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Original Article

Grid-Connected Microgrids' Day-Ahead Energy Scheduling for Demand-Side Management using Improved Moth-Flame Algorithm-IMFO

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Abstract - *Demand Side Management (DSM) is a useful technique for utilities since it controls system energy use and lowers peak load demand. The day-ahead energy scheduling for demand-side control in grid-connected microgrids using the Improved Moth-Flame Algorithm (IMFO) was proposed in this paper. Customers who participate in this process earn from the deployment of DSM, and utilities also benefit. Using various devices, this research proposes a load-shifting strategy-based DSM that minimizes the system's energy consumption pattern. Gaussian and chaos mutation are then used to enhance the moth-flame method, which has a tendency to slip into local optima. This suggests that the enhanced moth-flame algorithm is very effective and reliable for scheduling microgrid cluster optimization. Based on the enhanced moth-flame method, a scheduling model for microgrid cluster optimization is built. The experimental findings revealed that, following 160 iterations, the operational cost was 4286.21 yuan in islanding mode. After scheduling was optimized, the operational cost decreased by 8.7% to 3912.3 yuan. The enhanced moth-flame algorithm outperformed existing intelligent algorithms after 10–50 iterations; a consistent normal loss of 20% and 97.19% operating efficiency were attained. This suggests that the enhanced moth-flame algorithm operates with microgrids for Demand Side Management with great efficacy and dependability.*

Keywords - *Moth-Flame Algorithm, Micro Grid (MG), Demand Side Management (DSM), Energy management, Energy efficiency management.*

1. Introduction

In order to prevent significant supply interruptions and increase energy efficiency, demand-side control is an essential tactic. A smart energy management system, which may help reduce costs while meeting energy demands, generate patterns of energy consumption by customers, and respond to energy-saving algorithms and instructions, is an essential component of demand-side management. A demand-side management system that integrates with a smart home allows for the optimization of energy use by dynamically modifying consumption in response to current energy pricing and availability from several sources, including fuel cells, solar, and wind. A developing technology called the Internet of Things can efficiently control energy use in commercial, residential, and industrial settings in a smart environment [1]. Europe's WP and PV capacity mix and location have been improved through the development of a new technique for lowering residual demand. One definition of Mixed-integer linear programming is used in Micro-Grid Energy Management (MGEM) [2]. Rather, the allocation of loads is determined by their respective cost functions in order to reach the system's least generation cost. The total energy consumption must, however, equal the total energy production for any grid to function properly [3]. The tremendous restrictions on the construction of new generating plants combined with the sharp increase in the power demand is ushering in a new era of DSM to meet a nation's energy needs. DSM can offer a quick fix for issues like the main source of energy being produced by finite natural resources, the underutilisation of renewable energy sources, and the lack of utility regulations [4]. Demand-side management was developed in order to dispatch the best electricity and reduce operating costs.

The natural gas network is connected to the microgrid to counteract renewable energy's sporadic nature [5]. This study initially suggests a thorough day-ahead multi-objective microgrid optimisation framework that combines Demand Side Management (DSM), forecasted technologies, and Economic and Environmental Dispatch (EED) in tandem with the benefits of microgrid systems. The power supply plan is then derived from the EED model, and the load control plan is derived from the DSM model using two iterations of particle swarm optimization [6]. The microgrid system makes an effort to reduce daily operating costs while taking loads, signal prices, and renewable generation's stochastic behaviour into account [7].

The increased electrical load caused by Electric Vehicles (EVs) may be mitigated via Demand-Side Management (DSM). In order to facilitate sustainable development without requiring significant growth in the Smart Grid (SG), DSM restructures the power system [8]. The capacity to optimally coordinate many microgrids linked to the same main grid through the Demand Side Management (DSM) application. Both the importation of electricity from the main grid and the deviation from the anticipated demand for each microgrid decreased at the main grid level [9]. Hourly variations in load demand are common in Microgrid (MG) systems. The power system utility employs the load demand curve's rise and fall to calculate the electric power rate at various times of the day. Time-Of-Usage (TOU)-based power pricing is the name given to this tactic.

There are two types of load demand on an hourly basis: elastic and inelastic [10]. To enable central micro-grid management, optimise micro-grid performances and reduce energy output uncertainties from renewables, customers can choose from various available rates or express their interruptible/curtailable demand rate. In addition to DR, this study uses motivational payments in the form of predetermined price package volume to generate schedules for Demand Response (DR) activities [11]. However, at times of low market pricing, the uncoordinated customer response results in a new peak in the load profile. Framework that, in grid-connected microgrid systems, lowers operating costs while improving the effectiveness of demand response programs [8]. Smart grids employ Demand Side Management (DSM) initiatives to reduce utility networks' Peak to Average Ratio (PAR) and end-user electricity prices. To enhance the economic and environmental aspects for the end user, the DSM controller uses renewable energy in conjunction with an Energy Storage System (ESS) [12].

Several Demand Side Management (DSM) strategies were examined, and the best one for our research area was determined. Several metaheuristic algorithms were used to evaluate the off-grid system's efficiency, and the outcomes were very encouraging [13]. Gap in Research Renewable energy sources are becoming increasingly well-liked because of growing concerns about climate change and the electricity demand. However, intermittency and variability are two major obstacles to integrating these sources into the grid. Demand side management, or DSM, is essential in resolving this problem by balancing supply and demand through modifications to energy usage patterns. These problems might be resolved with the freedom that Demand Side Management (DSM) provides for community members to engage in the P2P electricity market. An inventive approach to energy management that incorporates DSM is used in this study [15]. The contributions of this article can be listed as follows:

- This study considers both grid-connected and islanded operations when determining how best to operate a microgrid system.
- Demand-side management is a strategy that uses specific, proven techniques to manage controlled loads in order to achieve even more cost-effective outcomes.
- DSM's impact on lowering microgrid generation costs was examined. Analysis was done on grid involvement options and how they affected the cost of microgrid generation.
- The effect of grid pricing techniques on the cost of microgrid generation was examined.

