-dominated solutions, or the Pareto front, in the basic principle.

Particle velocity and position can be updated by using the following equations

$$V_i^{K+1} = w^K . V_i^K + C_1 . r_1 (Pbest_i - X_i^K) + C_2 . r_2 (Gbest - X_i^K) \quad (3.19)$$

$$X_i^{K+1} = X_i^K + V_i^{K+1} \quad (3.20)$$

Where

K= no of iteration

w^K=inertia weight factor

C_1, C_2=acceleration coefficient

r_1, r_2 = The range of the two random numbers [0,1]

V_i^K = Velocity of particle I in the finding space at kth iteration

X_i^K = Current position of particle at ith iteration

$$w^K = w^{max} - \frac{w^{max} - w^{min}}{K^{max}} * K \quad (3.21)$$

w^{max}, w^{min} = are the maximum and minimum inertia weight factor

K^{max} = Maximum no of iteration

K = Current iteration

3.2.6. Basic Open Source MINLP (BONMIL)

Pierre Bonami oversaw the COIN-OR project, which produced the BONMIN solver [124]. Semi-continuous or semi-integer variables are not meant to be used with BONMIN; however, it can handle models with continuous, binary, and integer variables that incorporate differentiable functions.

3.3. Proposed Methodology

3.3.1. Enhanced BAT Algorithm (EBAT)

Xin-She Yang proposed the Bat Algorithm, often known as the BAT algorithm, in 2010 [125]. In this optimization technique inspiration is received from nature. The technique is dependent on how bats uses echolocation. To find prey and navigate in the dark, bats release ultrasonic pulses and listen for the echoes. Below is a step-by-step breakdown of how EBAT is implemented.

1. Establish a precise definition for the objective function that embodies the placement of the DG. Reducing expenses, and minimizing system losses are a few examples of this. The placements and sizes of the DG units ought to determine the objective function.

2. Start the bat population from scratch. Each bat represents a possible combination of DG unit sizes and locations that could be used as a solution.

   For every bat, set the initial values for pulse rate (r) and loudness (A). In the search space, the bat's velocity (V), locations (X), and frequency (F) are initialized at random.

3. Determine each bat's objective function value using the current DG placements to assess each bat's fitness.

4. Each bat's pulse rate (r) and loudness (A) are updated by pre-established guidelines. These variables regulate the bats' propensity for exploration and exploitation.

5. The bats' positions and velocity are updated by their current locations, the best solution thus far discovered, and the randomly generated solutions from equations (3.24) and (3.23) from the pulse emission step.

6. Using the random walk outlined in equation (3.25), a new solution is created locally for every bat, and the best current solution is selected at random for local search.

7. The optimal mix of DG unit sizes and locations that maximizes the microgrid's objective function is the result.

$$\mathcal{F}_i = rand * (\mathcal{F}_{max} - \mathcal{F}_{min}) + \mathcal{F}_{min} \tag{3.22}$$

$$V_i^{T+1} = V_i^T + \left(X_i^T - X_{gbest}^T\right) * \mathcal{F}_i \tag{3.23}$$

$$X_i^T = X_i^{T-1} + V_i^T \tag{3.24}$$

$$X_{new} = X_{old} + \epsilon A^T \tag{3.25}$$

X_{gbest}^T = Present The global Best where ϵ might be any integer between [-1, 1]. A bat will lower its loudness (Ai) and raise its pulse rate (ri) in an attempt to find a better solution once it has found its target solution. The variations in loudness and pulse rate are given by equations

(3.26) and (3.27), respectively. Here, α and γ stand for pulse rate and amplitude constants, respectively.

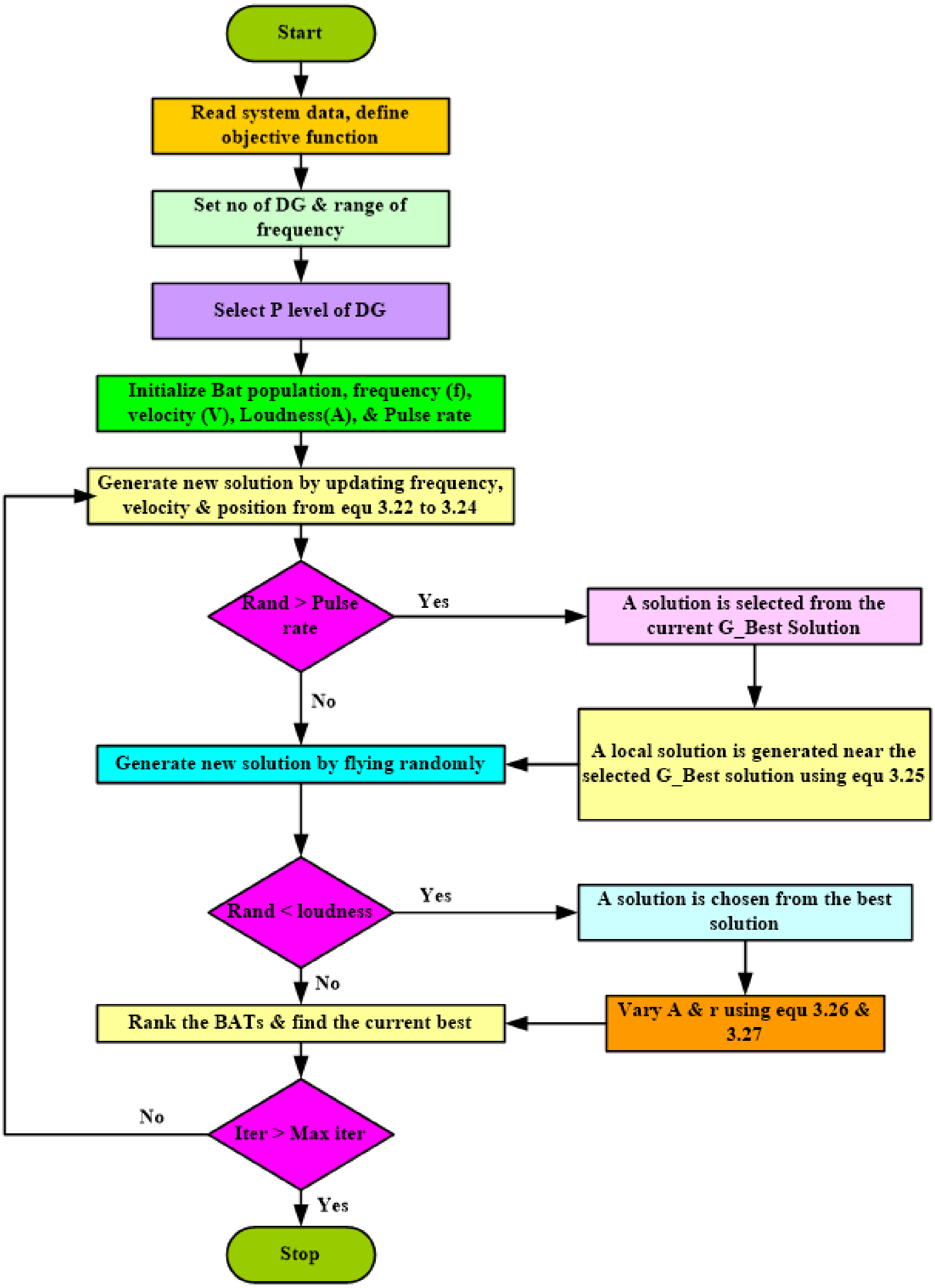

Fig. 3.2. Flowchart of EBAT algorithm

$$A_i^{T+1} = \alpha A_i^T \tag{3.26}$$

$$r_i^{T+1} = r_i^0[1 - exp(-\gamma T)] \tag{3.27}$$

The algorithm terminates and saves the relevant findings after completing its designated number of iterations. As far as bats go, the global best is the one with the highest fitness value. A flowchart in Fig. 3.2 illustrates the step-by-step execution of the bat algorithm.

3.4. Test system simulation result

3.4.1. Test system

To find the Multi-Objective problem with multiple DG installations in the IEEE 33 bus system, the proposed Enhanced Bat Algorithm is applied and the outcome is compared with different optimization algorithms. The total reactive and actual loads of the system are 2.300 MVAR and 3.715 MW, respectively. The IEEE 33 bus system is shown in Fig 3.3. Line data and load data are represented in Tables 3.1 & 3.2 respectively.

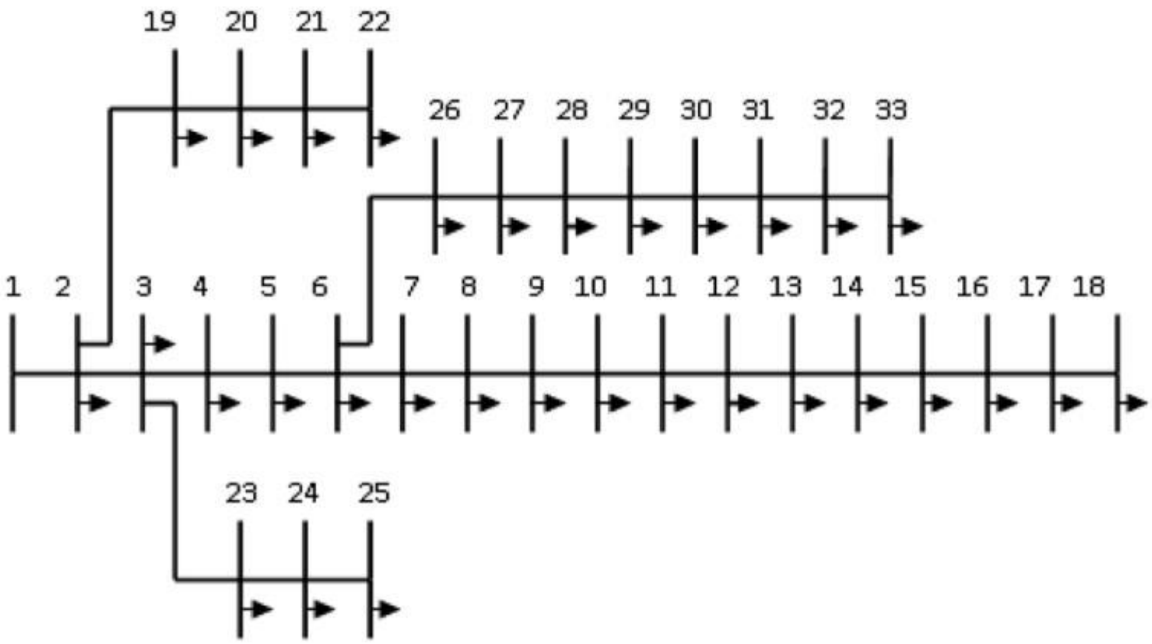

Fig. 3.3. IEEE 33 bus system

Table 3.1. The IEEE 33 bus system's Branch data

Branch Name	From Bus	To Bus	Length (km)	Branch Impedance	
				Resistance (Ω/km)	Reactance (Ω/km)
BRANCH - 1	1	2	1	0.0922	0.0470
BRANCH – 2	2	3	1	0.4930	0.2511
BRANCH – 3	3	4	1	0.3660	0.1864
BRANCH – 4	4	5	1	0.3811	0.1941
BRANCH – 5	5	6	1	0.8190	0.7070
BRANCH - 6	6	7	1	0.1872	0.6188
BRANCH – 7	7	8	1	1.7114	1.2351
BRANCH – 8	8	9	1	1.0300	0.7400
BRANCH – 9	9	10	1	1.0440	0.7400
BRANCH – 10	10	11	1	0.1966	0.0650
BRANCH – 11	11	12	1	0.3744	0.1238
BRANCH – 12	12	13	1	1.4680	1.1550
BRANCH – 13	13	14	1	0.5416	0.7129
BRANCH – 14	14	15	1	0.5910	0.5260
BRANCH – 15	15	16	1	0.7463	0.5450
BRANCH – 16	16	17	1	1.2890	1.7210
BRANCH – 17	17	18	1	0.7320	0.5740
BRANCH – 18	2	19	1	0.1640	0.1565
BRANCH – 19	19	20	1	1.5042	1.3554
BRANCH – 20	20	21	1	0.4095	0.4784
BRANCH – 21	21	22	1	0.7089	0.9373
BRANCH – 22	3	23	1	0.4512	0.3083
BRANCH – 23	23	24	1	0.8980	0.7091
BRANCH – 24	24	25	1	0.8960	0.7011
BRANCH – 25	6	26	1	0.2030	0.1034
BRANCH – 26	26	27	1	0.2842	0.1447
BRANCH – 27	27	28	1	1.0590	0.9337
BRANCH – 28	28	29	1	0.8042	0.7006
BRANCH – 29	29	30	1	0.5075	0.2585
BRANCH – 30	30	31	1	0.9744	0.9630
BRANCH – 31	31	32	1	0.3105	0.3619

BRANCH – 32	32	33	1	0.3410	0.5302

Table 3.2. The IEEE 33 bus system's Loading data

Load	**Location (Bus No)**	**Active Load (kW)**	**Reactive Load (kVAR)**
L2	2	100	60
L3	3	90	40
L4	4	120	80
L5	5	60	30
L6	6	60	20
L7	7	200	100
L8	8	200	100
L9	9	60	20
L10	10	60	20
L11	11	45	30
L12	12	60	35
L13	13	60	35
L14	14	120	80
L15	15	60	10
L16	16	60	20
L17	17	60	20
L18	18	90	40
L19	19	90	40
L20	20	90	40
L21	21	90	40
L22	22	90	40
L23	23	90	50
L24	24	420	200
L25	25	420	200
L26	26	60	25
L27	27	60	25
L28	28	60	20
L29	29	120	70
L30	30	200	600

L31	31	150	70
L32	32	210	100
L33	33	60	40
Total Load		3715	2300

3.4.2. Simulation Result

In order to minimize the multi objective functions and compare them, three DG units are employed. Active power loss and cost are the two different objective or target functions that are reviewed here. Two scenarios are considered with the objective functions i.e. only power loss is taken into consideration for scenario I and only cost is taken under consideration for scenario II.

3.4.2.1.Scenario I

The only objective function i.e. active power is considered here. The bus numbers 30, 24, 11 and the size 1.035, 1.035, 0.732 respectively are the optimal position and size obtained by applying the suggested EBAT algorithm. The optimum location and size, as determined by the PSO technique are bus number 10, 23, 29 and 0.9337, 1.0667, 0.9872 respectively. Subsequently, the outcomes were compared with a few popular methods, including PSOCFA [61], PPSO [62], ShBAT [63], MOPSO [64] and BONMIL [65] etc. Table 3.3 depicts the comparative study of the objective function using different metaheuristic techniques and the proposed EBAT algorithm. Fig. 3.4 shows the comparative view of the objective function, using different optimization techniques. Fig. 3.5 represents the comparative study of the iteration wise convergence of active power.

3.4.2.2.Scenario II

Here, the cost factor index is considered as the objective function. Below Table. 3.4 shows the comparative study of proposed EBAT with PSO algorithm. Fig. 3.6 represents the comparative study of the proposed EBAT and PSO technique also shows the convergence characteristics of the two algorithms.

Table 3.3. Comparative study of different optimizing techniques (Scenario I)

Sl. No.	Optimization Algorithm	Number of DG used	Optimized Location	Optimum Size of DG (MW)	Loss
1	Particle Swarm Optimization (PSO)	3	10 23 29	0.9337 1.0667 0.9872	72.3kW
2	PSO with Constriction Factor (PSOCFA)	3	10 25 30	1.0491 0.8786 0.8049	76kW
3	Phasor PSO (PPSO)	3	14 24 30	0.7538 1.0989 1.0711	71.4kW
4	Shuffled BAT Algorithm (ShBAT)	3	13 25 30	0.79 0.849 1.190	72.128kW
5	Multi Objective PSO (MOPSO)	2	12 32	0.97 1.053	87.89kW
6	Basic Open Source MINLP (BONMIN)	3	12 24 30	0.8976 1.0701 1.0280	66.3821kW
7	Enhanced BAT Algorithm (EBAT)	3	30 24 11	1.035 1.035 0.732	65.92kW

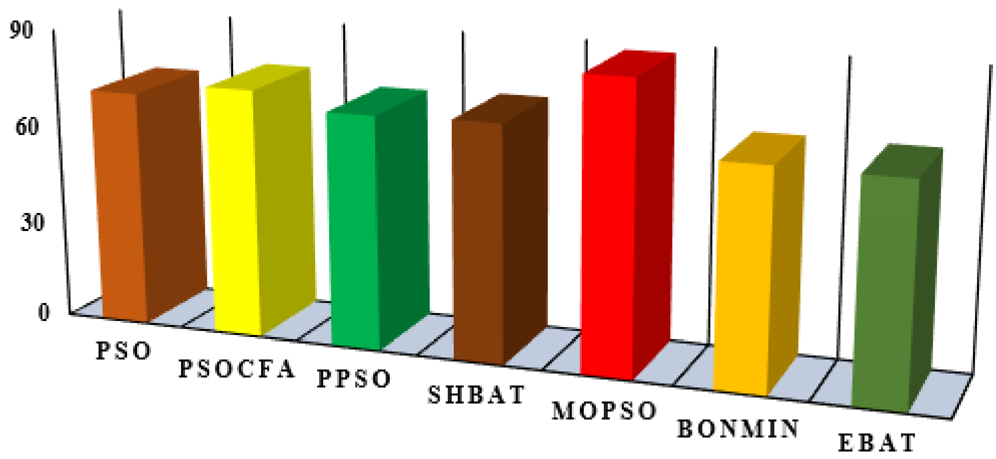

Fig. 3.4. Comparative study of different optimizing techniques (Scenario I)

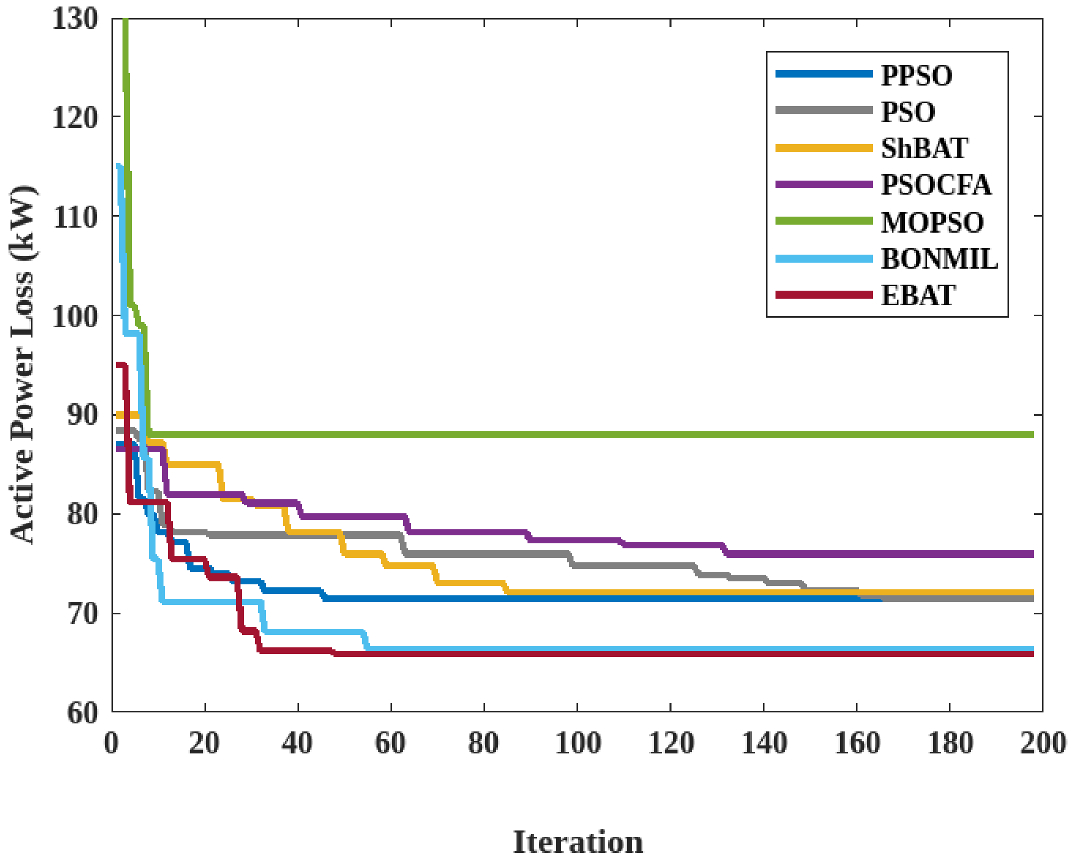

Fig. 3.5. Convergence of Real Power Loss for multiple optimization techniques (Scenario I)

