SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V11I7P121

Volume 11 Issue 7, 238-246, July 2024

Original Article

Demand Side Management Using a Novel Nature-Inspired Pelican Optimization Algorithm in a Smart Grid Environment

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Received: 10 May 2024 Revised: 12 June 2024 Accepted: 10 July 2024 Published: 26 July 2024

Abstract *- A global trend that creates many uses for the data generated by dynamic networks is the deployment of smart grids. Converting this enormous transformation of data into information that the electrical system can use is the difficult part. Using Demand-Side Management (DSM) strategies to maximize power system management in real-time is one illustration of this. This article presents the Pelican Optimization Algorithm (POA), a unique optimization technique influenced by its chaotic nature. It provides the DSM with many controlled devices with a load-shifting solution. The loading-shifting issue has been managed hourly through the day in order to minimize the Peak to Average load Ratio (PAR), reduce the cost of power, and lower peak demand. It is suggested to use the POA mathematical model to solve optimization issues. POA's performance is evaluated using twenty-three function objectives from different unimodal and multimodal categories. While the optimization results for multimodal functions provide a great ability using POA exploration to discover the major optimal region of the space for searching, the optimization findings at unimodal functions demonstrate the high exploitation power of POA for seeking the most practicable solution. Additionally, the efficiency of the POA in maximizing real-world applications is determined using four engineering design issues. To evaluate POA's optimization proficiency, its results are contrasted with those of eight popular metaheuristic algorithms. The Pelican Optimization Algorithm (POA) approach is used for residential loads in Singapore to minimize DSM issues and achieve load-shifting objectives. The results of the simulation show that the demand-side management approach under consideration lowers the highest load demand of the smart grid while producing significant cost savings.*

Keywords *- Peak to Average load Ratio (PAR), Pelican Optimization Algorithm (POA), Demand Side Management (DSM), Smart Grid (SG).*

1. Introduction

Effective management has grown in significance recently as a result of the rising complexity of electric power networks. This calls for the use of digital technical systems to apply a greater understanding of the entire electric system [1]. These devices may track the kind of consumption, record all occurrences and crises in the energy network, and offer information to enhance the administration of the electrical system. The foundation of smart grids is the coordinated use of automation, information technology, telecommunications, and electrical network control. They consist of sensors, digital network management devices, and smart meters. Real-time data processing enables the deployment of control strategies and the optimization of the electric network since it is bi-directional [2, 3].

Demand-Side Management (DSM) may be used to improve electrical system planning and management by providing a range of innovative services such as direct control load, differential charging, and dynamic pricing [4]. Digital power meters provide customers access to data that enables a more decentralized method of controlling their electricity usage. This smart grid function is really important since it allows customers to have more control over how much energy they use. In a distributed generating system, this allows users to input any extra energy back into the grid [5, 6].

Converting this massive amount of data into information that electrical system managers can utilize is a challenging task. Artificial neural networks, data mining techniques, and statistical methods are some of the tools that can be used to process this data to understand consumption patterns better and support the implementation of power management policies that are most appropriate for each situation, such as load profile classification for use in DSM [13].

1.1. Problem Statement

- A limited supply of energy primarily contributes to the industrialized region's goal of maximizing the average price of production, which depresses the local economy and supports price increases.
- As a result, this study analyses the DSM requirements and determines the best conservation approach for practical application. Because load shedding results from an energy and peak power constraint in small-scale communities.

The following are the research work's primary contributions:

- Using the appliances during periods of less grid demand can reduce PAR and end-user costs.
- To lower the peak electricity demand on the current network so that it can accommodate new energy sources being connected to the grid, and to give customers a more affordable and practical option.
- To achieve load shifting in residential loads in Singapore, the Pelican Optimisation Algorithm (POA) approach is applied, which downplays the issue for the DSM.

This paper is arranged as follows: The task associated with the system is explained in Section 2, and in Section 3, the design components of the suggested methodology are emphasized in Section 4. In Section 4, the results of the simulation are presented, examined, and commented on. Section 5 discusses the conclusion of the presented work.

2. Related Work

The three domains of smart energy management systems are EMS, smart appliances, and Wireless Sensor Networks (WSN) the EMS needs a reliable communication channel [5]. Wireless sensor network approaches have been used to construct this communication channel.

In [6], the architecture of EMS is described. The sensor nodes are connected via the ZigBee module. The system sends control signals to end nodes and monitors device usage statistics during periods of high load. Nevertheless, the lifespan of the WSN network shortens with the addition of new sensors over time.

Furthermore, the method for utilizing WSN with the ZigBee protocol, which is essential for tracking and communication, was covered by Han et al. in [7]. Furthermore, the Internet Protocol stack is interfaced with the ZigBee protocol to facilitate bidirectional communication between home device control and sensor systems.

The GSM/GPRS networks outlined in [8, 9] were used to remotely control the end devices, while the WSN networks previously discussed were extended to larger ranges under the IoT framework. HVAC system methods are monitored and managed by IoT technologies. HVAC energy consumption is thus controlled and described in [10-12]. According to this study, the ideal HVAC system for commercial buildings that use electromagnetically-assisted thermal energy storage is a model-predictive-control strategy.