The paper's organisation, the 1st section explains why this project is needed and presents the subject. The Related works are in the 2nd section. Section 3 contains the proposed method for this paper. Section 4 contains the Results and discussion. Finally, section Fifth has the Conclusion.

2. Literature Survey

In Bishwajit et al. 2023 [16], demand side management, or DSM, lowers the overall cost of a distribution system by separating elastic and inelastic loads and rearranging the load demand model. This is achieved by moving variable loads to times when utility bills are lower per unit. A low voltage microgrid system that runs in grid-connected mode and uses fossil fuel generators, renewable energy sources, and battery energy storage has its operational costs decreased in this study with the use of a bi-level optimisation method. At the first optimisation stage, the load model is reorganised using the DSM participation level. In Mustafa Shakir et al. 2023 [17], demand side control is A key tactic for preventing significant supply disruptions and enhancing energy efficiency. Demand-side management necessitates an intelligent energy management system since it can develop client energy consumption patterns, respond to energy-saving algorithms and instructions, and help reduce costs while satisfying energy demands.

One new technology that can be used to efficiently regulate energy use in residences, workplaces, and industries in a smart setting is the Internet of Things. A clever energy management system is shown in this paper in smart settings that provides efficient demand side control by integrating an Energy Controller with the Internet of Things middleware module. In Shahzad Siddiqui et al. 2023 [18], a novel demand-side management paradigm based on intelligent optimisation is presented in this paper for smart grids that integrate renewable energy. The proposed system uses fuzzy logic to predict patterns of consumer energy consumption and incorporates electric utility companies' real-time demand response programs. The results show that total electricity prices and carbon emissions have dramatically decreased compared to the load management-free technique. In Abdul Haseeb et al. 2024 [18], by establishing a market that incentivises the use of inexpensive energy, micro-grids comprising various energy resources enable energy sharing to balance fluctuations. This proposed system is divided into three sections. In the first step, DSM lowers consumption prices to 7.1% without DER, but customer comfort suffers as a result. The Feed-In Tariff (FIT) program lowers energy consumption-related tariffs to 92.2% in the second stage, which includes microgrids. In the last phase, 122.1% of microgrids (ESS, diesel, and RER) had lower fees than those charged by the grid as a result of the energy market being included for trading.

According to Peter Anuoluwapo et al. 2024 [19], the difficulties in managing energy, particularly in microgrids, are due to Demand Response (DR). It highlights that in order to optimise the potential of DR resources, efficient control mechanisms and market frameworks are required. Novel control algorithms are necessary because of the distributed, stochastic, and intermittent character of patterns of generation and consumption. Li et al. 2024 [20] The enhanced moth-flame technique serves as the foundation for the construction of a microgrid cluster optimization scheduling model. This suggests that the enhanced moth-flame technique is highly dependable and efficient for scheduling microgrid cluster optimization.

3. Proposed System

The DSM method for the MG system is introduced. DSM serves as the main method, also referred to as load shifting. Increasing the use of RES, increasing the economic benefit, and lowering the need for peak load are the three key goals of DSM. The MG manager sets up the goal of a load curve according to the DSM target. The main objective of the job is to get the load curve as close as possible to the possible target load curve. Minimising electricity bills and market prices are inversely correlated. An appropriate objective load curve is thus selected based on this criterion. If new loads are added, control measures are needed. Through the integration of various renewable energy sources and the provision of intelligent control over household energy consumption, energy management systems seek to increase efficiency and cost-effectiveness. Because the current method is completely independent of the criterion used to produce the goal load curve, it may thus be expanded. DSM occurs when a predetermined control period, typically lasting one day, is initialised. In Figure 1, the microgrid's demand-side management structure is displayed.

3.1. Demand Side Management

Current energy scheduling and DSM developments highlight the increased focus on maximizing energy use and enhancing grid efficiency. These studies' methods and conclusions may prove useful for additional study and advancement in this area. By adding new generating units, each service provider organisation aims to reduce the additional time and expense required to meet the residential sector's expanding energy demands. The best way to address this issue is to make efficient use of the energy that is now available.

Therefore, DSM programs are implemented by the service provider firm to control users' energy usage. Therefore, DSM's main objective is to control family use in order to reduce electricity prices. DSM is a word used to inform and motivate consumers about energy management initiatives. The general definition of demand-side management is the collection of guidelines for tracking and executing consumer awareness campaigns for peak shaving and energy efficiency management, as well as motivating consumers to adopt energy management to reduce their energy use. As seen in Figure 2, DSM may generally be separated into two major categories.

Two facets of demand-side management that are discussed here are demand response and energy efficiency:

1) Energy efficiency: This is accomplished by putting in place customer-focused initiatives for customers with lower energy needs. This behaviour leads to a reduction in energy use. Although energy efficiency is crucial, this strategy is impractical because it is impossible to compel customers to reduce their electricity usage.
2) Demand response: The service provider uses this tactic to move the load, lower the amount of electricity used, and switch from peak to off-peak hours. Demand-especially the scheduling of domestic appliances-is the main subject of this poll. This entails urging customers to alter how they use their appliances, which may help lower peak shaving and electricity costs. Two variations of the demand response approach are price-based and incentive-based, in which consumers get varying tariffs throughout the day and rewards for altering their consumption habits.