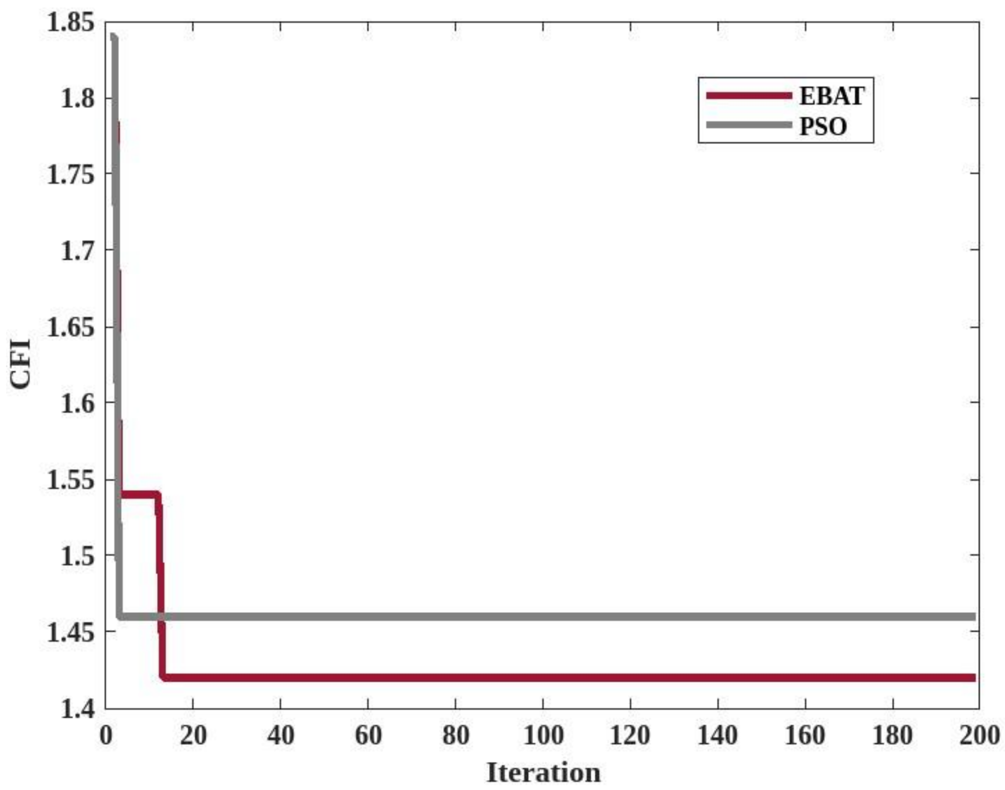

Fig. 3.6. Convergence of CFI for different optimization techniques (Scenario II)

Table 3.4. Comparative study of different optimization techniques (Scenario II)

Sl. No.	Optimization Algorithm	Number of DG used	Optimized Location	Optimum Size of DG (MW)	Cost
1	Particle Swarm Optimization (PSO)	3	9 17 7	0.751 0.882 1.093	1.4603
2	Enhanced BAT Algorithm (EBAT)	3	8 5 30	0.514 0.515 0.524	1.4163

Table 3.5. Simulation result of EBAT algorithm for scenarios I and II

Algorithm	Scenario	Objective Values	DG Location	DG size, P (MW)
EBAT	Power Loss	65.92kW	30 24 11	1.035 1.035 0.732
	Cost	1.4163	8 5 30	0.514 0.515 0.524

The optimal compromise solutions for the multi-objective issue with multiple DGs are shown in Table 3.5 for all possible scenarios. The best places for DGs with Scenarios-1 and Scenario-2 are bus numbers 30, 24, 11 and 8, 5, 30 respectively. The best sizes are 1.035, 1.035, 0.732 MW and 0.514, 0.515, 0.524kW respectively. Individually, the equivalent Objective Values are 65.92kW and 1.4163. Simulation demonstrate that EBAT algorithm is more effective than other current optimization strategies at reducing both the cost of DGs and active power loss of microgrid. The suggested technique can also lead to a decrease in the total size of the DGs.

3.5. Conclusion

With an emphasis on energy efficiency, the developed optimization method shows interest in concurrently selecting the best locations and sizes for Distributed Generation (DG) units.

Our methodology can find strategic configurations of distributed generation units (DG) through a thorough investigation of microgrid structure, load profiles, and generation capacity, together with the application of mathematical optimization tools.

The two objective functions i.e. reduction of active power loss and cost are investigated by using the proposed EBAT optimization algorithm and the results after simulation are compared with other existing techniques like PSO, PPSO, ShBAT, MOPSO, PSOCFA, BONMIL, etc. The simulation result reveals that the proposed EBAT algorithm gives better results in the diminution of active power loss and cost. Also, using the EBAT technique, the size of the DGs can be decreased.

Chapter 4

Management of Energy of Microgrid

4. Microgrid Energy Management with Heat and Electricity Coupled Demand Response

Operating in either isolate mode or grid linked mode, MG functions as a single unit that may contain a cluster of loads and Distributed Energy Resources (DER) devices. Microturbines (MT), fuel cells (FC), photovoltaic (PV) cells, energy storage systems (ESS), and other devices may be part of a distributed energy resource (DER).

A highly effective method of producing useful thermal energy and electric power from a single energy source is cogeneration, sometimes referred to as combined heat and power (CHP) systems. Using a prime mover, such as an engine or turbine, the basic idea is to concurrently produce useful heat and electricity from the same energy source. A small and effective way to generate heat and electricity at the same time is with a combined heat and power (CHP) system based on microturbines. Power output from microturbines, which are small turbines, ranges from 25 kW to several hundred kW.

In the MG, the CHP system is regarded as one of the DERs. A CHP system produces electricity and collects waste heat for use in thermal applications at the same time. The system's operations include monitoring the facility's total energy requirements and optimizing efficiency by tracking both the thermal and electric loads. There are two distinct operating strategies that CHP systems can operate under: generation following thermal load (FTL) and generation following electric load (FEL) [67, 68]. In addition, the loads associated with electric appliances are typically divided into two categories: the base load, which is unchangeable and fixed, and the variable load, which is flexible and is considered variable during scheduling. Numerous studies on the operation of CHP-MG have been conducted, including the control model [69], the optimum scheduling [70–73], the feasibility study [74–76], etc. A CHP system's overall profit from selling power to the end user is described in [73]. The total operating expenses of

CHP system is given in [78]. The main energy savings and utilization [77] are used to illustrate how cost-effective the CHP system is.

A microgrid operator (MGO) is used to control the MG's operation strategy based on the end customers' overall energy consumption. The major goal of the operation is to minimize the cost of electricity acquired from the grid and boost the economic benefits using generation of DER.

PV integration on a significant scale can impact distribution system performance. Energy policies in many nations encourage end users to adopt photovoltaic energy systems. They have the option to use the electricity produced for their own needs or export it to the utility grid. Here comes the concept of prosumer. A prosumer is a person or an organization that generates and uses electricity. Decentralized energy generation—especially from renewable sources—where customers actively participate in the production and distribution of electricity, is strongly related to this idea. An essential component of a prosumer is as follows:

- Generation of Energy: By installing renewable energy systems like solar panels, wind turbines, or other distributed energy resources, a prosumer produces their own electricity.

  Usually, the prosumer's energy production is situated on-site, like on a home or business building's roof.
- Consumption: By generating their own electricity on-site and minimizing reliance on the traditional grid, prosumers frequently aim to meet their own electrical needs.
- Interaction with Grid: Most prosumers are wired into the electrical grid. They can contribute to the total energy supply by feeding any extra electricity they produce back into the grid, frequently via feed-in tariffs or net metering.

- Storage Integration: Certain prosumers use energy storage devices, like batteries, to retain extra energy produced during light load condition. Then, during times of peak demand or when renewable output is less available, this stored energy can be used.
- Management of Energy: Energy management systems and smart technologies are frequently utilized by prosumers to maximize their generated energy, reduce waste, and improve overall energy efficiency.
- Economic Benefit: Prosumers can profit monetarily from producing their own power by doing things like cutting their electricity costs, possibly making money from selling extra energy to the grid, and receiving government incentives or subsidies to promote the use of renewable energy.
- Sustainability of Environment: Reduced reliance on fossil fuels, decreased greenhouse gas emissions from electricity use, and encouragement of the switch to greener energy sources are the ways that power prosumers help environmental sustainability.

A more dispersed and participatory energy system, where people actively participate in the generation and consumption of electricity, is what the prosumer model aims to achieve. This will help create a more robust and sustainable energy future.

A multi-party energy management system is proposed in this work for the operation of MG. The CHP system that powers the MG produces electricity in three different modes: following electric load (FEL), following thermal load (FTL), and following hybrid load (FHL). During the day, PV sources supply the base generation capacity. In the study, end customers who have PV systems installed are referred to as PV Prosumers. However, depending on the situation and required net load, a prosumer in this study can switch between roles at different times, either as a net buyer or a net seller.

In the operation of the microgrid, every prosumer is given equal authority. As a result, we view MGO as the authority when it comes to making decisions on the purchase and sale of necessary power. Prosumers follows the type of load, thermal or electrical to modify their energy usage patterns in response to fluctuating prices. The MGO manages the MG's financial operations to ensure that users pay the least amount of power possible.

4.1. Framework for Energy Management

Fig. 4.1. shows the flow of heat and electric power from the CHP system to the users. MTs and boilers are essentially combined to form a CHP system. Utilizing the same energy source, a Combined Heat and Power (CHP) system simultaneously produces electricity and useable heat as its output.

The type of CHP technology employed and the overall system architecture determine the output's particular features. The following are the primary parts of a CHP system's output:

- **Electricity:**
    - Electricity is the main output produced by the CHP system.
    - Either local electrical loads or the grid can be supplied with the generated electricity.
- **Thermal Energy:**
    - Concurrent generation of useable heat from waste heat generated during the production of electricity is one of CHP's main benefits.
    - Many thermal uses, including industrial processes, absorption cooling, hot water production, and space heating, can make use of the recovered heat.

The excess heat energy will be extracted from the boiler if the turbine is unable to produce the necessary amount. Additionally, the turbine provides electrical energy. However, if for any reason the turbine is unable to provide the appropriate amount of electrical energy, grid power will be used instead.

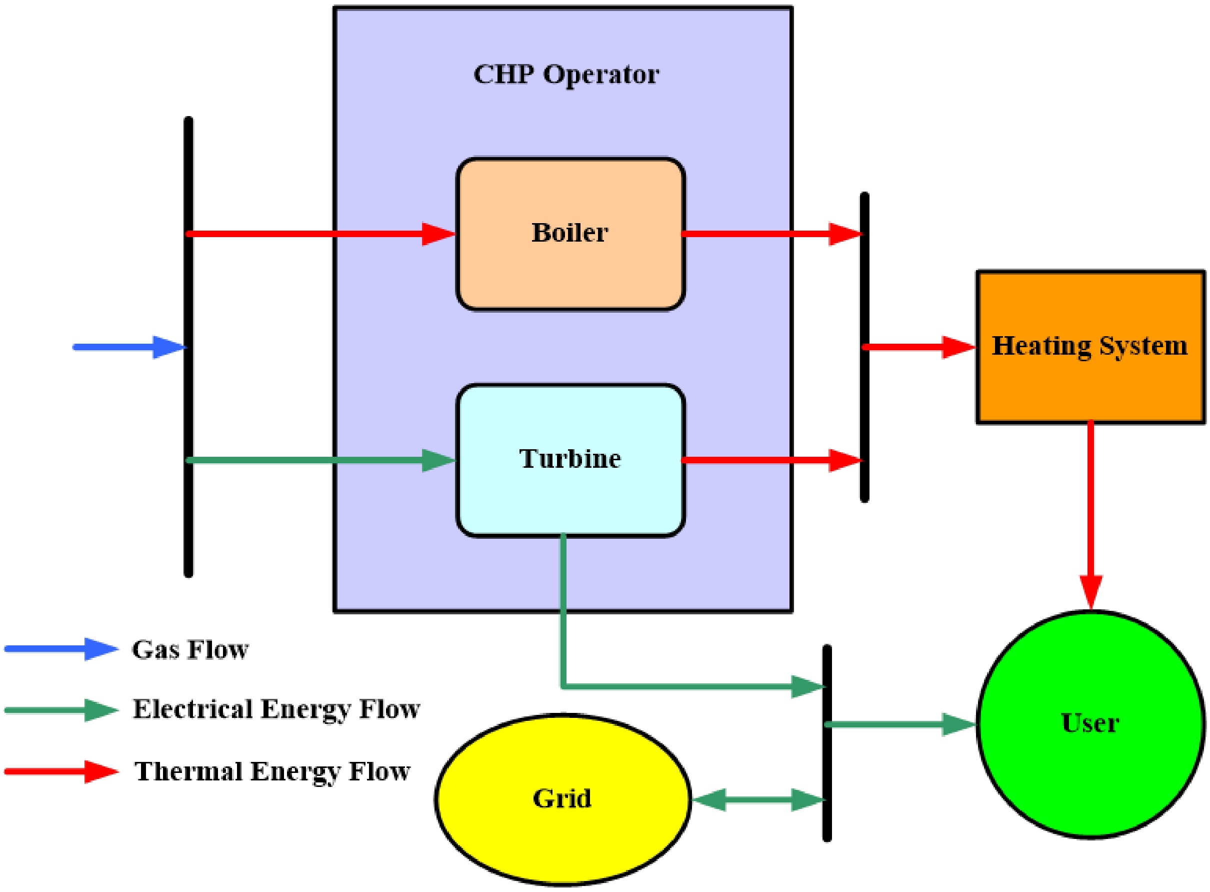

Figure. 4.1. CHP System

The microgrid architecture is presented in Fig. 4.2. Three different sections are combined in the microgrid and these are

- The power generating system i.e. CHP
- The prosumers
- MGO, the energy management system.

Six prosumers are considered here in the architecture. All prosumers are connected with a common bus. MGO regulates how much energy must be drawn from the grid or how much energy surplus is sent back to the grid. This framework is taken into consideration for the cooperative operation of the FTL/FEL modes of CHP and the PV prosumers inside the grid-connected MG with the prosumers' interface with MGO.

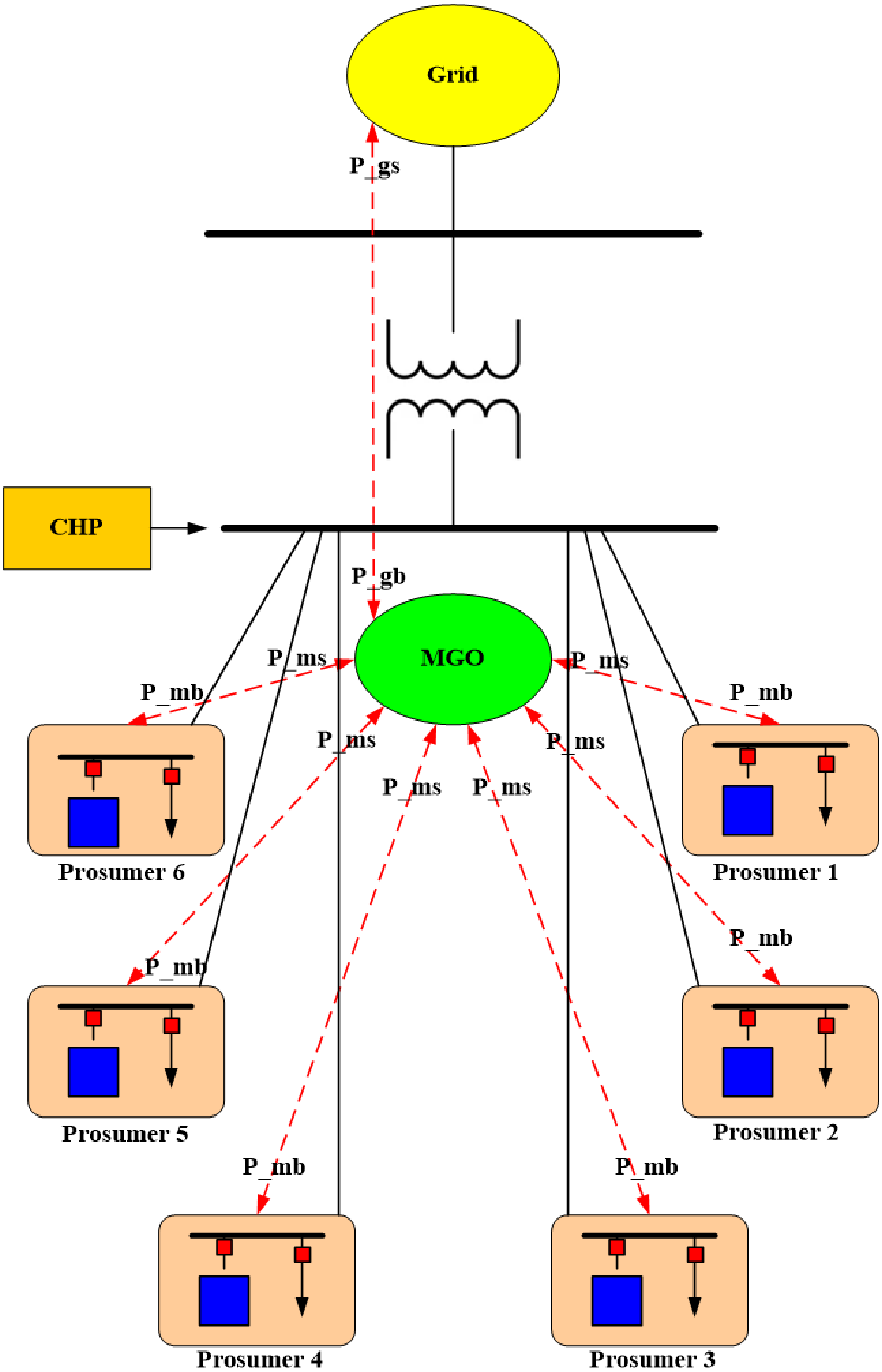

Figure. 4.2. Framework of Energy Management

PV. Prosumers are end users that have a PV system installed on their roof. The prosumers are able to supply and load energy onto the MG. In cases where the prosumers' overall consumption exceeds their self-produced PV energy, they can obtain additional energy from the MGO at an internal purchase price of P_mb. Prosumer can sell their excess energy to MGO for an internal selling price P_ms.

MGO is in charge of optimizing energy sharing between PV prosumers. The MGO is tasked with providing heat load to the prosumers in MG throughout the winter. In addition, it purchases electricity from the grid and from consumers who have excess power output, which it subsequently sells to the MG's end users. When there is an internal power mismatch between demand from load and generation from PV, the MGO schedules the demand from the grid to balance the demand and generation. P_gs and P_gb, respectively, represent the cost of importing and exporting energy. The Prosumers' internal selling and buying prices, represented by P_ms and P_mb, are also established by the MGO.

MGO’s profit is maximized by dynamically choosing the FTL and FEL modes of operation of the CHP system. This model takes into account the cost of gas, the profit from selling energy to consumers and end users, and the profit from selling excess electricity to the utility grid. Another working mode, called generation following hybrid load (FHL), is also explored. This mode uses FEL mode and FTL mode at different period of operation.

4.2. Modelling of Prosumer

Two distinct modes of generation are proposed in the study i.e. FEL and FHL. Electric appliance loads are also generally separated into two types: the variable load, which is adjustable and considered when scheduling, and the base load, which is fixed and unchangeable.