The suggested method optimizes the HVAC operation through the application of a model predictive control algorithm. As summed up in [13, 14], in this analysis, all energy usage statistics and telemetry for homeowners are gathered by a centralized controller, which also uses sensors to monitor all of the active devices in homes.

A centralized regional broker unit is set up in a big community to handle the many home network gadgets, such as security cameras. In this study [15-17], a smart control method for commercial buildings' HVAC systems is proposed. This strategy can minimize energy consumption while maintaining interior air quality and thermal comfort. The Pelican Optimisation Algorithm and Political Optimizer are used in this study to address the microgrid's energy management issue.

These cutting-edge optimization algorithms have three main goals: They lower operating expenses, preserve supply-load balance, and increase the microgrid's ability to generate power from renewable energy sources. Extensive numerical outcomes and statistical evaluations demonstrate the efficacy and superiority of the recommended optimization solutions.

Results indicate that compared to typical algorithms, there can be up to 25% of cost savings. The findings and statistical analysis so show that a variety of optimisation challenges can be successfully handled by the Political Optimizer or Pelican Optimisation Algorithms, yielding optimal results in the initial iterations [18].

3. Proposed Methodology

With distributed solar photovoltaic power and energy storage, smart grids that include homes are intended to use this work to establish a framework for performing the DSM. With this approach, a battery management system is created to lower consumer electricity costs. If the higher loading time and the higher daily electricity cost occur on the same day, it also helps to delay the investments in grid expansion.

This methodology's primary goal is to reduce distribution system overload, which occurs when there is a higher grid overload and higher electricity tariffs. The algorithm used for pelican optimization is the decision-making process of this suggested methodology. The POA calculates the load energy that is transferred into and out of the battery. PV generation, converter, load, storage, manager, and smart grid are the components of this suggested methodology, which is shown in Figure 1.

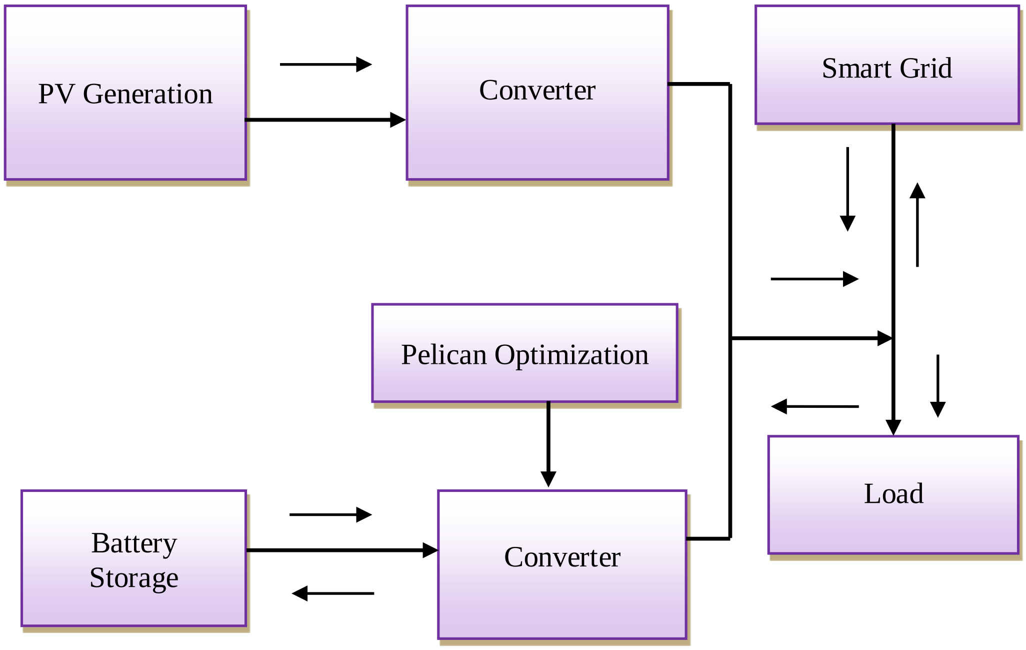


Fig. 1 Demand Side Management (DMS) block diagram with the Pelican Optimization Algorithm proposed

3.1. Demand Side Management (DSM)

Energy management can be divided into two main categories: Demand-Side Management, which emphasises cutting waste and utilising more efficient machinery, and Supply-Side Management (SSM), which entails building new power plants and managing consumption with energy-saving measures. Reducing the peak is one of DSM's objectives.

Data acquisition. A series of procedures, techniques, and actions are used in data gathering in order to obtain data. An important consideration in the foundational research and electrical system design is the calibre and consistency of the data that was gathered. Processing a vast amount of data is necessary for this system in order to keep up a knowledge base on its many aspects.

The management program's effectiveness is closely related to its round-the-clock monitoring; as a result, the behaviour of every kind of load, including its usual and nontypical days, is identified and utilised to guide the exact measures needed in each situation. To achieve this, though, management must categorise the different kinds of loads according to the type of consumption.