3.2. Load Demand Description

We took into account Where N, jN j is the total amount of users, N loads are used by users, without sacrificing generality. Let Mn = f {In, ∪Sn∪Rng} represent all household devices for each user n 2 ∈N; when necessary, shiftable and throttleable devices are denoted by In, Sn, and Rn. We define the energy consumption scheduling vector for these three device kinds as follows:

$$e_{n,i}\,\Delta[e_{n,i}^{1}\,,\dots,e_{n,i}^{t}\,,\dots,e_{n,i}^{T}\,] \tag{1}$$

$$e_{n,s}\,\Delta[e_{n,s}^{1}\,,\dots,e_{n,s}^{t}\,,\dots,e_{n,s}^{T}\,] \tag{2}$$

$$e_{n,r}\,\Delta[e_{n,r}^{1}\,,\dots,e_{n,r}^{t}\,,\dots,e_{n,r}^{T}\,] \tag{3}$$

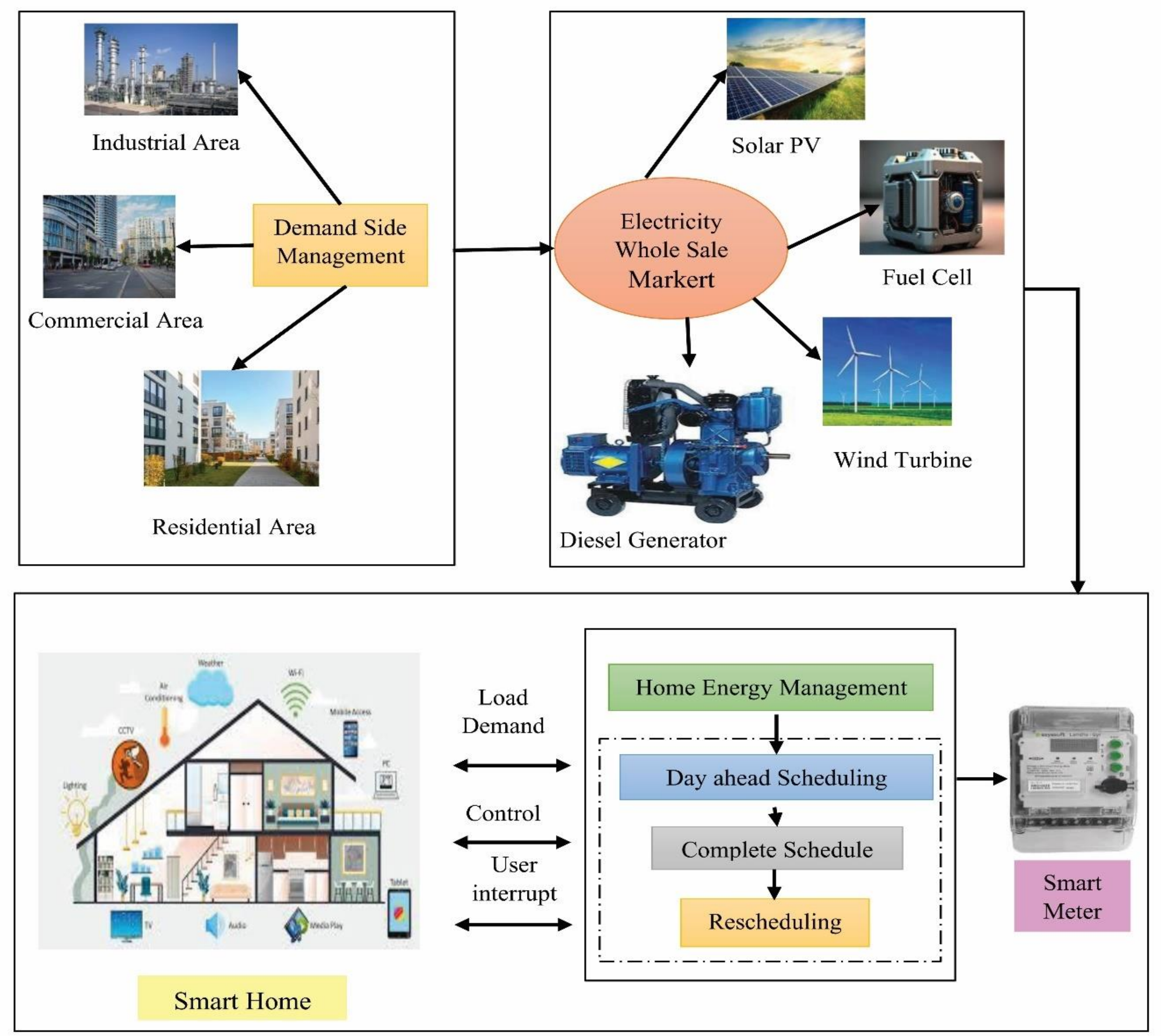


Fig. 1 Block diagram of Demand Side Management in microgrid

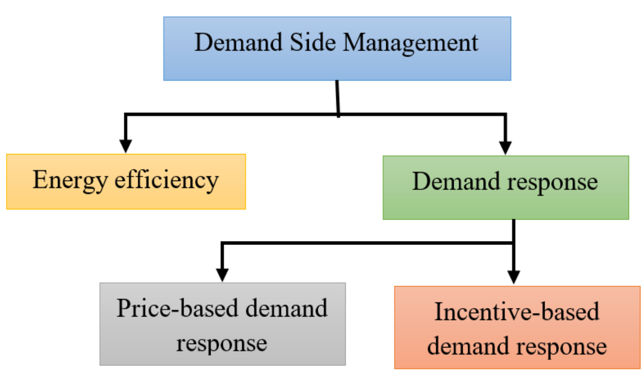


Fig. 2 Demand Side Management

Assume that xn,t represents the total energy used for the duration by the user t 2 T3 = f1,..., Tg. This implies that:

$$X_{n,t} = \sum_{i,s,r \in M_n} [e^1_{n,i} + e^t_{n,s} + e^t_{n,r}] \qquad t \in T \qquad (4)$$