4.2.1. Electric Load

The two main categories of electric loads that prosumers often have are fixed loads and shiftable loads. The shiftable loads can be modified in terms of both the duration and the magnitude of the load.

4.2.1.1.Fixed Load

High reliability and a permanent or constant power supply are the two distinct needs of fixed loads. For everyday convenience, many loads like lights, fans, refrigerators, televisions, and so forth are considered fixed loads. For ith building and hth time slot the fixed load given as

$$EFL_i^h = [efl_1^1, efl_2^2, efl_3^3 \dots efl_n^h] \tag{4.1}$$

Where n denotes the total no of prosumers.

4.2.1.2.Shiftable Load

Prosumers who have shiftable loads can choose when to utilize electricity based on the cost of the power. Here, the end users are provided with certain movable loads (appliances or equipment) to utilize. Among these appliances are dryers, washers, and so forth. For ith building and hth time slot the shiftable load given as

$$ESL_i^h = [esl_1^1, esl_2^2, esl_3^3 \dots esl_n^h] \tag{4.2}$$

Where n denotes the total no of prosumers.

Hence the total load TEL_i^h can be given as the addition of the fixed load and the shiftable load.

$$TEL_i^h = EFL_i^h + ESL_i^h \tag{4.3}$$

Also, the net electric load can be given as

$$NEL_i^h = TEL_i^h - PV_i^h \tag{4.4}$$

Where, PV_i^h is the total solar based electrical energy generated by ith building in hth time slots.

$$PV_i^h = [pv_1^1, pv_2^2, pv_3^3, \dots pv_n^h] \tag{4.5}$$

4.2.2. Heat Load

The heat generated by the CHP is used to meet prosumers' thermal needs. The end user's thermal requirements could include heat for other household tasks and hot water throughout the winter. The heat demand for i^{th} building in h^{th} time slot can be given as

$$HL_i^h = [hl_1^1, hl_2^2, hl_3^3 \dots hl_n^h] \tag{4.6}$$

4.3. Profit Model of MGO

In addition to maintaining prosumers' profits, MGO is responsible for providing heat energy to prosumers in MG through the use of a model. Additionally, it buys electricity from prosumers and the grid that has excess power output, selling the extra electricity to the MG's end consumers. The MGO profit (Pro.mgo.g) for the h^{th} time slot from selling/buying power from the grid is as follows:

$$Pro.mgo.g(1,h) = -P.gs(1,h) * \min(Net.load(1,h) - ep.chp(1,h), 0) - P.gb(1,h) * \max(Net.load(1,h) - ep.chp(1,h), 0) \tag{4.7}$$

The following is the MGO profit (Pro.mgo.u) for buying/ selling power from the prosumer during the h^{th} time slot:

$$Pro.mgo.u(1,h) = (P.ms(1,h) * \max(Net.load(1,h), 0)) + (P.mb(1,h) * \min(Net.load(1,h), 0)) \tag{4.8}$$

The profit made by MGO (Pro.mgo.ht) by selling the heat energy to the consumer during the h^{th} time slot is listed as

$$Pro.mgo.ht(1,h) = ht.r * P.ht.sum(1,h) \tag{4.9}$$

The CHP running cost (C.chp) in h^{th} time slot can be given as

$$C.chp(1,h) = p.gas * (ep.chp(1,h) * L * n.chp) \quad (4.10)$$

By selling/ buying power, the total profit of MGO is given as

$$Pro.mgo(1,h) = Pro.mgo.g(1,h) + Pro.mgo.u(1,h) + Pro.mgo.ht(1,h) - C.chp(1,h) \quad (4.11)$$

In the above equations,

P.gs = Selling price of power to the main grid by MGO

ep.chp = CHP electrical power generation

P.gb = Buying price of power from the main grid by MGO

P.ms = Selling price of power to the prosumer by MGO

P.mb = Buying price of power from the prosumer by MGO

ht.r = rate of price of supplied heat load

P.ht.sum = total demand of heat by the prosumer

p.gas = price of natural gas

L = Heat content of natural gas

n.chp = CHP plants electrical efficiency

The costs associated with purchasing electric and thermal loads from MGO, selling electricity to MGO, and the government subsidies for using PV generation make up prosumers' overall profit. The profit of prosumer (Pro.prosumer) can be given as

$$Pro.prosumer(1,j) = ki * \ln\big(1 + total..load(1,j)\big) - P.ms(1,j) * \max(Net.load(1,j),0) - P.mb(1,j) * \min(Net.load(1,j),0) - ht.r * P.ht.sum(1,h) + pv.sum(1,j) * pv.rate \quad (4.12)$$

In the above equation, the amount of electricity supplied to the distribution system is denoted by pv_sum, while the government subsidy rate per kWh is denoted by pv_rate.

Fig. 4.3 represents the prosumer and MGO profit flowchart:

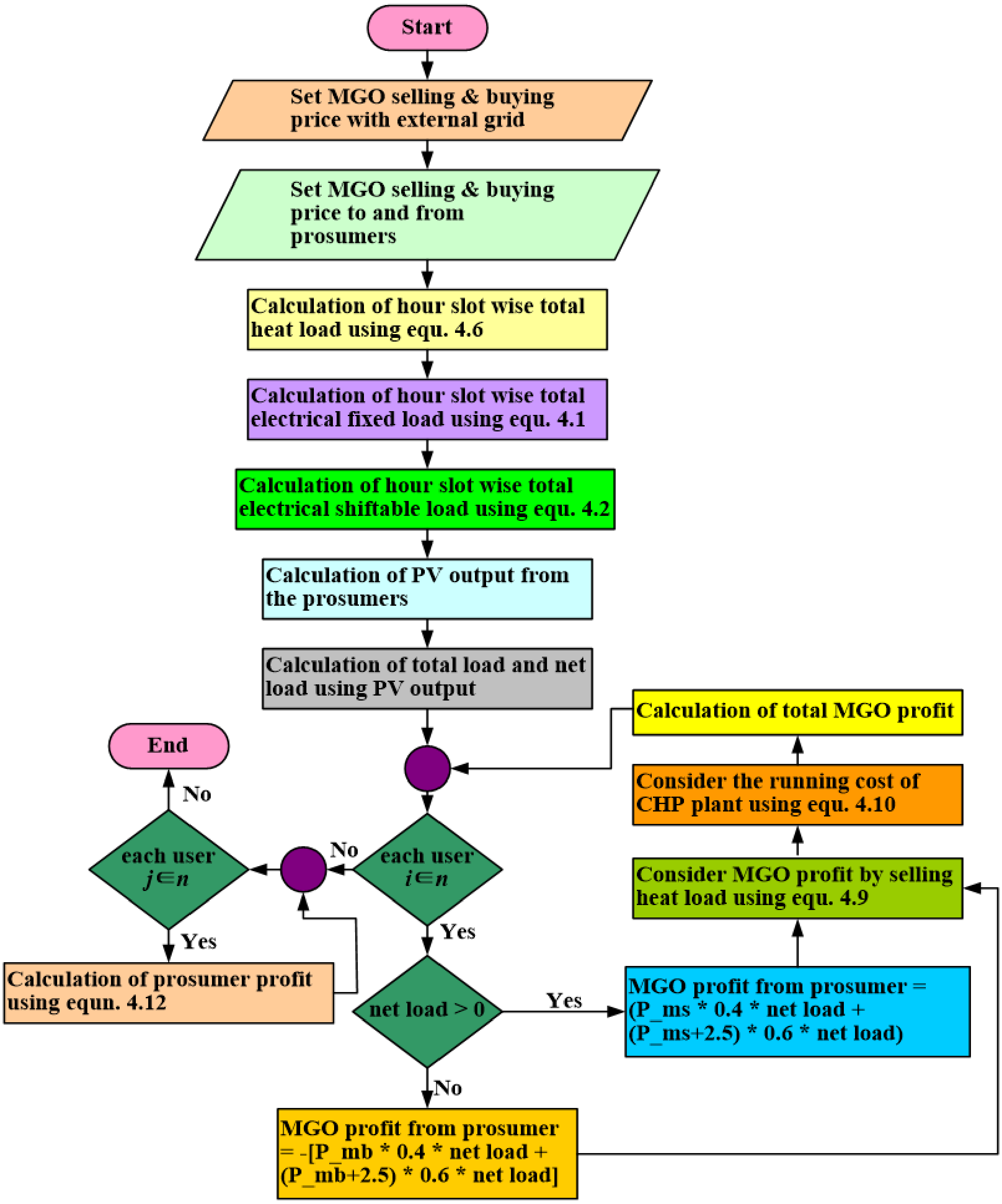

Figure. 4.3. Prosumer & MGO profit flowchart

4.4. Simulation and Result

4.4.1. Prosumer input data

Six residential buildings are taken into consideration as prosumers who belong to the MG. Figures 4.4, 4.5, and 4.6 show the prosumers' electrical fixed load, electrical shiftable load, and heat load, respectively. A day is divided into six slots, each of which represents four hours. The first slot is from 6 a.m. to 10 a.m., the second is from 10 a.m. to 2 p.m., and the sixth and last slot concludes at 6 a.m. the following day. Based on figures 4.4 and 4.5, the electric fixed load and shiftable load peaks are estimated to occur between 19:00 and 22:00 hours. The different prosumer's electric loads (fixed & shiftable) and heat loads are given in Table 4.1 below.

Table. 4.1. Prosumer electrical 7 heat load

Different Loading	Slots	Prosumer1	Prosumer2	Prosumer3	Prosumer4	Prosumer5	Prosumer6
Electrical Fixed Load	Slot 1	10	70	100	160	190	220
	Slot 2	20	60	80	120	150	180
	Slot 3	50	80	110	180	200	220
	Slot4	190	380	500	650	820	1000
	Slot 5	80	90	140	180	200	240
	Slot 6	20	20	80	100	160	180
Different Loading	**Slots**	**Prosumer1**	**Prosumer2**	**Prosumer3**	**Prosumer4**	**Prosumer5**	**Prosumer6**
Electrical Shiftable Load	Slot 1	100	150	350	480	600	600
	Slot 2	80	60	200	250	400	510
	Slot 3	70	80	250	300	350	400
	Slot4	350	600	900	1250	1500	1800
	Slot 5	50	80	200	180	200	200
	Slot 6	10	60	80	80	50	50
Different Loading	**Slots**	**Prosumer1**	**Prosumer2**	**Prosumer3**	**Prosumer4**	**Prosumer5**	**Prosumer6**
Heat Load	Slot 1	80	150	210	300	460	610
	Slot 2	90	160	230	310	490	640
	Slot 3	90	160	250	320	500	660
	Slot4	95	150	240	315	490	630
	Slot 5	80	150	250	315	490	630
	Slot 6	80	155	260	320	500	660

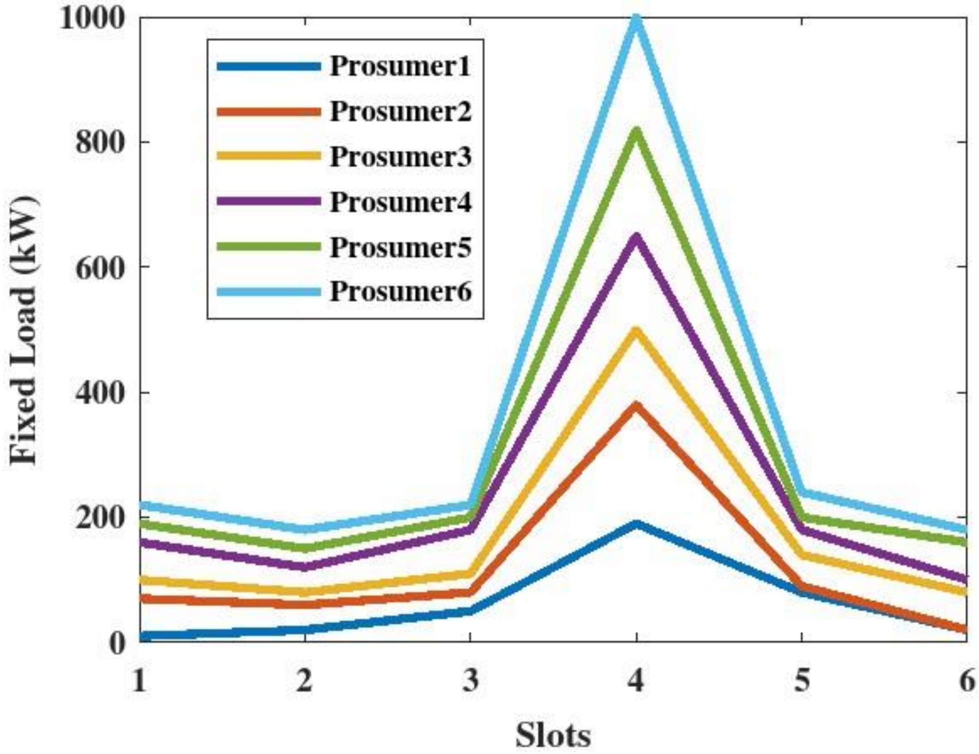

Figure. 4.4. Prosumer electrical fixed load

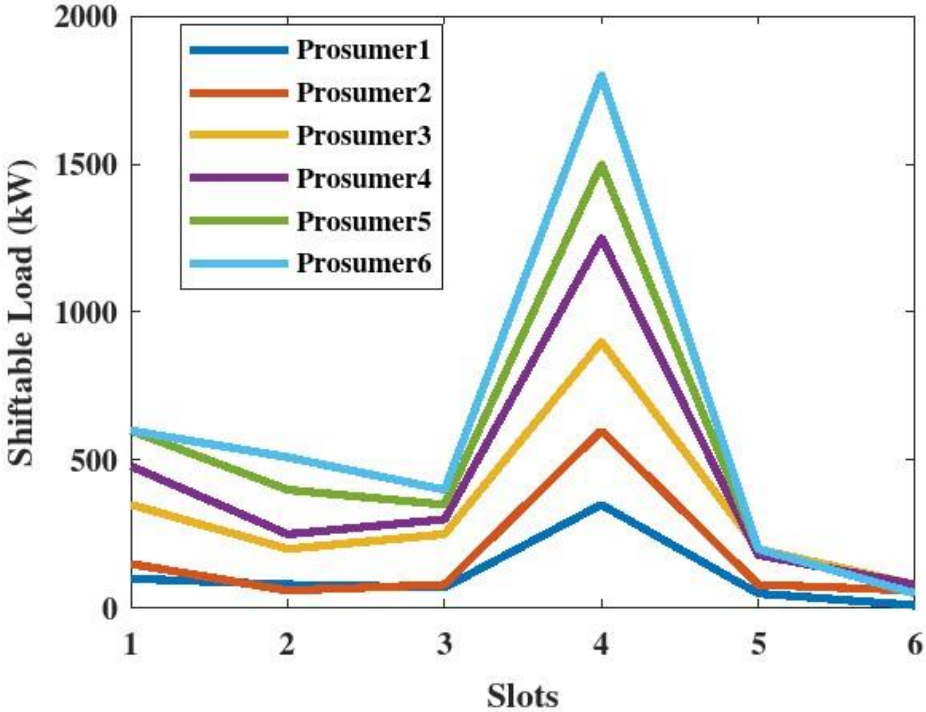

Figure. 4.5. Prosumer Electrical Shiftable load

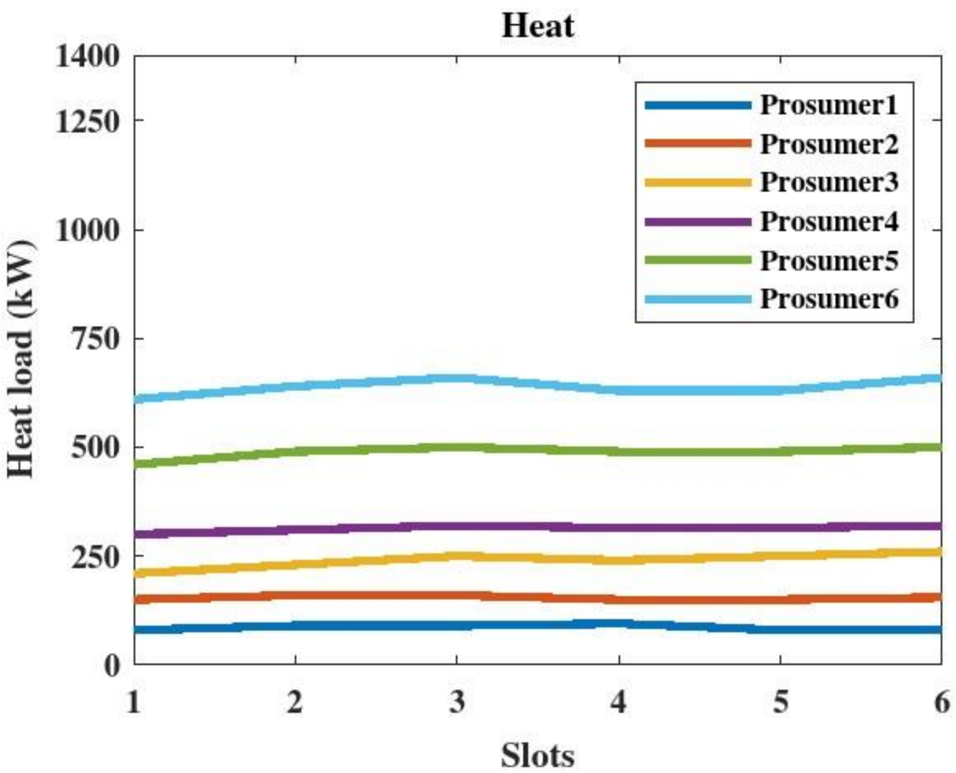

Figure. 4.6. Prosumer heat load

4.4.2. Profit calculation

4.4.2.1.Profit of MGO

Utilizing the MATLAB platform, the aforementioned model is applied to analyze and resolve the problem. Table 4.2 shows the total profit of MGO under various operating modes, such as following thermal load (FTL), following electric load (FEL), and following hybrid load (FHL) for two modes of operation i.e. without source (PV) at the end user and considering the source. Fig. 4.7, 4.8 & 4.9 shows the MGO profit without considering the source (PV) at end user and Fig. 4.10, 4.11 & 4.12 shows the MGO profit with PV source at end user. Also, Table 4.3 shows the total prosumer profit following thermal load (FTL) and following electrical load (FEL).