As a result, the user n's total daily energy requirement is:

$$\sum_{t \in O_n} X_{n,t} = E_n \qquad (5)$$

The user n's battery profile vector can be expressed as follows:

$$a_n = [a_{n,1}, \dots, a_{n,t}, \dots, a_{n,T}] \qquad (6)$$

If it needs to meet the maximum charge and discharge rate,

$$-1 \leq a_{n,t} \leq 1 \qquad (7)$$

User n's battery is being charged if an, t > 0. If a t is less than zero, the battery is being discharged. Furthermore, the battery is idle if an, t = 0.

Following each charge and discharge, each battery's level needs to be higher than zero but lower than its maximum capacity. This is how the constraint is expressed mathematically:

$$0 \leq b_{n,0} + \sum_{i=1}^{t} a_{n,j}\, r_n \leq B_n, \forall t \in T \quad (8)$$

We assume that there is neither a surplus nor a lack of energy at the conclusion of a cycle T. As a result, the battery's bn,0 charge level is constant. The following is an expression for this assumption:

$$\sum_{t=1}^{T} a_{n,t} = 0 \quad (9)$$

The user's battery has less energy than what the user needs to uses throughout each time interval t. This is how the constraint is presented:

$$X_{n,t} + a_{n,t}\, r_n \geq 0 \quad (10)$$

The load demands the customer needs to buy from the utility will vary over time based on the battery's condition and discharge strategy.

$$L_{n,t} = X_{n,t} + a_{n,t}\, r_n \quad (11)$$

With the help of these parameters, we can determine the overall load that each user consumed over the period t 2 T as follows:

$$L_t = \sum_{n \in N} L_{n,t} \quad (12)$$

3.3. Microgrid

An electrical system including loads and generators is known as a microgrid topology that can operate alone, in a network of other microgrids, or combination with other grids (minigrids or macrogrids). The system uses generators powered by REs or a mix of fossil fuels.

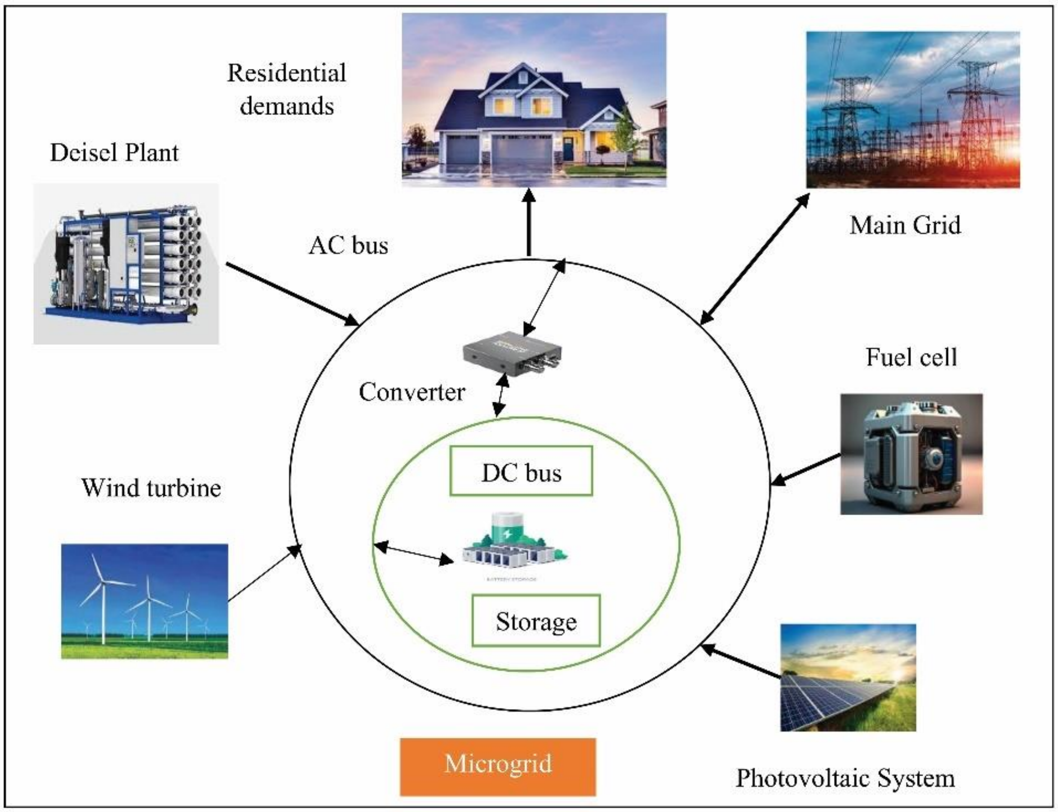


Fig. 3 multi-energy structure of renewable energy-based grid interactive microgrid

Although the World Bank states that the microgrid topology's operational voltages are less than 11 kV, it may not have a specific size. In terms of size and variety, the technologies that microgrid topologies support are extremely varied. As shown in Figure 3, One typical illustration of DG system networks with poorly connected resources is a microgrid. Complex structures resulting from combining various energy sources and insufficient standardisations are problems influencing this topology. Microgrid prospects now face industry-wide technical standardisation due to a very limited market. It is anticipated that appropriate standardisations in microgrid systems will be required to attain significant cost savings and high levels of interoperability.

3.4. Moth-Flame Algorithm

The key to obtaining an effective, reliable, and sustainable power supply for microgrid clusters is the optimisation scheduling strategy. Traditional optimisation techniques, however, have steadily proven inadequate in handling complicated and multi-constrained optimisation issues as the demand for multi-objective optimisation and novel energy system inputs has increased. An IMFO can optimise the microgrid scheduling model based on Gaussian mutation, and chaotic mapping is created. It was moths flying around flames that inspired the IMFO algorithm. Individuals in IMOF can be classified as either flames or moths. Choosing to fly in a spiral fashion, moths search for the flame.

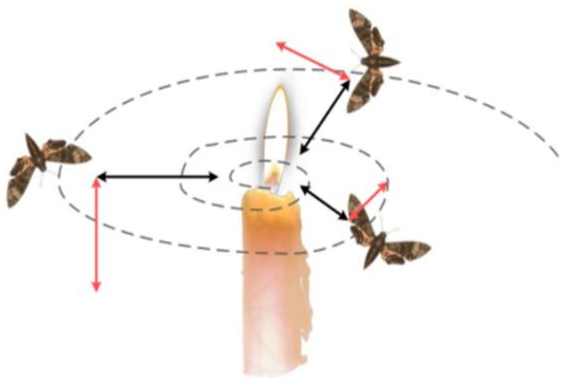


Fig. 4 Biomimetic schematic diagram of IMFO

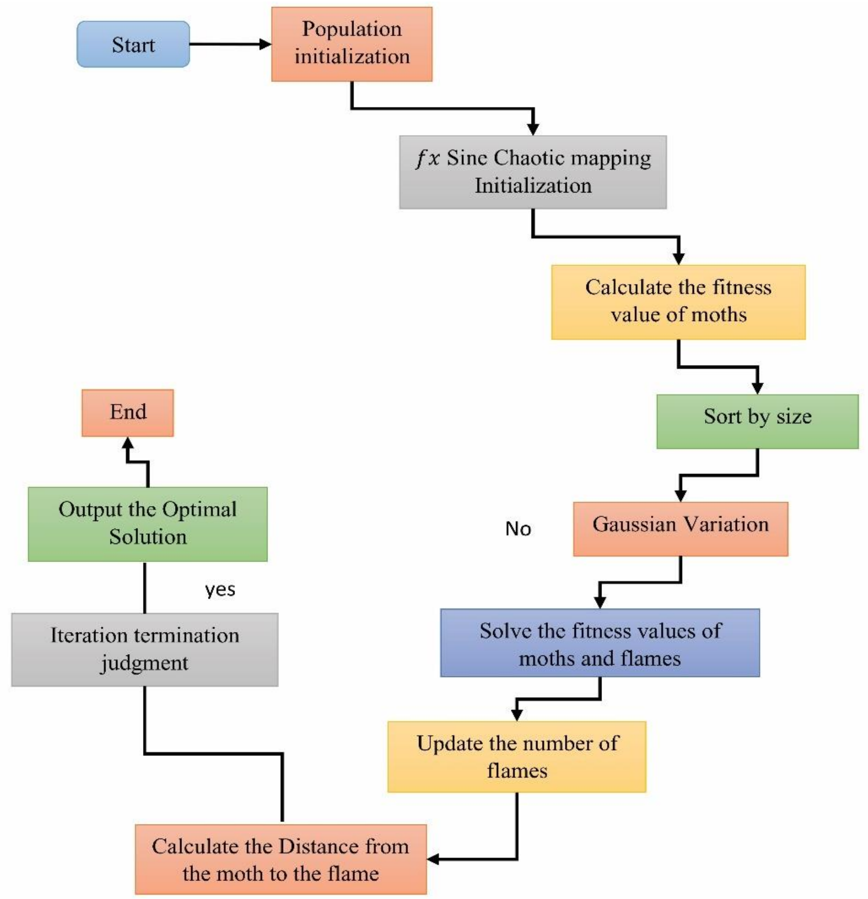


Fig. 5 IMFO algorithm step diagram

Table 1. Microgrid electricity pricing by time of use

Transaction Form	/	Time Interval	Power Grid	Microgrid
Power grid purchase	Full-time period	00:00–24:00	0.50	/
Selling electricity	Peak segment	08:00–11:00 19:00–24:00	0.79	0.56
-	Flat section	06:00–08:00 13:00–19:00	0.57	0.54
-	Valley section	00:00–06:00 24:00–01:00	0.52	0.51