Table. 4.2. Profit of MGO at different modes of operation

Different Mode	MGO Profit (Rs)					
	Slot 1	**Slot 2**	**Slot 3**	**Slot 4**	**Slot 5**	**Slot 6**
Without PV Source						
FTL	11374.6	10898.2	10304.1	20352	9185.53	8424.22
FEL	82761.2	65520	45461.1	284820	26923.1	8959.9
FHL	82761.2	65520	45461.1	284820	26923.1	8959.9
With PV Source						
FTL	4768.73	4348.45	4762.53	20352	9185.53	8424.22
FEL	-10598	-15230	-14522	284820	26923.1	8959.94
FHL	4768.73	4348.45	4762.53	284820	26923.1	8959.94

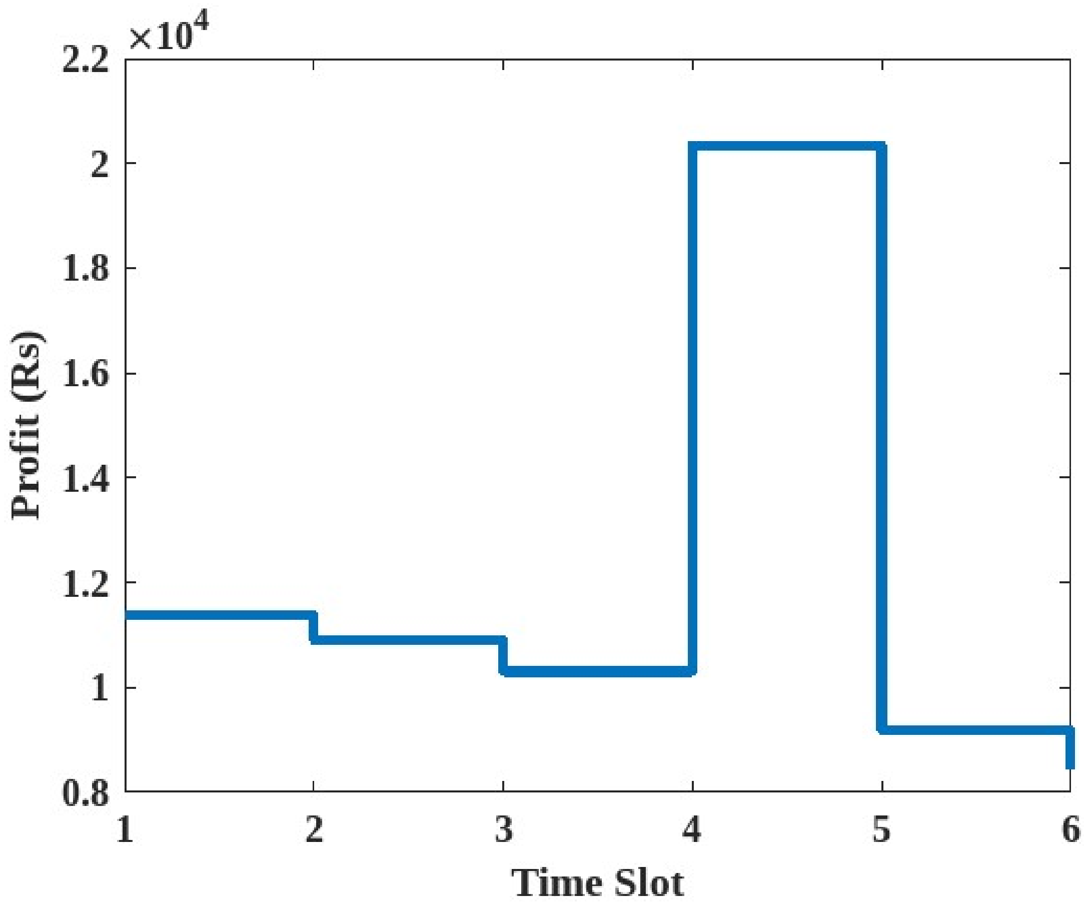

Figure. 4.7. Profit of MGO at FTL mode without PV

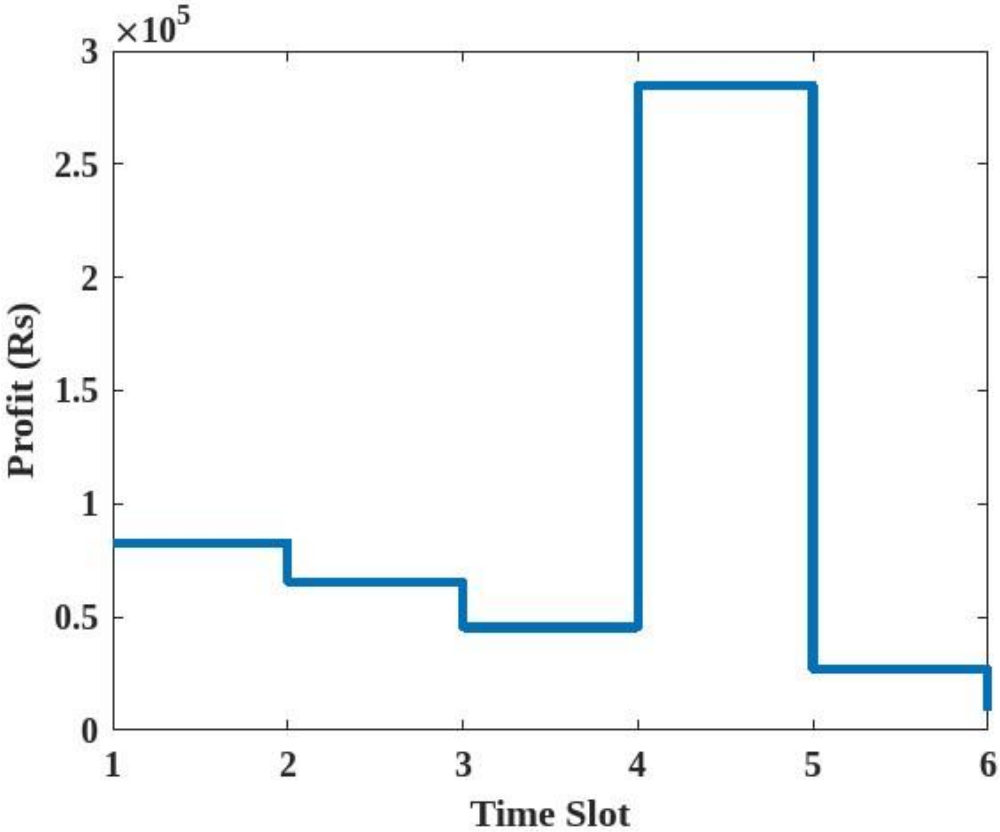

Figure. 4.8. Profit of MGO at FEL without PV

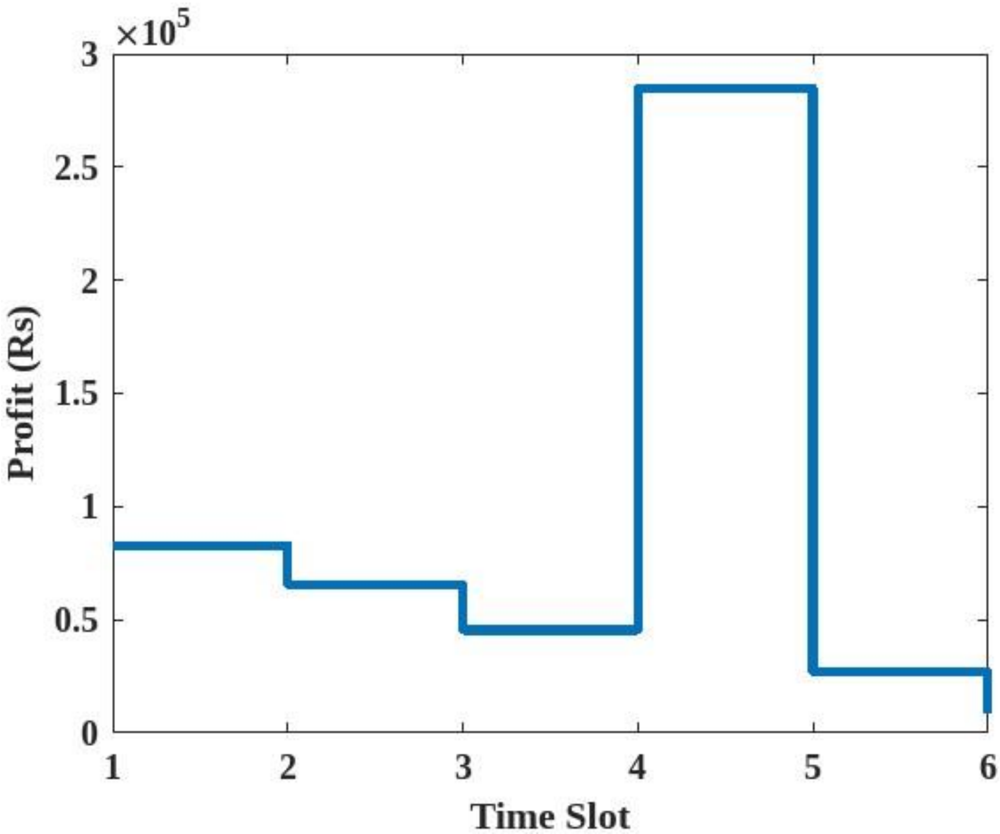

Figure. 4.9. Profit of MGO at FHL without PV

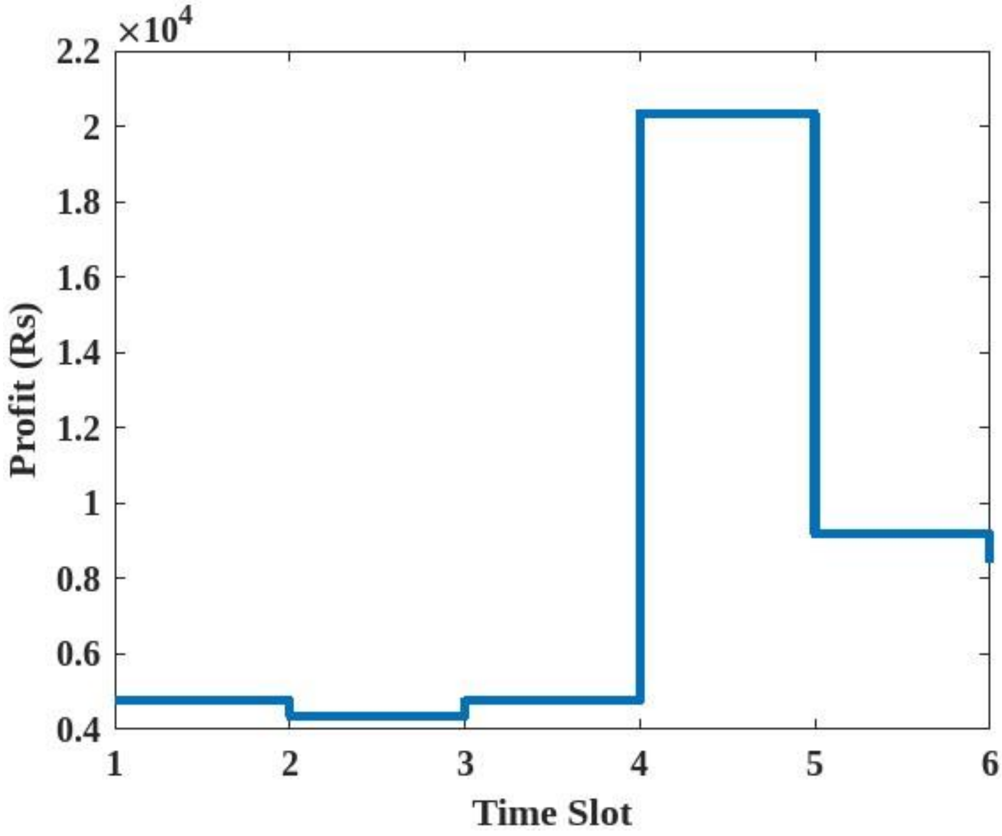

Figure. 4.10. MGO profit at FTL with PV

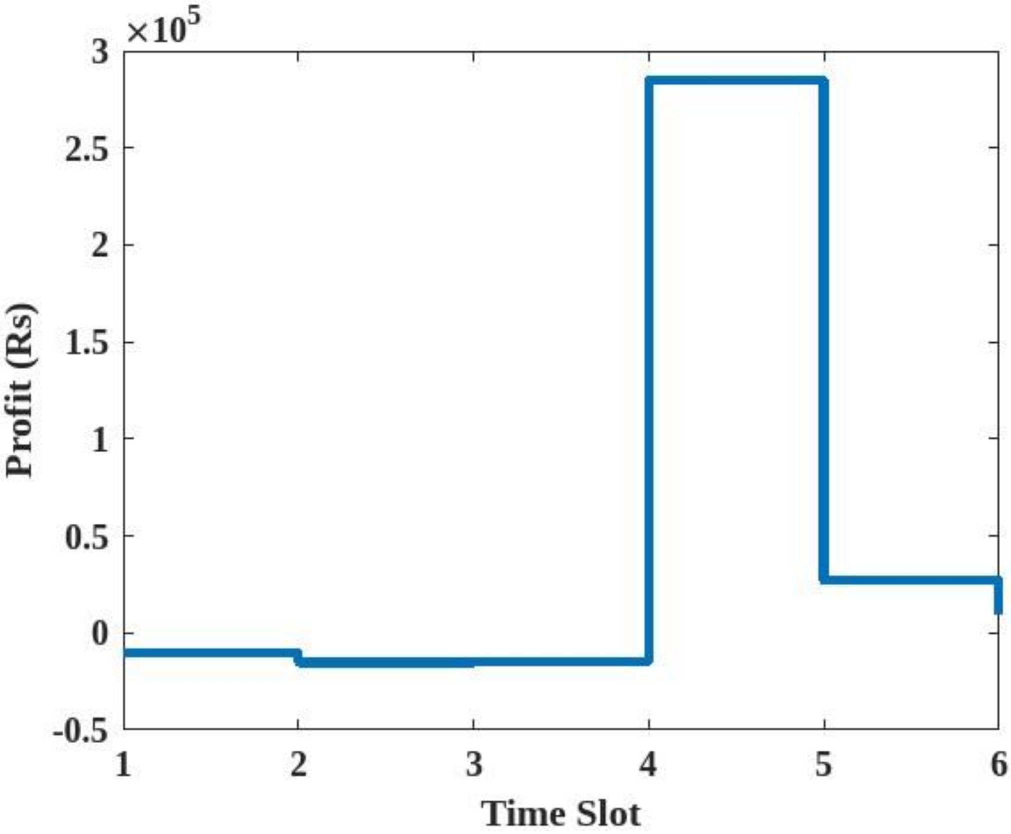

Figure. 4.11. MGO profit at FEL with PV

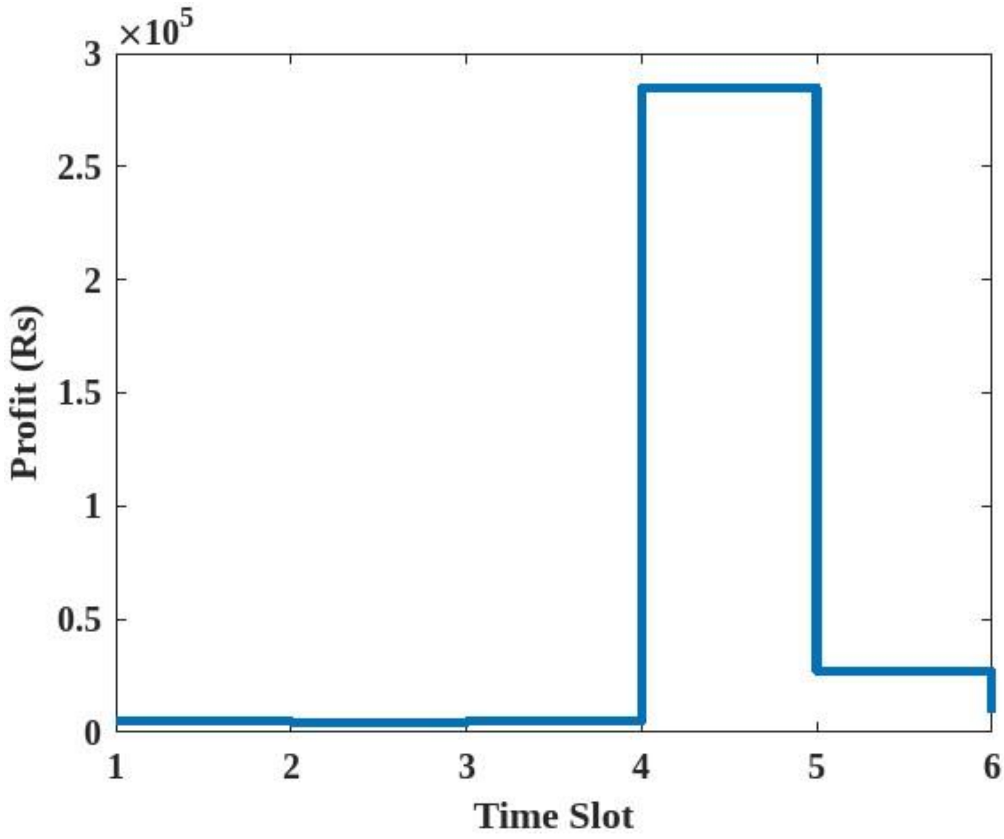

Figure. 4.12. MGO profit at FHL with PV

4.4.2.2.Profit of the Prosumer

In Table 4.3, the total profit made by prosumers at FEL, FTL mode, without PV, and with PV connection is displayed. Here, the prosumers' profit when they use PV sources to reduce their demand is shown by the positive sign, while their expenses when they operate without PV sources and purchase all of their necessary energy (electric and thermal) under the supervision of MGO are shown by the negative sign. Fig. 4.13, 4.14 represents the prosumer profit without considering PV sources and Fig. 4.15 and 4.16 depicts the prosumer profit considering the PV source.

Table. 4.3. Profit of Prosumer at different modes of operation

Different Mode	Prosumers Profit (Rs)					
	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6
Without PV Source						
FTL	-7665.8	-7686.7	-7718.1	-7547.9	-7761.6	-7850.5
FEL	-82958	-65560	-45325	-287032	-26633	-9086
With PV Source						
FTL	10511.8	12970.6	11299.5	-7547.9	-7761.6	-7850.5
FEL	-1931.1	-3500.7	-5228.4	-287032	-26633	-9086.9

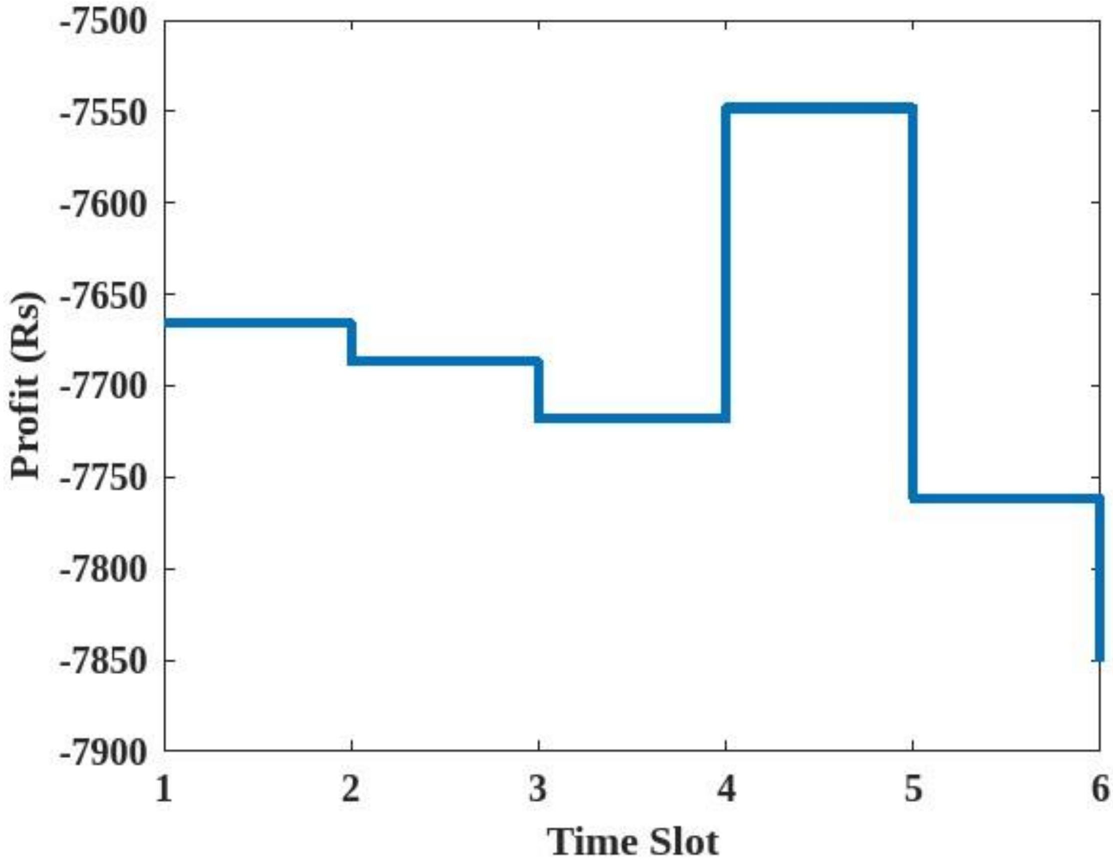

Figure. 4.13. Prosumer profit at FTL mode without PV

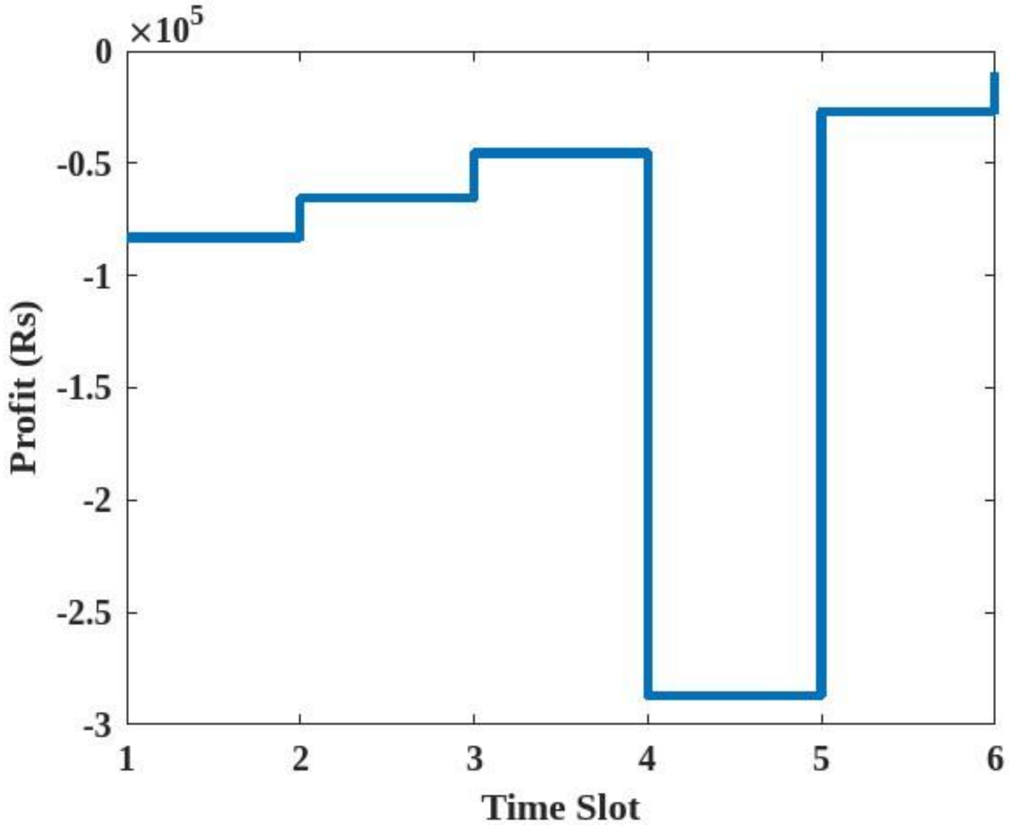

Figure. 4.14. Prosumer profit at FEL mode without PV

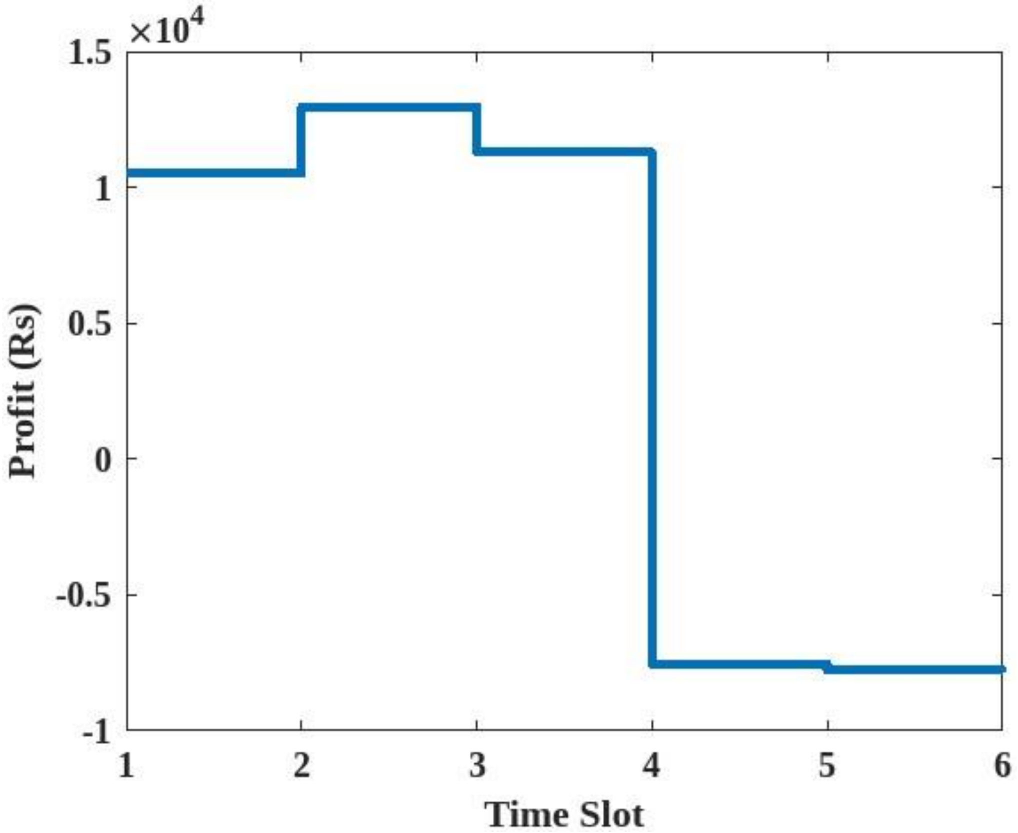

Figure. 4.15. Prosumer profit at FTL mode with PV

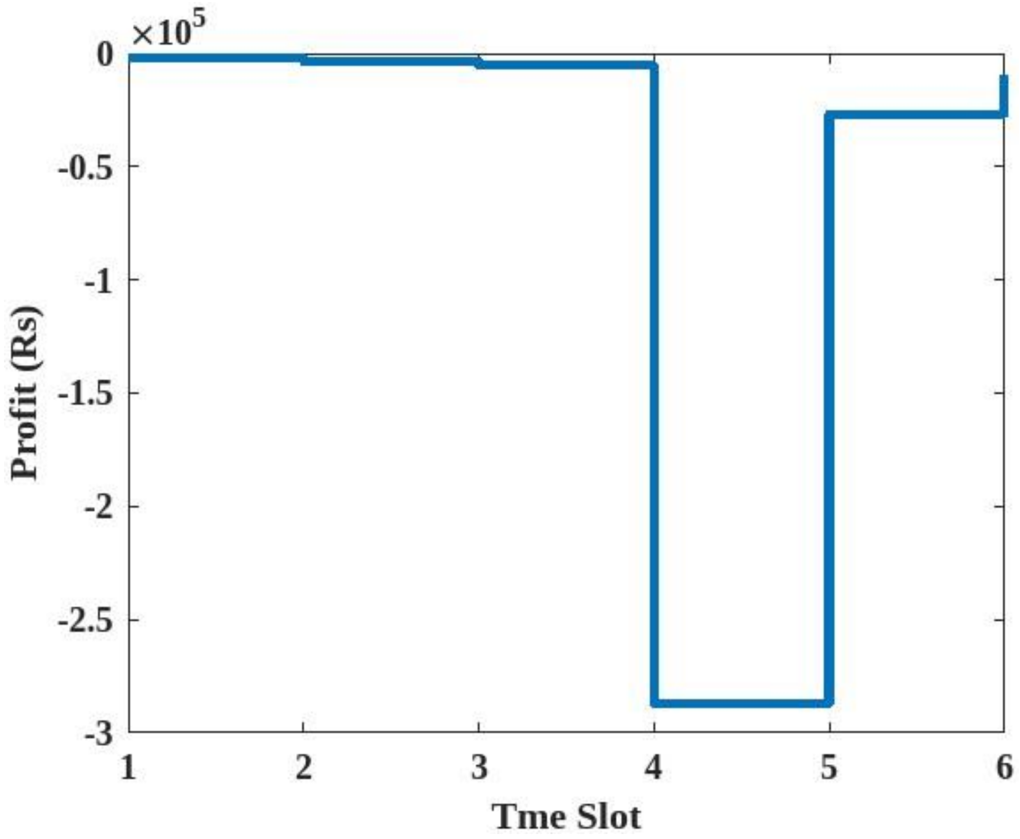

Figure. 4.16. Prosumer profit at FEL mode with PV

4.4.3. Comparison with existing mode of operation

The existing generation system follow the electrical load (FEL). This research proposes following hybrid load (FHL) which is a combination of FEL and FTL mode. A comparison of the two mode is examined in this section. The total profit for MGO in the existing mode is displayed in Fig. 4.17. Fig. 4.12 shows how much profit the suggested system would make utilizing the FHL mode. In Table 4.4, the hourly slot-wise and overall MGO profit for both the existing mode and the suggested mode are shown. When considering the full 24 hours of a day, it is noted that the overall profit of MGO is higher than that of the existing mode of operation.

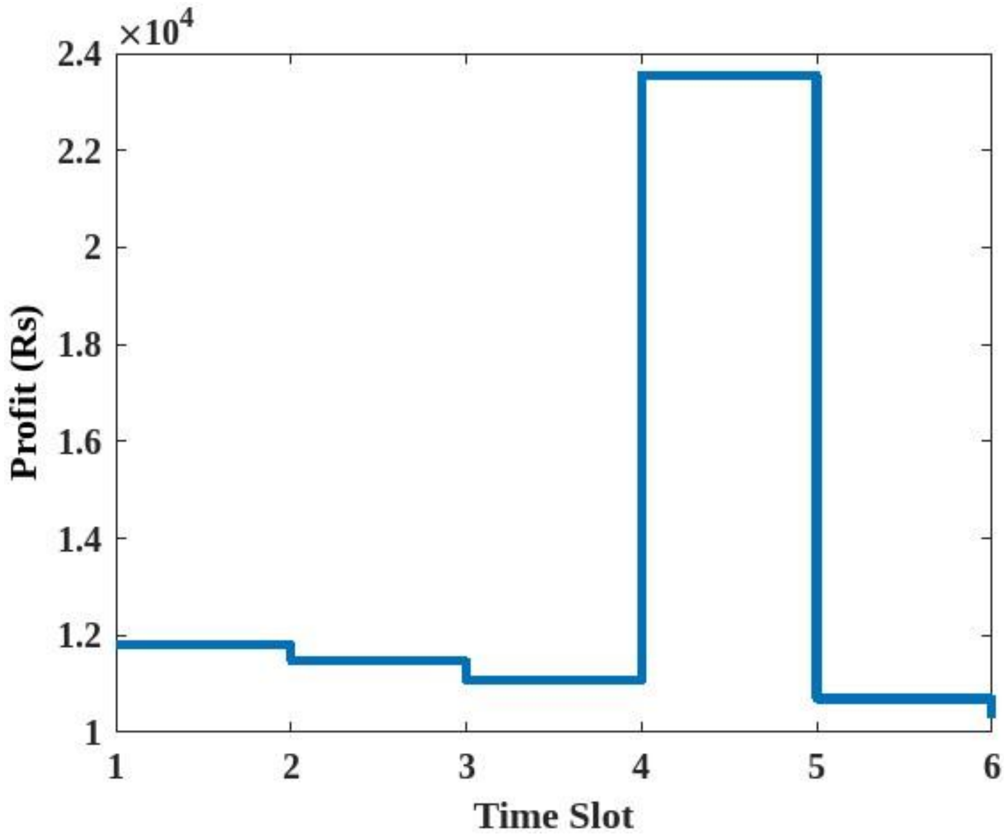

Figure. 14.17. MGO profit for existing mode of operation

Table. 4.4. Comparison of MGO profit for existing system & proposed model

Different Mode	**MGO Profit (Rs)**						
	Slot 1	**Slot 2**	**Slot 3**	**Slot 4**	**Slot 5**	**Slot 6**	**Total**
Without PV Source							
FHL	82761.2	65520	45461.1	284820	26923.1	8959.9	514445.3
With PV Source							
FHL	4768.73	4348.45	4762.53	284820	26923.1	8959.94	334582.75
Existing System							
FEL	11806.6	11466.6	11070.3	23560.6	10693.1	10284.1	78881.3

4.5. Conclusion

This study suggests an energy management system for consumers who are located in a grid-connected microgrid (MG) and have PV and CHP sources. There are two conceivable modes of operation: Following Electric Load (FEL) and Following Thermal Load (FTL). By utilizing FEL and FTL in different slots, one can create a hybrid of the two modes. In order to optimize end users' profit and MGO's profits through coordination between CHP and PV prosumers, the MGO's point of view takes precedence. Prosumer with rooftop photovoltaic source profits during the day time. During night time, as PV is not producing energy, it can still earn profit if it has sufficient battery storage capacity. The research shows that the profit for MGO is higher in the FHL mode when compared to only FEL or FTL modes of operation.

Chapter 5
Power Sharing in a Community Microgrid

5. Priority based Inter-microgrid Mutual Power Sharing in a Community Microgrid

A microgrid (MG) is a small, frequently decentralized collection of loads and power sources that functions as a single, regulated unit. Energy storage devices, such as batteries, conventional generators, and renewable energy sources (RES), like solar panels or wind turbines, are examples of distributed energy resources (DER) that can work alone or in tandem with the power grid.

To satisfy a larger community's energy demands, several localized energy systems must be integrated and coordinated to form a community microgrid consisting of numerous microgrids. This kind of setup is frequently called a "multi-microgrid" or "networked microgrid" strategy. A community microgrid is a small-scale, frequently decentralized energy system designed to meet the energy needs of a specific community, like a town, village, or neighborhood. To produce, store, and distribute electricity throughout the community, entails the connection of many DERs, energy storage, and sophisticated control systems. Increasing the local power supply's sustainability, resilience, and dependability is the main target of a community microgrid.

Important characteristics of a community microgrid are:

DERs: Community microgrids use different types of energy sources, including solar PV panels, wind turbines (WT), combined heat power (CHP) units, and other locally generated electricity sources. A dependable and sustainable energy supply is aided by this diversification.

Energy Storage: Batteries are a common type of energy storage equipment that is essential to community microgrids. When demand is low or renewable energy production is high, these systems store excess energy that may be used when demand is at its highest or when RES is not producing power.

Robust Control Systems: To oversee the operation of diverse energy resources inside the community, community microgrids depend on highly developed control systems. To keep the grid stable, these technologies maximize energy output, storage, and usage.

Grid Connectivity: Community microgrids have the option of running alone or connecting to the main power grid. Grid connectivity permits the interchange of electricity with the main grid, providing extra assistance in times of emergency or high demand. Increased resilience to grid failures is a result of autonomous operation.

Resilience and Reliability: Enhancing the resilience and dependability of the local energy supply is one of the main goals of putting community microgrids into place. Even when the grid is unavailable, the microgrid can keep vital buildings and services powered.

Sustainability: Using renewable energy sources is an essential part of community microgrids, which helps the community achieve its sustainability objectives and lessens its need for fossil fuels.

Community microgrids can be installed in a variety of locations, including access issues in rural places to dependable electricity and urban neighborhoods looking to increase their energy resilience. These microgrids, which are matched with the particular requirements and goals of the communities they serve, represent a localized and community-centric approach to energy generation and distribution.

Community microgrid (CMG) is created when many adjacent microgrids are linked together by a community interface controller. MG clustering is a novel idea to make use of nearby MGs' cooperative operation. To achieve the intended goals, which are made possible by the MG and CMG concepts, an energy management system (EMS) must be used [94]. The basic idea about CMG is given in [95]. Microgrids can collaborate with other adjacent microgrids for emergency backup and economic purposes. Combining the benefits of dc and ac microgrids could result in a CMG, which would also improve the dependability and financial performance of separate microgrid systems. Each microgrid would be linked to both the local microgrid network and the main grid independently. The benefits of CMG when it is linked with other MG via an ac bus is given [96].

Here, the primary goal is to feed any excess power generated by microgrids to the neighborhood's main AC bus, allowing other microgrids to use the electricity to make up for any power shortages at the appropriate times. A priority-based distribution algorithm will be used by community Microgrid controller (CMGC) to calculate the flow of excess power to the remaining microgrid on a priority basis.

The production of extra power has a limit. This extra power could compete with quite a few microgrids. The microgrids (one or more) that will receive this electricity, along with the amount and duration of operation, are prioritized. A prioritization-based distribution algorithm is the one created for the same purpose. This algorithm determines whether to allow or reject the microgrids' extra power through communications sent by the controller to their smart meters. When permitted to draw electricity, the smart meter will begin using the community bus for as long as it is permitted to. This is the extra electricity flowing in priority order. Microgrids that are discovered to consume more electricity than allotted, or for longer periods of time than allotted, will incur penalties.

5.1. System Model

A community interface controller is used to connect multiple microgrids in the neighborhood to create a community microgrid. With the help of the system, a community microgrid (CMG) including a few MGs, smart metering (SM) infrastructures, and data connectivity among the constituent parts are established. Every power transaction is monitored and recorded by a community microgrid controller (CMGC). It also computes fines on MG and creates contracts. Every microgrid will stay linked to the primary utility grid and maintain connections with other nearby microgrids. In order to handle crises and achieve financial objectives, each microgrid in the neighborhood can cooperate with other microgrids to supply backup power.

A network of 'n' connected MGs exists that has the ability to share power. The smart metering (SM) network that is built into every microgrid monitors how the MGs are linked to the community bus and computes the actual power consumption within the microgrid on behalf of the main grid. Any excess electricity in any of the microgrids inside the CMG is constantly looked into by CMGC. The CMGC will examine the demand conditions of the other MGs if it detects surplus power generated by any of the MGs. At the same time, if the controller detects that any MGs are experiencing a power outage, it will notify them of the excess power so they can use a priority-based distribution mechanism to draw the excess power from the community bus. Depending on the amount of demand in each microgrid—a hospital, an industrial, an academic department, etc.—the MG priority list is already in place with CMGC. Every MG has an SM to monitor the agreement-based power flow conditions between MGs. The MGs will be penalized if they begin to use power over what is agreed upon. Furthermore, by combining the advantages of both ac and dc microgrids, a community microgrid improves the dependability and financial performance of each microgrid.

The CMG arrangement is displayed in Fig. 5.1. Microgrids in the community range in size from MG1 to MGn. Microgrids are connected to both the grid bus and the community bus using the relevant community interface controllers (IC1 to ICn). Connecting to buses is done with selectable electrical switches. The switches for the grid bus go from Sg1 to Sgn, and the switches for the community bus go from Sc1 to Scn. With the assistance of CMGC, they may provide emergency backup and switch over the connection. Each microgrid controller (MC)

(MC1 through MCn) is unique to that microgrid. Any MG that generates excess power will notify the excess to CMGC.