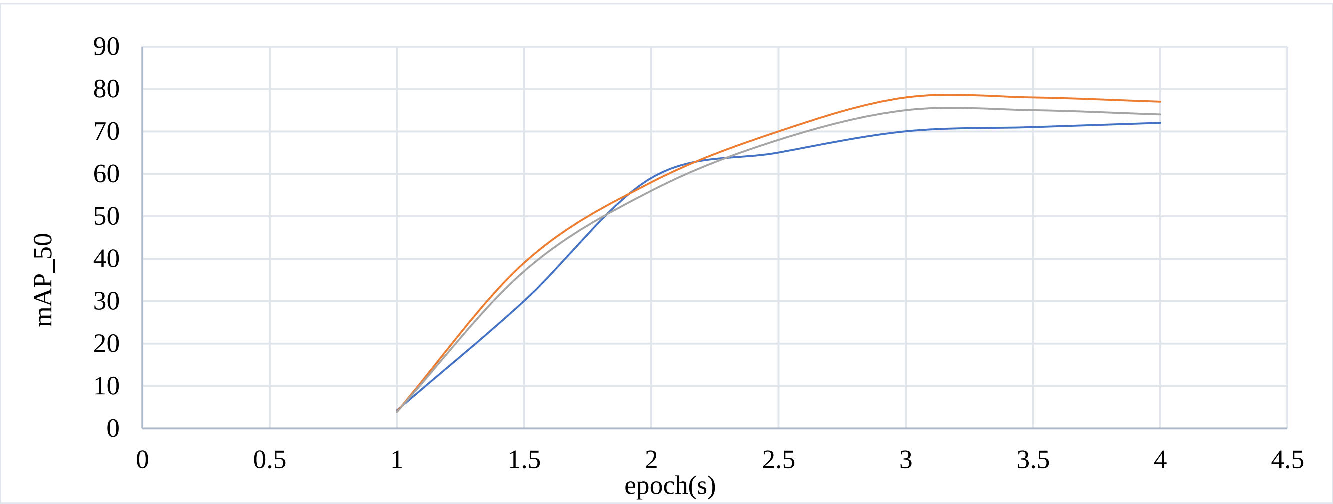
This section initially verifies that the optimization scheduling technique for microgrid operation is efficient. The IMFO-based microgrid optimization scheduling model's efficacy is then evaluated using a range of grid operation modes. Researchers in many different domains employ the Moth-Flame Optimisation Method (MFO) because of its superior global optimisation performance and excellent parallel optimisation capacity. An approach for optimising node placement for distant environment identification was presented by Yao et al. An adaptive inertia method was employed by this algorithm to enhance MFO's global search capabilities. To steer clear of local optima, the path optimisation process made use of the disturbance factor in MFO. Compared with previous algorithms that created an impact evaluation model for assessing social networks, its coverage was noticeably wider, and its performance benefits were more apparent. The node set with the most influence was found using MFO based on the value scheme of the surrounding nodes in this model.

3.4.1. Validation of the Microgrid Operation Optimization Scheduling Scheme

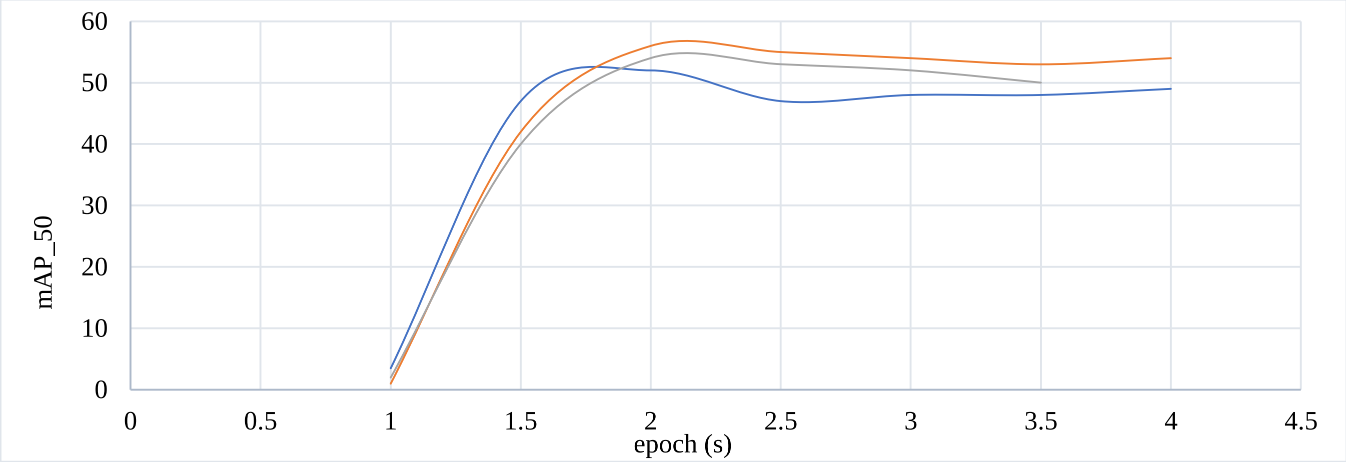
Three interconnected microgrids were used to test the proposed optimisation scheduling scheme for microgrid cluster operation with energy storage devices, wind turbines, gas turbines, and photovoltaics. Table 1 shows how much electricity costs for a single day.

4. Results

In Figure 6, the IMFO's loss and operating efficiency are compared. The average IMFO loss value stabilised at 20% during 10–50 iterations, as shown in Figure 6 (a). A comparison between GA and LSO revealed an 8% decline in the IMFO's average loss value. When determining the least loss value, IMFO has a considerable advantage. It can also lower the loss in demand-side management microgrids more successfully, increasing the overall economic benefit and resource utilization.