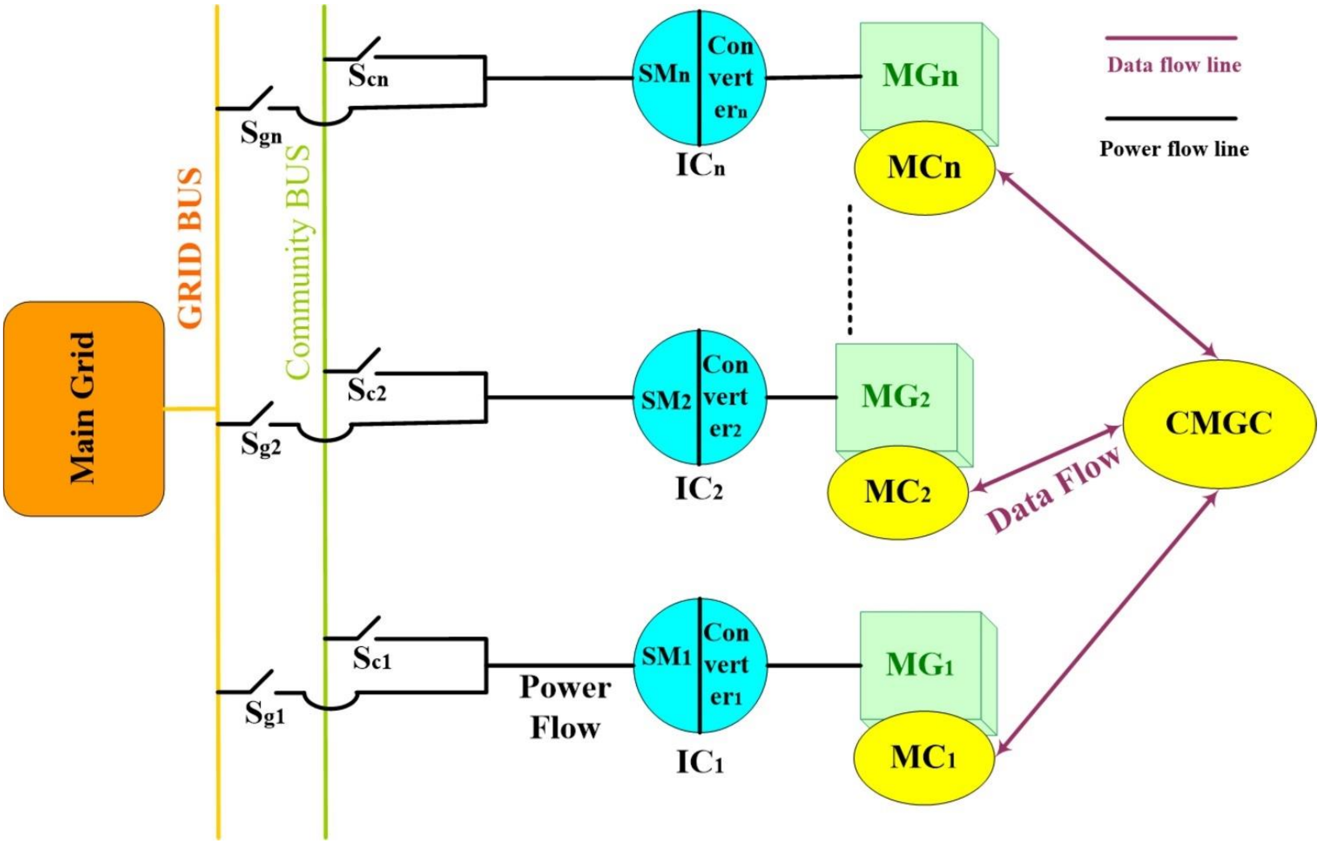

Figure. 5.1. Community Microgrid (CMG)

In essence, the ICs serve as a buffer between the microgrids, allowing them to operate independently. If there was ever an ac microgrid, the IC functions as an ac-ac or ac-dc-ac converter; in the event of a dc microgrid, it functions as a dc-ac converter. In the event of unintentional islanding, each microgrid's resilience is enhanced by having a backup connection with the utility grid.

Fig. 5.2 presents the comprehensive workflow of the CMG with assistance from CMGC. Any microgrid producing extra power in this case will submit the information to the CMGC, which will then initiate an inquiry into the other MGs' power conditions. CMGC will calculate the amount of surplus power that will be sent to those MGs through a previous arrangement if another MG or MGs at that time report a power requirement due to a shortfall. A priority-based distribution mechanism is used by CMGC to determine which MG will get extra power first.

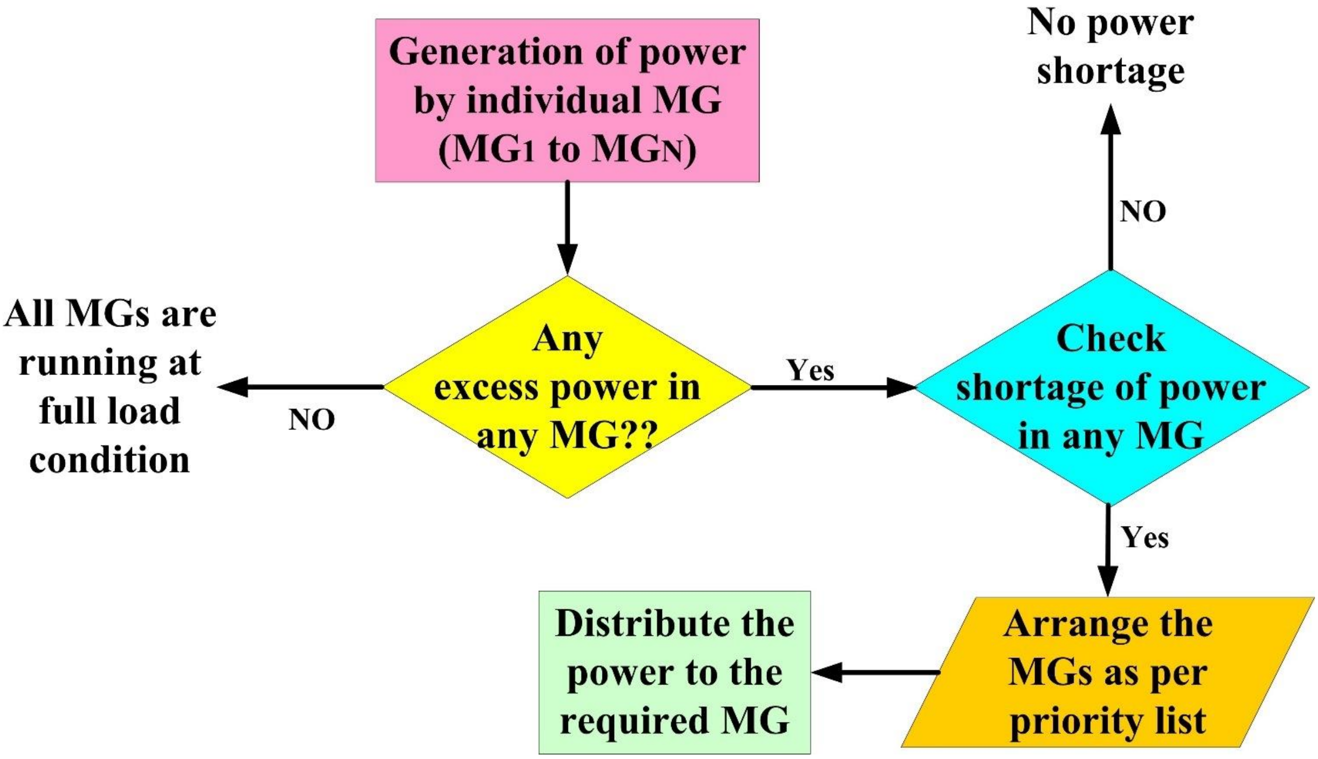

Figure. 5.2. Workflow Diagram

Let Pi stand for the surplus power generated by the source MG, Si and Xj for the excess power that Bj is now using, and let Bj represent the MGs that are experiencing a power outage and reporting it to CMGC. The extra power that the MG source produces is:

$$P_{excc} = \sum P_i, \qquad i \in y \tag{5.1}$$

Here, y is the source MG, where y < n.

The total consumed power by the MGs who are facing power outage problems,

$$X_{short} = \sum X_j, \qquad j \in (n - y) \tag{5.2}$$

If multiple MGs file reports of power outages, CMGC will utilize the priority list to decide which MG will get power first. Every MG has an SM system available to monitor the power delivery status; fines will be applied if any MG is discovered to be over the agreed-upon power consumption. If multiple MGs report a power shortage, the arrangement will be as follows: the MG with the greatest priority will be the first to receive the required power, followed by the MG with the second highest priority, and so on.

The excess power will be distributed equally among the MGs if the power shortage reports that arrive from them are at the same priority level and can be calculated as follows.

$$X_{equ} = \frac{P_{excc}}{n-y} \tag{5.3}$$

Penalties will be imposed on each and every MG that breaches the terms of the contract. These are calculated about power and charged at 10% of the main grid rate (SR_{main}). An MG is assessed a penalty ($X_{Penalty}$) at a rate that is 10% greater than that of the main grid if it uses more power (X_{extra}) than what is specified in the contract. The penalty can be calculated as:

$$X_{Penalty} = \left(X_{extra} - X_{equ}\right) * 1.1 * SR_{main} \tag{5.4}$$

The advantages associated with the given architecture are as follows:

- Individual microgrids do not have to exchange information about their power needs with one another. When a crisis arises, the IC of each MG can send any extra power to the community bus so that others might use it.
- A high-bandwidth connecting path between each MC is not necessary.
- Connectivity between any two microgrids or high-bandwidth cables is not economically feasible or practicable owing to the risk of a breakdown in communication, increased cost, complexity, and poor robustness as a result of unknown communication parameters. Therefore, it would be best to cut off these channels of contact.

5.2. Distribution Algorithm

A community interface controller is employed to connect each and every microgrid in the CMG setup shown in Figure 1 with other microgrids via a community bus. When a microgrid on a CMG's power generation isn't fully consumed by its own load, any extra power can be shared by other MGs on the same CMG with the assistance of the CMGC. The excess report is communicated with CMGC, and the excess electricity is sent to the community bus. In the meantime, the controller processes the extra power in the community bus to the necessary MG if it receives a notification of a power outage. Multiple microgrids may simultaneously provide reports on power shortages. The MG/MGs that will get the excess power sharing after that will be decided by CMGC using a priority-based distribution process. Priority-based load distribution in a community-based microgrid refers to the distribution and management of electricity loads based on predefined priorities.

Collaboratively managing energy resources to improve sustainability, efficiency, and dependability is part of sharing power within a community microgrid. Community microgrid can be powered by the following broad plan for power sharing:

- Install a centralized EMS to keep an eye on, manage, and improve the community microgrid's overall performance. All of the community's microgrids should provide real-time data on energy generation, consumption, and storage to the EMS.
- Establish who is responsible for administering and maintaining the community's microgrids, as well as clearly defining each one's limits. Identifying the resources (generation, storage, etc.) that each microgrid is in charge of is part of this process.
- Connect the microgrids both electrically and physically to enable power exchange. To provide smooth power sharing, this would entail installing switchgear, communication infrastructure, and smart inverters.

- Determine most important community loads and should be given priority to ensure a steady and dependable power supply. Make sure that during power sharing and distribution, these vital loads are sufficiently maintained and safeguarded.

Provide resilience strategies for the community microgrid that address islanding capabilities, energy storage technologies, and backup power sources. Make backup plans so that in case of emergencies or other disruptions the community can carry on with business as usual.

Fig. 5.3 shows the flowchart for the priority-based distribution algorithm.

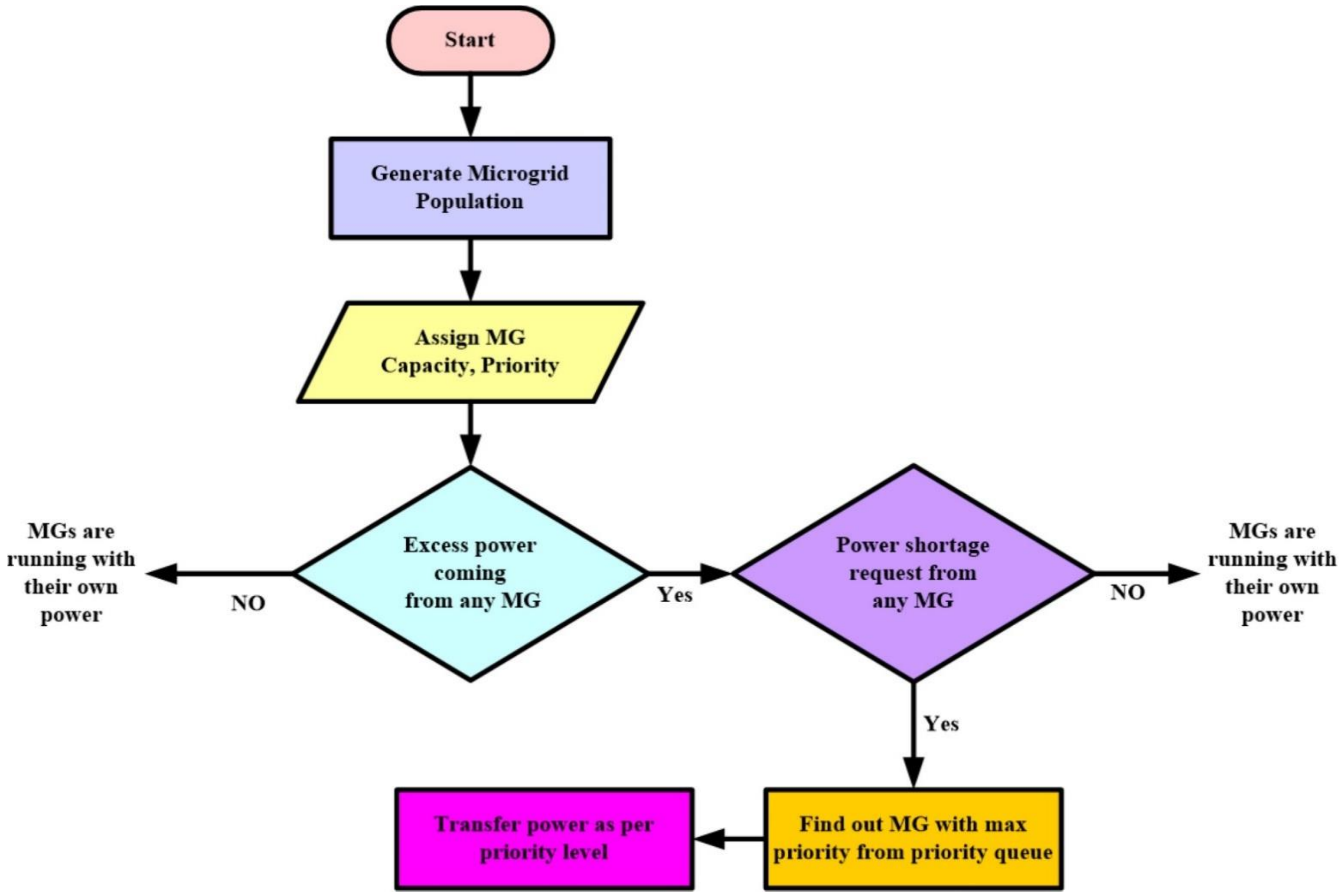

Figure. 5.3. Flowchart of Distribution Algorithm

A community microgrid can effectively transfer electricity across its microgrids and promote resilience, sustainability, and energy efficiency for the whole community by putting into practice a comprehensive approach that considers these concerns.

If numerous MGs submit reports to CMGC about their power shortage issues, CMGC will use a priority-based distribution algorithm to determine how much power to provide to each MG depending on its need. A variety of case studies are used to analyze various scenarios. For every microgrid that was included in the case studies, the peak voltage and frequency were 500V and 50Hz, respectively.

5.2.1. Case Study I

Figure 5.4 illustrates the allocation of power to the necessary MGs according to their priority when a power shortage report is received by CMGC from various MGs with varying levels of priority.

According to Fig. 5.4, CMGC received power shortage reports from four separate MGs, of which MG2 has the highest priority level based on its current load and delivered a 3kW power shortfall report. Once it has used all of its energy, the remaining power is given to MG4, the second priority level MG. With MG5, the same procedure is followed. However, as no excess power is available with the source MG, it won't be possible to satisfy the need of the fourth level MG. In Fig. 4, the power availability scenario is explained.

The state of power availability in various MGs is displayed in Fig. 5.5. The first MG, or source MG, is producing 15kW of power, of which it is using 8kW. The remaining 7kW of power can be delivered, under CMGC's management, to the community ac bus. A power deficit report is simultaneously sent to CMGC by MG2, MG4, MG5, and MG7. Commands on the schedule of power allotted to MG2, MG4, and MG5 are sent from CMGC to them based on their priority level. No power is scheduled for MG7 because there is no excess power in the source MG following power sharing with these three MGs. From the surplus 7kW, MG2 will receive 3kW of power, with a range of 6kW to 9kW, in response to their claim of a 3kW power shortage. MG4, the second priority level, will receive the 3kW deficiency power, boosting its output from 10kW to 13kW. MG5, the third highest priority level MG, is the one that delivered the report regarding the 2kW power deficit. MG5 is only given 1kW of power because that is all that is available, even though it is capable of producing 13 to 14kW.