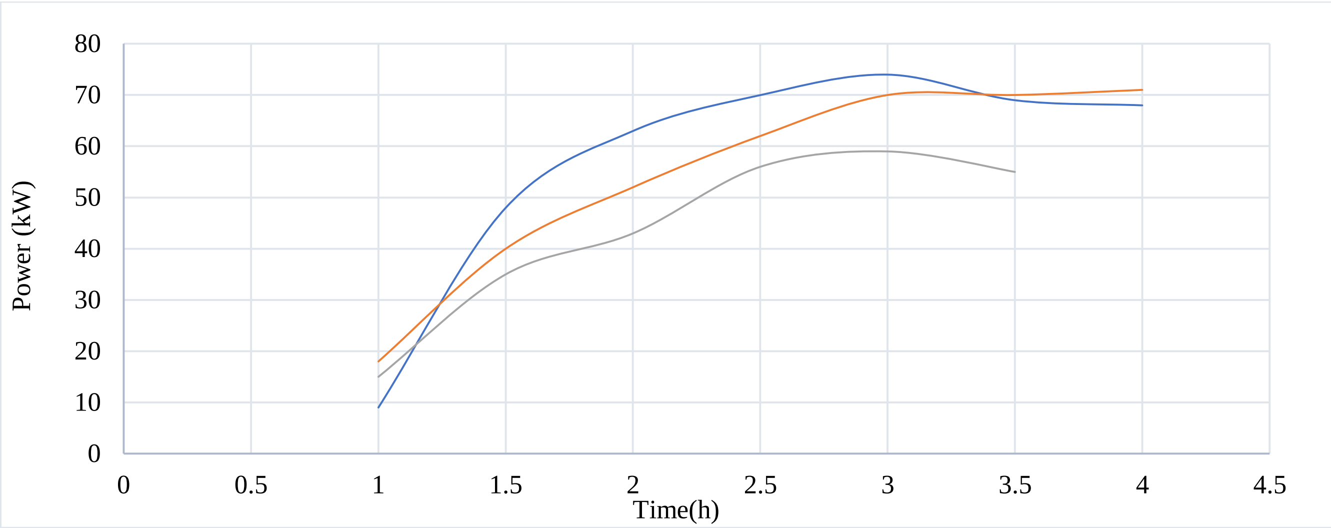
(a)



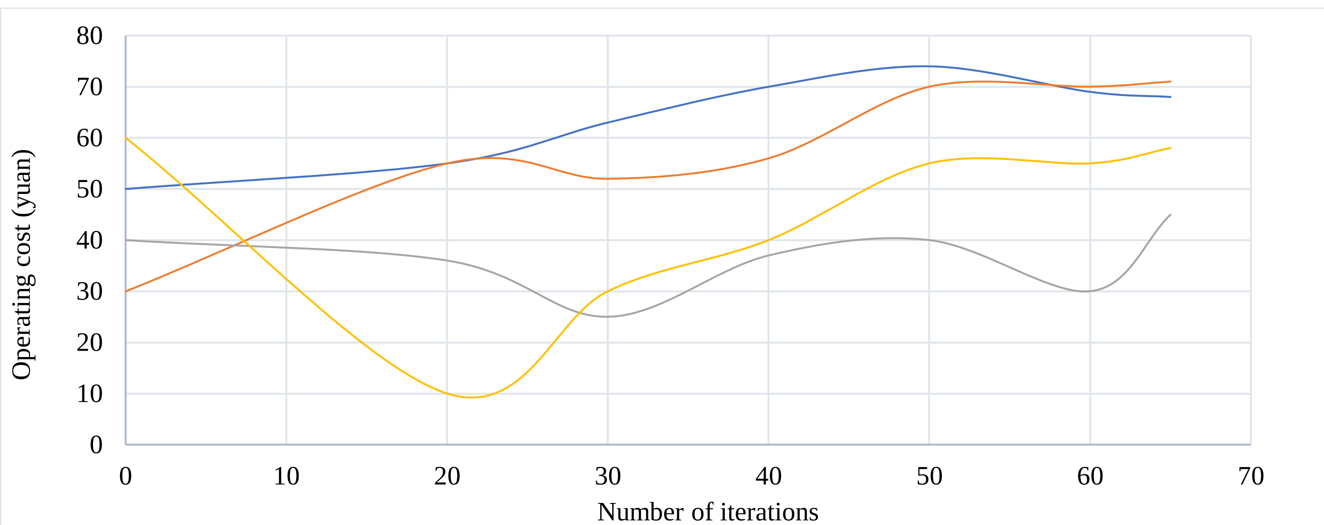
(b)

Fig. 6 (a) Training process diagram of ablation experiments for IMFO, and (b) Training process diagram of ablation experiments for IMFO using MP50.

With an operational efficiency of 97.19%, IMFO has the highest performance in Figure 6 (b). GA and LSO have respective operating efficiencies of 96.30% and 96.94%. IMDO, on the other hand, rose by 0.89% and 0.25%, respectively. Even though these variations are minor, they can add up to considerable performance improvements in scheduling large-scale microgrid clusters. The findings show that IMFO is very reliable and successful in microgrid demand-side management scheduling.



(a)



(b)

Fig. 7 The output and running expenses of different energy sources when they are in islanding mode, (a) Power generation situation of various energy sources, and (b) Operating cost of microgrid system.

Figure 6, Energy use and wind power generation before and after demand-side management optimisation When the microgrid cluster scheduling optimisation is in the islanding operating mode, the microgrid displays the electricity produced by fuel cells, sun, and wind. Due to their low production, solar, wind, and other power generation equipment failed to meet load needs between 12 a.m. and 6 a.m. and between 12 p.m. and 8 p.m. Currently, electricity must be produced using fuel cells.