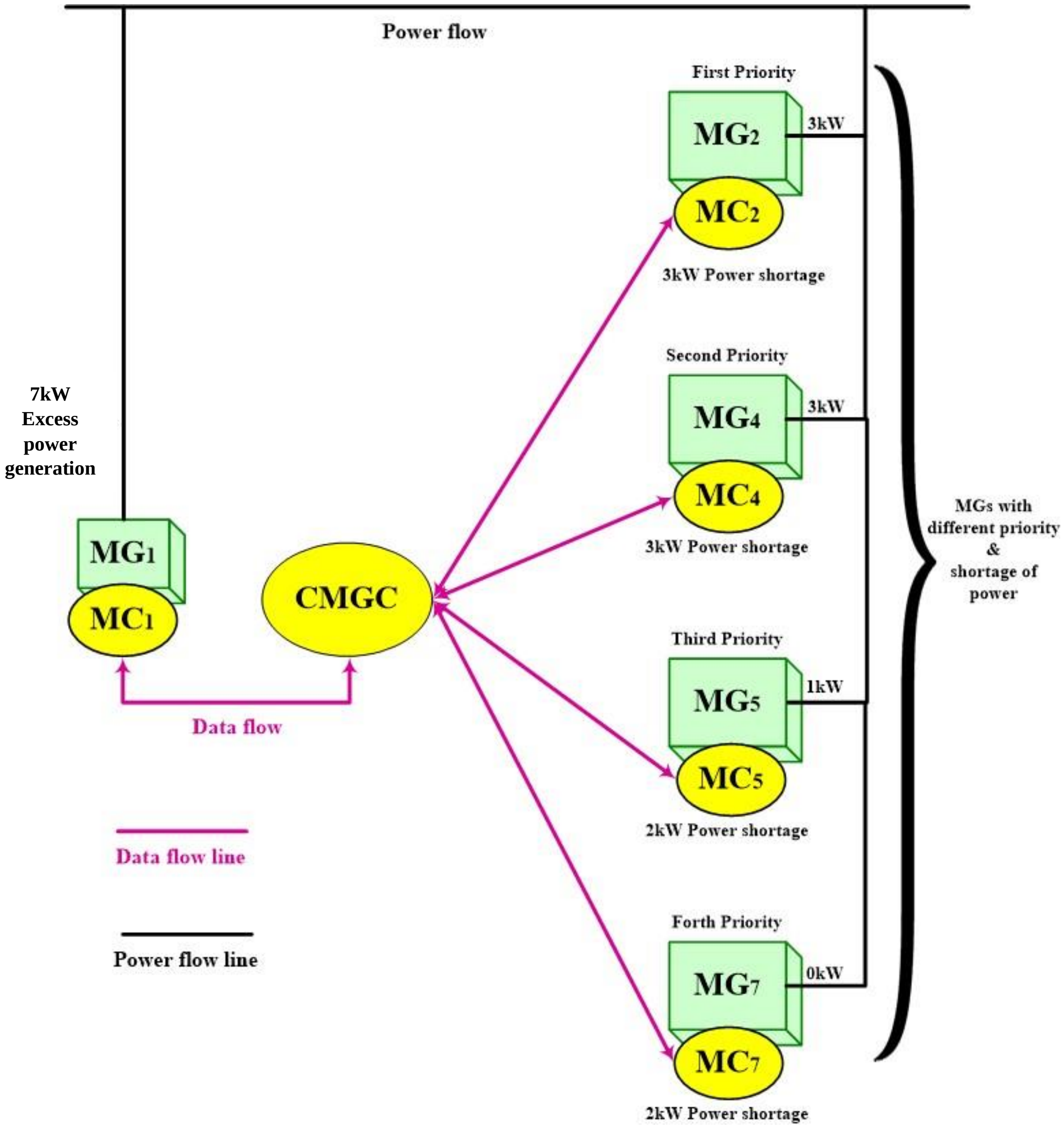

Figure. 5.4. Priority based distribution of power to the MGs

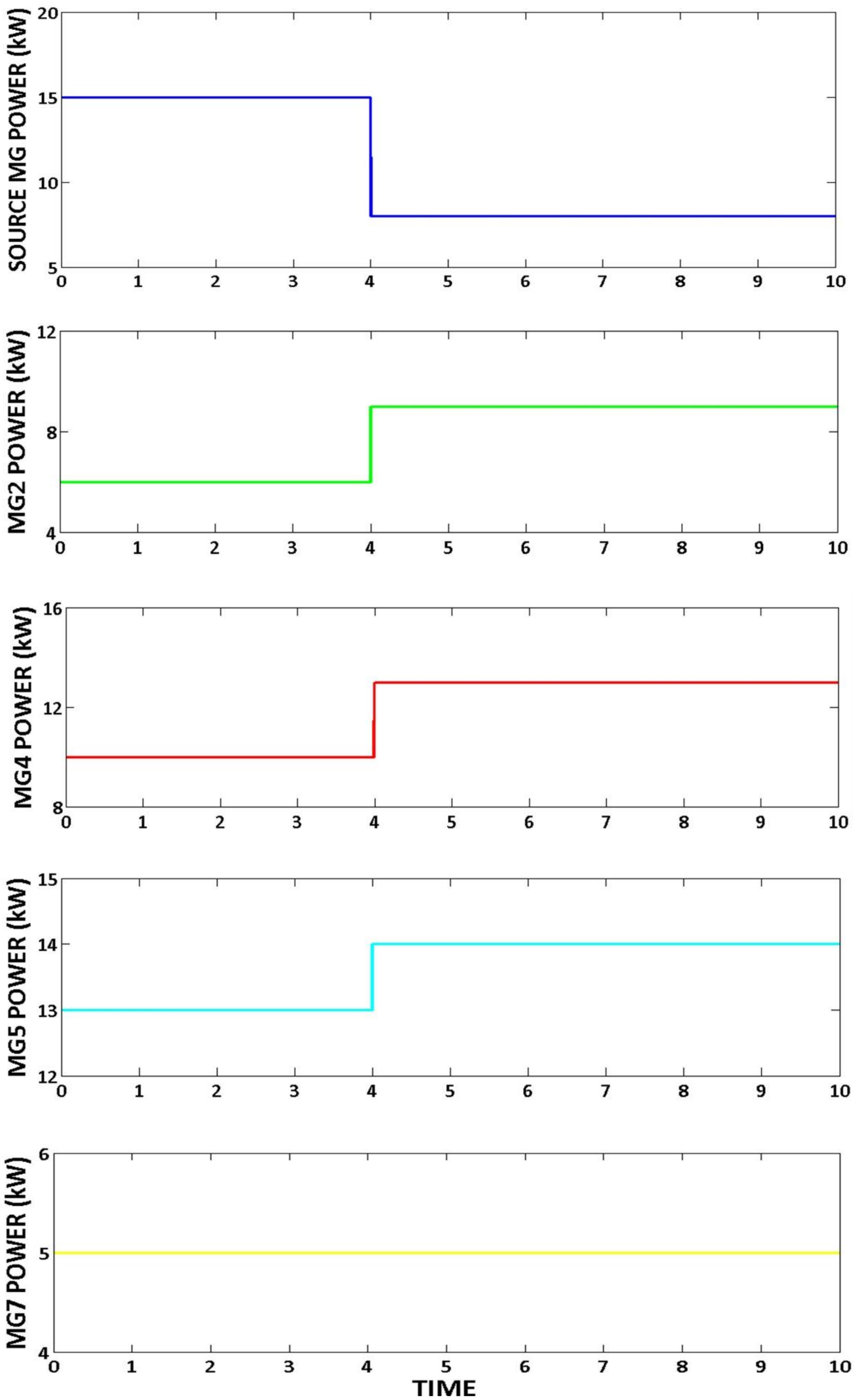

Figure. 5.5. Simulation of Case Study I

5.2.2. Case Study II

As illustrated in Fig. 5.6, the CMGC chooses to distribute power to the necessary MGs equally upon receiving a power shortage notification from various MGs that are at the same priority level.

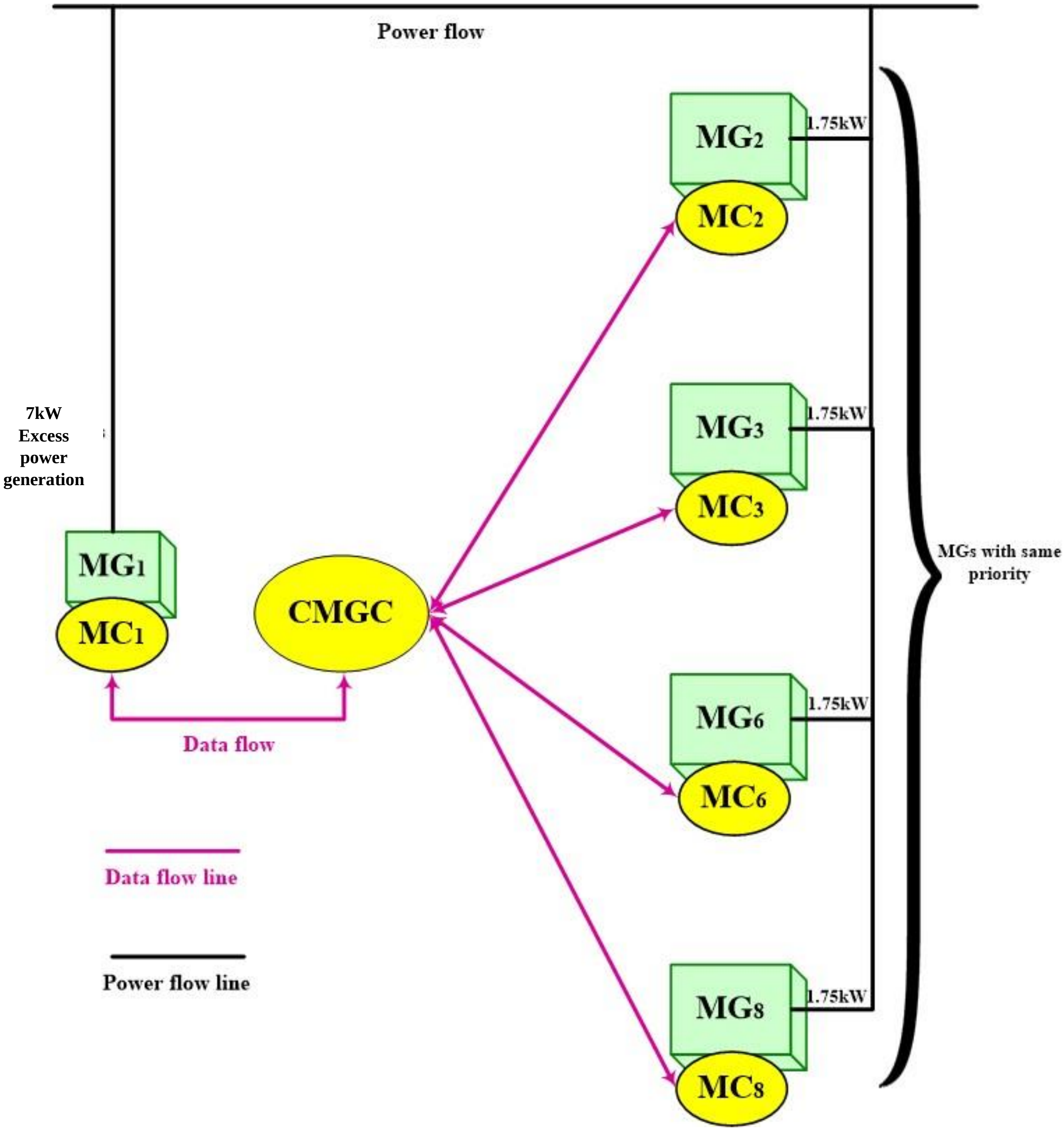

Figure. 5.6. Distribution of power to the MGs with same priority level

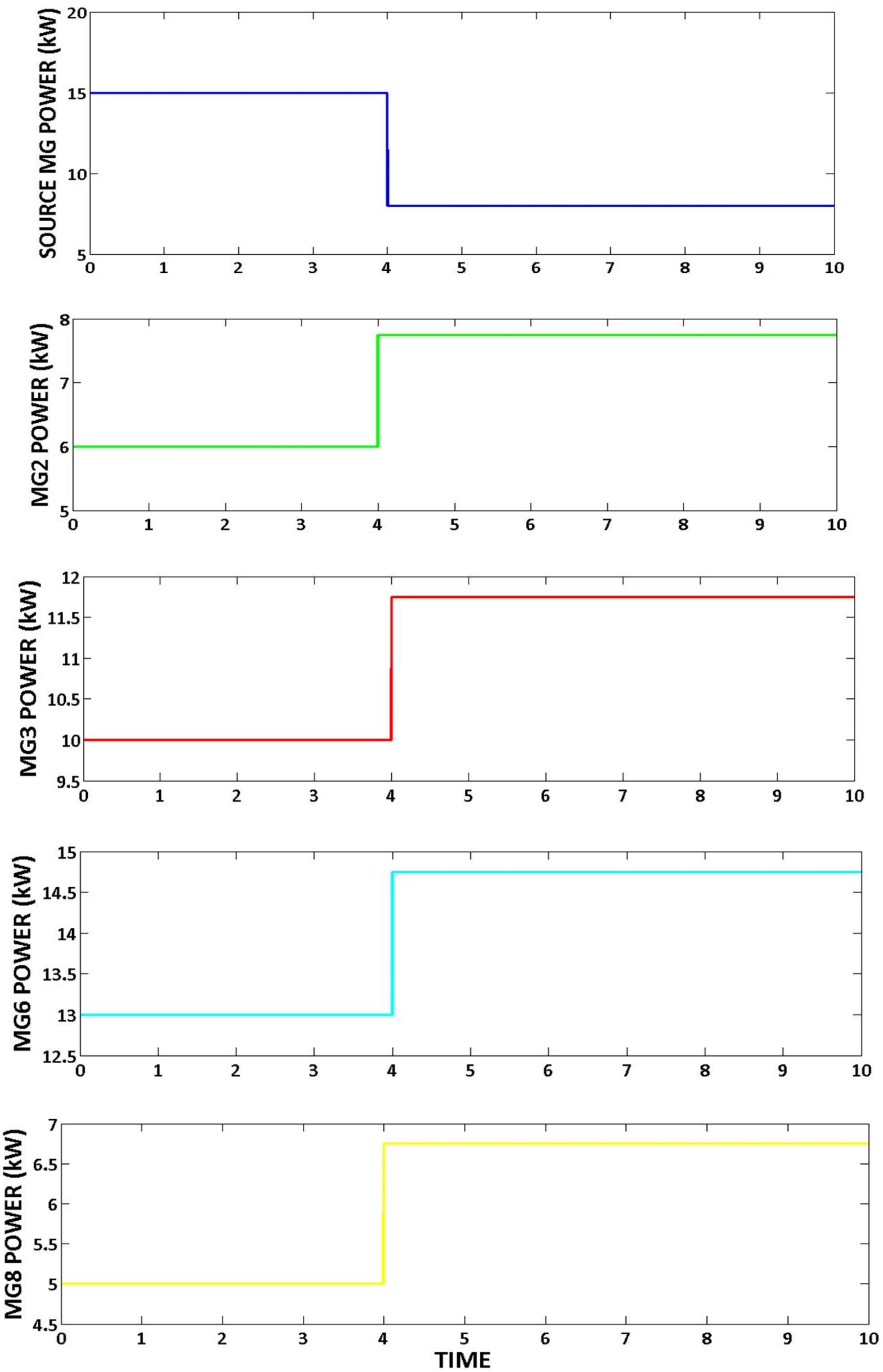

Figure. 5.7. Simulation of Case Study II

The case study II power distribution is shown in Figure 5.7. The data presented in Figure 5.7 indicates that the 7kW extra power being used by source MG, or MG1, is being sent to the community bus. Meanwhile, reports of power outages from MG2, MG3, MG6, and MG8 arrive at CMGC. The extra power from the source microgrid will be distributed evenly among the four MGs because, according to CMGC, all four are on the same priority level.

5.2.3. Case Study III

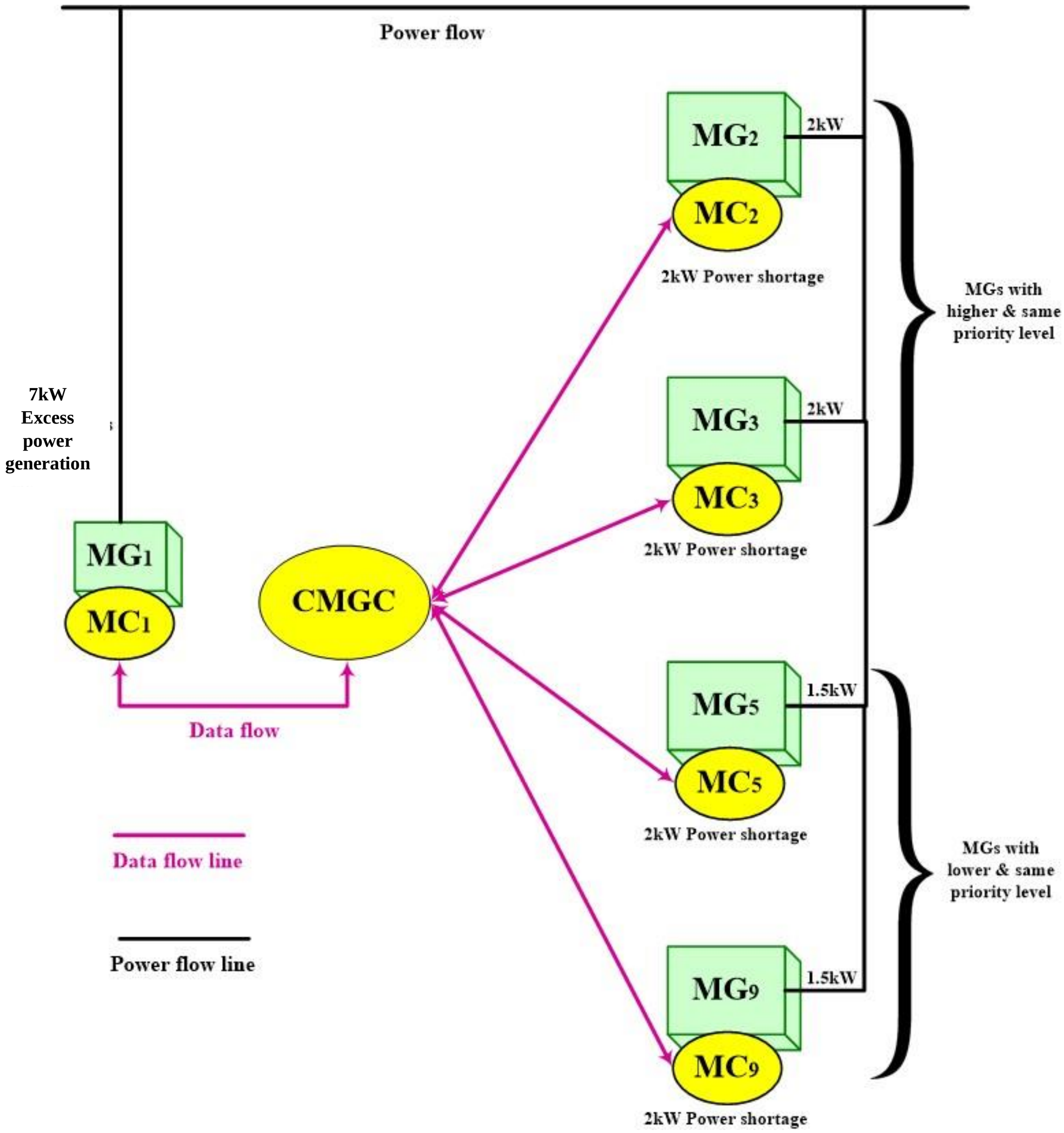

Figure. 5.8. Distribution of power to more than one MG with the same priority level

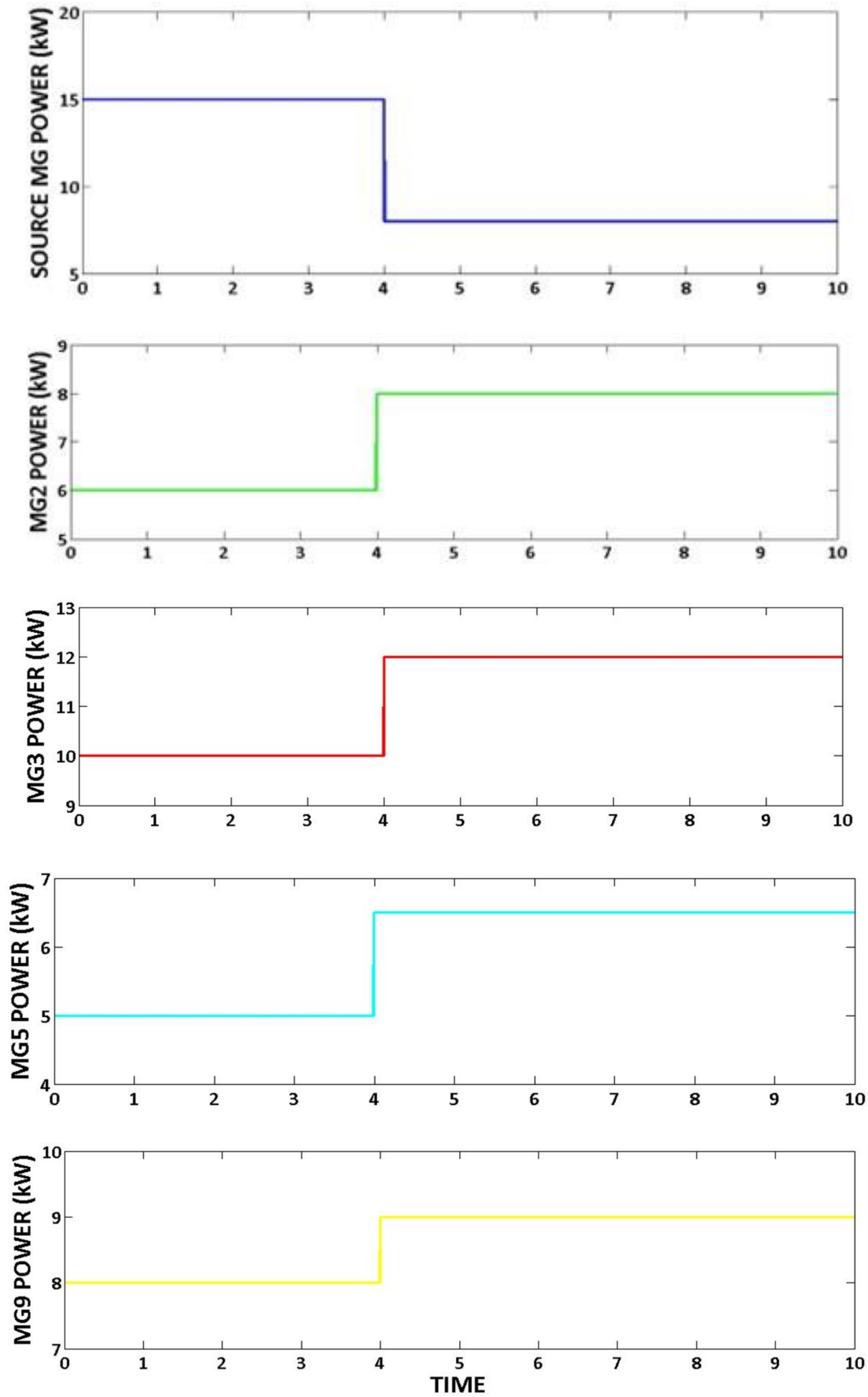

Figure.5.9. Simulation of Case Study III

Figure 5.8 illustrates the power distribution to the MGs in question when many MGs in the same priority submit CMGC a report on a power shortfall. MG2 and MG3 are given precedence in this case since their priority levels are equal. Following their fulfillment of conditions, MG5 and MG9 are given second priority. The same amount of electricity is allocated to MG5 and MG9 because they are on the same priority level.

When there is surplus power available on the community bus, Fig. 5.9 displays the power drawn by the MGs. MG2 and MG3 are shown in Fig. 5.9 as having the same priority level and having each submitted a request for 2kW of power. Additionally, MG5 and MG9 submit requests for 2 kW of power from each MG and are on the same priority level. MG2 and MG3 receive their requests first since they have a higher priority level than the other two MGs. Following the delivery of excess power to MG2 and MG3, the remaining 3kW excess power will be shared equally with MG5 and MG9 because the other two MGs are on the same priority level.

5.3. Community Microgrid Simulation

Fig. 5.10 shows the operating simulation cases for a community microgrid. Here, bus number one (B1) is connected to VSC 1. For the VSC to be used as a microgrid controller for the MG, it must be properly regulated as a power electronics converter. The VSC 1 and Pulse Width Modulator (PWM) controller 1 work together to create the microgrid controller, which regulates the voltage and frequency. To store electrical energy, one battery is linked to VSC 1. Bidirectional energy flow is made possible by the VSC. Because of their constant fluctuation in voltage based on factors like reactive power, the VSCs are typically not connected directly to the bus. So, between the bus and the VSCs, there is a transformer inserted. Both the resistance and reactance (for VSC 1 R0& X0 and VSC 2 Rg& Xg) are the transformers' corresponding resistance and leakage reactance. Generators 1 and 2 are connected to buses 2 (B2) and 4 (B4), which are designated as the generator buses. Induction generators are used in these units. Every generator has banks of capacitors to provide steady generation even in the absence of a load. The MG controller dynamically supplies the necessary reactive power to sustain the voltage as the load grows. Loads 1 and 2 are connected to load bus 3 (B3) using breakers. The following formula is used to generate the shaft torque from the rpm for simulation purposes.

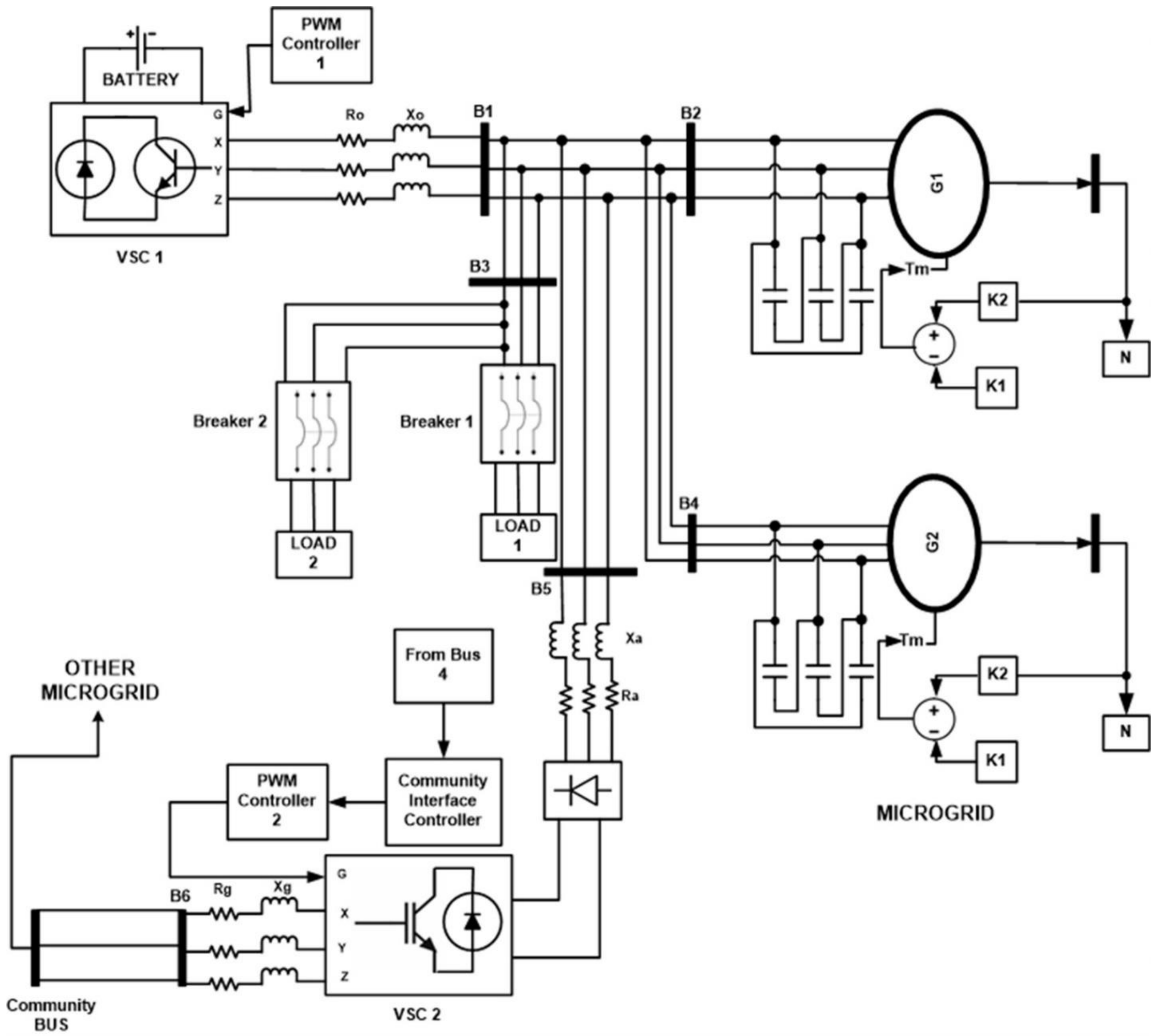

Figure. 5.10. MATLAB model of community microgrid

Prime mover characteristics equation can be

$$T_{sh} = K_1 - K_2 N \quad (5.5)$$

Where, $K_1 = 2910$ and $K_2 = 2$.

In this instance, bus 6 (B6) is connected to VSC 2. The interlink controller is composed of the VSC 2 and the diode bridge rectifier. The feeder from the microgrid to the interlink controller is represented by the resistance and reactance (Ra and Xa). If there is any excess power in the MG, it will go to the community bus and then be distributed to the other MGs who have reported their power shortages to CMGC.

5.4. Simulation Result

Figures 5.11 and 5.12 illustrate how the microgrid functions in relation to the production of extra power, how to detect it, and how to dump it onto the community bus. The microgrid's voltage is managed by the MG controller in response to changes in load. It displays waveforms of MG working in simulation mode under various loads and within installed capacity. Microgrid voltages (V_{XYZ}), currents flowing through generators 1 and 2 (I_{XYZ1}, I_{XYZ2}), microgrid controller current (I_{CXYZ}), the simulated load current waveforms (I_{LXYZ}) of the microgrid, power used by the local load (P), power going to the community bus (P_{flow}), and generator speed (N).

The MG's performance is shown in Fig. 5.12 as the local load is changed. The MG has an installed capacity of 15kW. An initial 8 kW load is supplied to the MG at the load bus. The Community Interphase controller detects a 7kW extra generation on the MG, which moves the excess generation onto the Community Bus. This power is consumed by the local MGs. This is seen in Fig. 5.12's Pflow graph. This keeps the surplus generation from the MG from being wasted and the generators from running too fast, which would raise the MG's frequency.

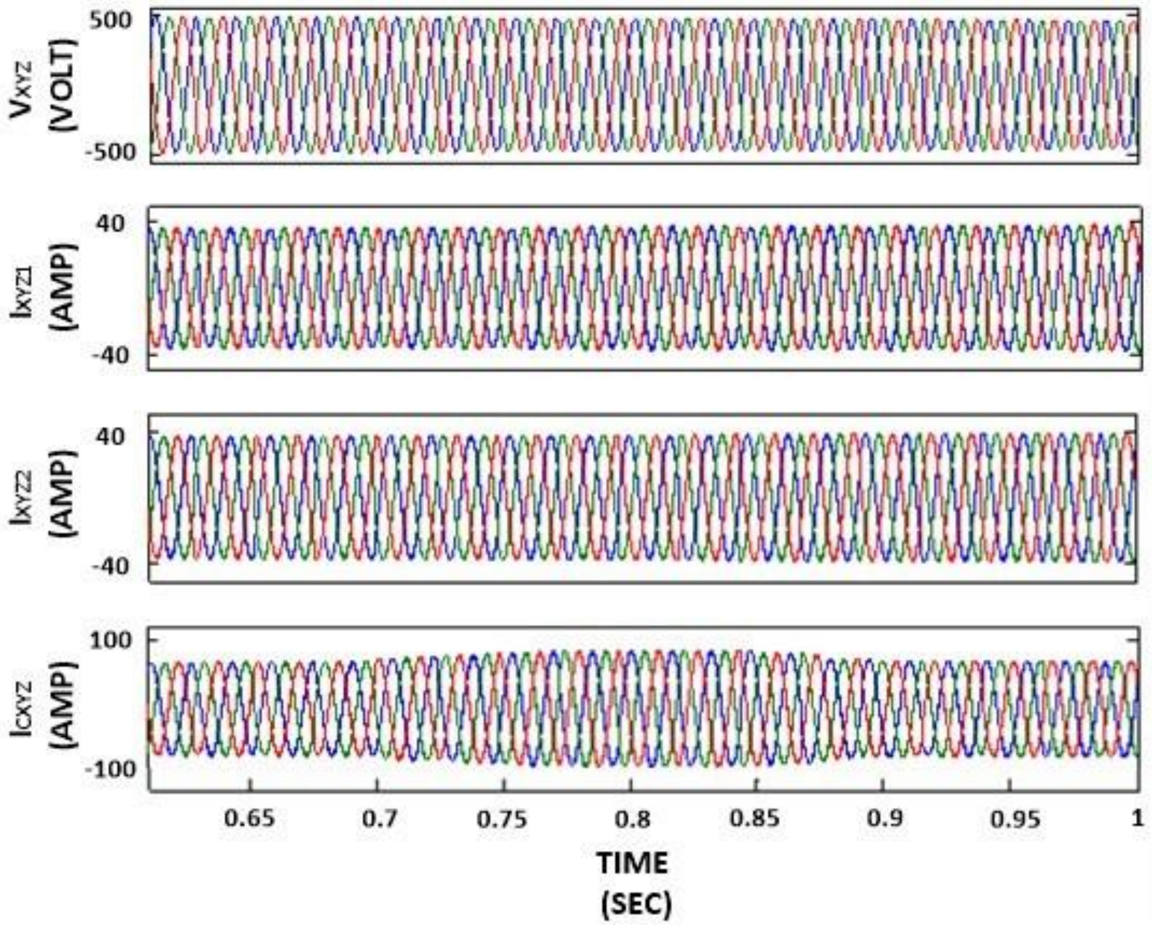

Figure. 5.11. functioning of the MG under different load conditions

At 0.7 seconds, the second 7kW load is turned on, bringing the total load to 15kW. The MG's local load is now using up all of its generation, so there is no longer any surplus generation on the device. The Community Interface Controller detects it and cuts the Community Bus's power supply. This is brought to light in Fig. 5.12 by the zero value of the graph during this period. By turning off the 7kW load at 0.85s, the burden on the MG is again lowered to 8kW. The community interface controller detects the excess generation and lets it to flow to the Community Bus so that the local MG can use it. An increased Pflow value indicates this. The generator speed in the MG, denoted by N on the graph, stays constant at about 1450 rpm throughout the simulation because the load on the MG equals its generation.

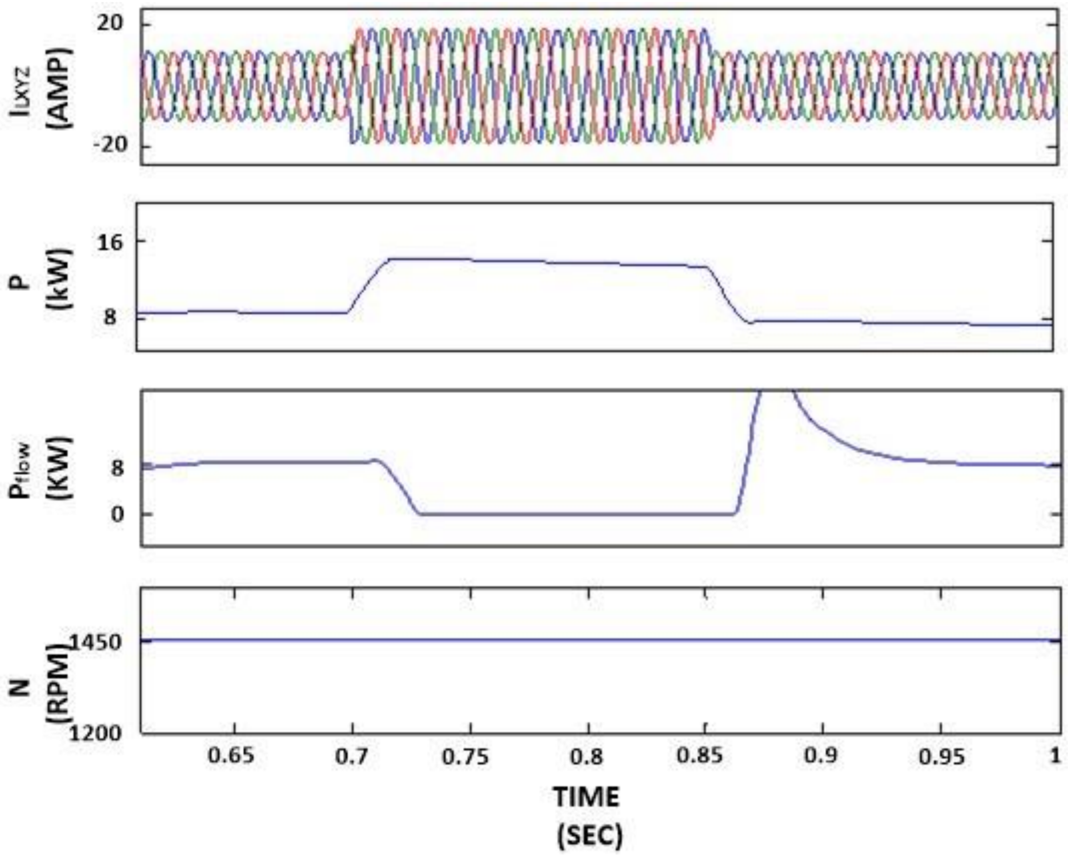

Figure. 5.12. Source MG's performance under various load scenarios while staying within its maximum power capacity

5.5. Conclusion

During contingencies the microgrids connected to the utility's distribution system must either have additional installed capacity (such as spinning reserves) or take surplus power from the main grid. This research investigates the Community Microgrid concept that uses the community bus to allow MGs in the neighborhood to share with each other any excess electricity generated. As a result, the MGs avoid having to pay a high cost for purchasing power from the main grid. Power exchanges between MGs can be free of charge or based on a cost-sharing arrangement.

A major issue that is causing a rise in frequency is the excess generation of MG. By utilizing a priority-based distribution algorithm and keeping the neighborhood MG's generators operating at full load, this study proposes a novel way to share this excess power. For their unforeseen needs, this is beneficial. Moreover, the MGs can perform properly with less installed capacity.

An elaborate priority-based power sharing algorithm is a prerequisite for every community microgrid's energy management plan. By striking a balance between the energy needs of the community, it enhances dependability and adds to the overall sustainability and resilience of the energy system. An energy system's ability to continuously monitor, adjust, and offer feedback determines how well it performs in controlling the erratic energy supply and demand in a community microgrid.

This research established a coordination mechanism to guarantee an optimal flow of energy from the community bus so that the nearby microgrid can use the excess power when needed. The CMG system would increase the economies and dependability of the community's power supply since local loads are supplied by distinct microgrids, and because individual microgrids also give extra energy to the community bus for other MGs in the community. A major benefit in metropolitan regions with high population density could be the ability of individual microgrids to reduce the installed capacity that they may require.

Chapter 6
Conclusion

6.1. Conclusion

The research offers a noteworthy progression in the area of microgrid optimization. The suggested method takes care of the important details of distributed generation (DG) placement and sizing to increase the energy efficiency. The research adds to the improvement of microgrid sustainability and overall performance by incorporating a new optimization technique into the microgrid framework. The outcomes show how the algorithm works well for placing and sizing distributed solar panels (DGs), which increases system dependability and energy efficiency. This work has the potential to advance the design and operation of microgrids, which will benefit scholars, experts, and stakeholders in the pursuit of more robust and sustainable energy systems.

The exploration of energy management represents a noteworthy advancement in the incorporation of demand response tactics in microgrid architectures. The research presents a multi-party energy management strategy to improve overall system efficiency in addition to highlighting the interaction between heat and power demands. The research adds to a more thorough and adaptable energy management framework by taking into account the cooperative efforts of many entities inside the microgrid. The findings show how well the suggested strategy works to optimize energy use, cut expenses, and create a more environmentally friendly energy ecosystem. This research contributes to our understanding of simultaneous demand response techniques in microgrids and has applications in the real world, resulting in an energy infrastructure that is more adaptable and resilient.

The study highlights cooperation and effective resource allocation among networked microgrids by introducing a novel priority-based mutual power sharing method. Through the application of predetermined criteria for prioritization, the research enables a flexible and adaptable energy-sharing mechanism that maximizes power distribution in the community microgrid. The results show that the suggested strategy is successful in encouraging fair power sharing, improving system dependability, and guaranteeing a balanced use of resources. This research adds to the current discussion on community microgrid management while also offering useful advice on how to create resilient, sustainable energy networks that meet the individual requirements of a community's heterogeneous user base.

6.2. Future Work

The research has a lot of potential in the future, considering how smart grid technologies, energy decentralization, and the integration of renewable energy are developing. The use of cutting-edge optimization methods to improve the accuracy and effectiveness of distributed generation (DG) deployment and energy management, including artificial intelligence (AI), deep learning algorithms, and machine learning (ML), is one exciting field. These techniques can aid in the creation of adaptive systems that use pricing signals, renewable generation patterns, and load predictions to make decisions in real time. Microgrids that can handle the unpredictability and intermittent nature of renewable energy sources like solar and wind power would become more robust, effective, and self-regulating as a result of this integration.

The investigation of energy storage systems (ESS) and hybrid power systems in microgrids is a crucial area for future research. Energy storage becomes essential for controlling intermittency and maintaining grid stability as the share of renewable energy sources rises. Future research could concentrate on the ideal location and size of storage technologies (such as supercapacitors and batteries), considering aspects such as cost, efficacy, and environmental effects. Furthermore, hybrid microgrids have chances to improve energy reliability and lower carbon emissions by combining storage systems with a variety of renewable energy sources, such as biomass, solar, and wind. This field of study could look into how to coordinate these components for best results under different circumstances.

Further research can examine the function of peer-to-peer (P2P) energy trading in microgrids, where users can become prosumers by producing and consuming energy, as the energy sector transitions to decentralize and democratize energy systems. Participants in microgrids could transact energy safely and transparently by utilizing blockchain technology. In conclusion, the future scope may also include investigating policy and regulatory frameworks to facilitate the broader implementation of microgrids. To make microgrids more scalable and financially feasible in a variety of international contexts, these studies should address the economic and policy consequences of microgrid integration, such as market incentives, regulatory impediments, and models for decentralized energy markets.

6.3. Shortcomings or Limitations

The different limitations of the work are as follows:

Accurate data generation, load profiles, and network configurations are frequently necessary for optimal distributed generation location and energy management. Nevertheless, the models' actual applicability may be limited in real-world applications due to inadequate or unavailable data.

Variability in load patterns is a characteristic of intermittent renewable energy sources like wind and solar power. Predicting loads and generation accurately is a difficult task, and mistakes in this regard can seriously impair the effectiveness of suggested work.

The suggested solutions might be effective for small-scale microgrids, but they might not scale to bigger networks or more intricate urban settings where DGs and numerous microgrids need to communicate with the main grid. It has to take to test bench microgrid for hardware implementation. After a successful result, it can be applied to a large scale.

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