Micro grid cluster optimization scheduling's operational cost at various iterations is displayed in Figure 7(b). After 100 iterations, the operation cost converged to 1023.3 yuan, and more optimization was achieved by the IMFO algorithm than by MFO, LSO, GA, or other algorithms. When it comes to scheduling strategy optimisation, the IMFO algorithm performs better. It converges more quickly, which can effectively lower costs while enhancing the stability and operational efficiency of microgrid systems.

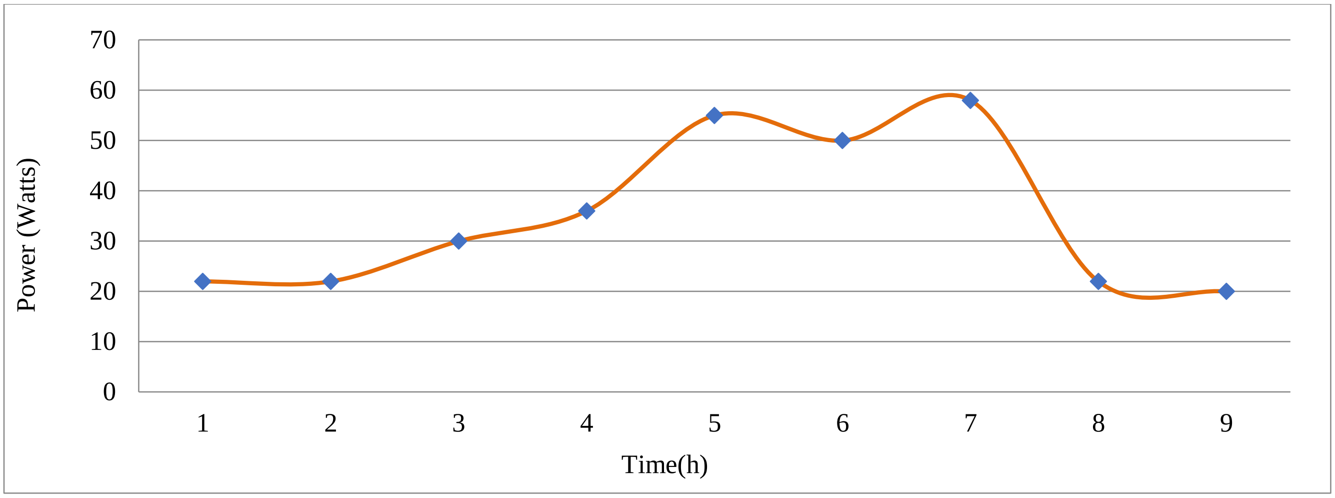


Fig. 8 Demand curve of residential load

Table 2. Comparison of proposed system with existing method

Reference	Methodology	Efficiency
Shen, Y et al. [21]	The first step was to reduce carbon emissions and economic costs by developing an optimisation model with several objectives for integrated DR-based planning of numerous energy storage facilities. Then, to respond to the scenario design's flexibility, we employ adaptive dynamic weighting variables.	96.8%
Carli, R et al. [22]	The multi-carrier microgrid's characteristics are susceptible to a number of disruptions, including variations in the supply of renewable energy, fluctuations in the demand for electricity and heat, and unpredictability in the price of gas and electricity.	96.58%
Carli, R et al. [23]	Here, we present a new hybrid AC/DC MEMG architecture that uses a two-level scheduling approach and a three-stage SST that combines demand response utilizing a Stackelberg game and takes load generation and uncertainty into account.	96.74%
Nikmehr, N. et al. [24]	In order to make use of microgrids' capacity to meet various energy demands, this study examines the EH concept in the context of networked microgrids (MGs). The distribution network and MGs are separate entities with local scheduling issues in the suggested concept.	97.6%
Proposed	Demand-side management of grid-connected microgrids through day-ahead energy scheduling with the Improved Moth-flame algorithm (IMFO)	97.19%

Figure 8 displays demand curves for the various individual locations. The residential area experienced a 20-watt peak demand in the morning, followed by a decrease in demand in the afternoon. Many loads were in operation in the morning hours, and the peak demand in the business area was approximately 15 watts. The industrial area's peak demand was approximately 80 watts, and the loads' operation hours fluctuated throughout the day.

5. Conclusion

An IMFO-based microgrid optimisation scheduling model is suggested to enhance the demand side management microgrid's energy scheduling performance and lower operational expenses throughout the energy scheduling process. Relevant experiments were performed to assess its efficacy and rationale. Using fast convergence evolutionary planning technology and quasi-opposite learning, the microgrid was dispatched the day before, resulting in a cost reduction of 0.52% to 0.78%. Conversely, Operating expenses are reduced by 8.7% in islanding mode using the proposed IMFO algorithm. This suggests the IMFO algorithm can enhance economic benefits and efficiently lower operating costs. The suggested IMFO algorithm shows faster convergence speed and stability by stabilising with less iterations. Grid-connected microgrids' day-ahead energy scheduling for demand-side management using Improved Moth-flame algorithm-IMFO.

Voltage quality issues may arise if the distribution network cluster has more than one microgrid, which is the study's limitation. In particular, the suggested IMFO algorithm has a running efficiency of up to 97.19% and stabilises at an average loss value of 20% after 10 to 50 iterations. In the future, microgrid cluster scheduling optimization will be used to improve the objective function, which will be voltage quality concerns. In order to ensure the effectiveness and dependability of scheduling outcomes, IMFO requires fewer rounds and can converge quickly.

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