Demand-Side Management (DSM) has long been acknowledged as a key strategy for reducing energy demands while maintaining ongoing development. DSM has grown significantly in prominence recently and is now a crucial component of practically all state and federal programmes that promote energy efficiency. Utility companies have benefited from DSM interventions by postponing large expenditures in generating, transmission, and distribution networks in addition to lowering peak electricity demand.

In the energy sector, Demand-Side Management (DSM) strategies are an economical instrument. DSM programmes support the installation of energy-efficient end-use devices as a customer approach, which can lower or shift the customers' overall electric expenditure. By using DSM programmes to lower their peak power purchases on the wholesale market, utilities can lower their overall operating costs.

To implement DSM in their various regions, the DISCOMs require help in the form of capacity building and other measures. The Bureau of Energy Efficiency has initiated a plan to enhance the competence of DISCOMs in this context. This will help to strengthen the capacity of DISCOM officials and encourage the development of multiple initiatives to promote DSM in their different areas.

3.2. Proposed Algorithm for Pelican Optimization Algorithm (POA)

The underlying challenge of solving optimisation problems in several scientific disciplines is optimisation. This study presents the Pelican Optimisation Algorithm (POA), a new probabilistic nature-inspired optimisation technique. The primary concept of the planned POA's design is to mimic pelicans' natural hunting behaviour. In POA, pelicans explore for food sources as search agents. It is suggested to use a POA-based mathematical model to solve optimisation issues.

Twenty-three measurement functions of various unimodal and multimodal categories are used to assess POA's performance. The findings of optimisation of unimodal functions demonstrate a strong capacity to explore POA to find the most optimal area of the search space, whilst the results for multimodal functions demonstrate a strong ability to exploit POA to get the optimal solution. Additionally, the efficiency of the POA in maximising real-world applications is determined using four engineering design issues. To evaluate POA's optimisation proficiency, its results are contrasted with those of eight popular metaheuristic algorithms. The mathematical idea and source of the inspiration for the proposed swarm-based Pelican Optimisation Algorithm (POA) are presented in this section.

3.2.1. Pelican Motivation and Behavior during Hunting

The enormous pelican utilizes its enormous neck pouch to grasp and swallow its food. Its mouth is long as well. This species loves to be among the several hundred pelicans that make up its flocks of choice. Pelicans weigh between 2.75 and 15 kg and range in height from 1.07 to 1.82 meters. Some of the latter might even eat prawns if they were really hungry. Pelicans typically hunt in groups. Pelicans must dive 10 to 20 meters above the surface to reach their prey after they have identified it. Of course, certain species also hunt at lower altitudes. The fish are forced to relocate to shallower waters as a result, where they may more easily use their wings to flap against the water's surface in search of food. The proposed POA refines recommended improvements by imitating the behavior and strategies of pelicans during prey assaults and maybe even during hunting. There are two stages to simulating this hunting technique:

- Moving in on the target (the investigation phase).
- Winging over the sea during the exploitation phase.

3.2.2. Approaching the Prey

The first phase is when the pelicans locate their prey and migrate there. The proposed POA's exploration step is enhanced in detecting different search space regions by emulating this pelican's methodology. Once the prey's position is determined, the pelicans head in that direction. By simulating this pelican's approach, search space scanning and the suggested POA's exploration abilities in identifying various search area sites become feasible.

POA is dependent on a randomly generated prey position within the search area. As a result, POA is able to search the problem-solving space more precisely and completely. The position of the prey in the search space is generated randomly, which is a key component of POA. This increases POA's exploration capacity in the particular hunt for a dilemma space solution. Equation (1), which describes the pelican's approach to its prey, gives a mathematical illustration of the previously discussed ideas.

$$x_{i,j}^{P_1} = \begin{cases} x_{i,j} + rand.\left(p_j - I.x_{i,j}\right), & F_p < F_i; \\ x_{i,j} + rand.\left(x_{i,j} - p_j\right), & else, \end{cases} \quad (1)$$

Where represents the updated status of the i^th^ pelican in the j^th^ dimension (F_p), the prey's position in the j^th^ dimension (p_j), and I, which might represent one or two random variables, reflects the function for which it was designed. The integer specified by variable I could randomly be either 1 or 2. For every member and iteration, this parameter is selected at random.

A member is further displaced when the value of this parameter is two, which may lead to newer positions. Consequently, parameter I affects how well the POA can precisely scan the search space. The Pelican Optimization Algorithm (POA) optimization problem is addressed using swarm intelligence-based metaheuristic optimization techniques. The fact that pelicans usually hunt in groups to capture prey like fish served as inspiration for the invention of the algorithm.

If the value of the objective function rises at that point, the suggested POA recognizes the pelican's new location. This updating, sometimes called effective updating, stops the algorithm from travelling to less-than-ideal places. The procedure is represented by Equation (2).

$$X_i = \begin{cases} x_i^{P_1}, F_i^{P_1} < F_i; \\ X_i, \quad else \end{cases} \quad (2)$$

Where the new status of the i^th pelican is represented by $x_i^{(P_1)}$, and the objective function value of stage serves as the foundation for $F_i^{(P_1)}$.

3.2.3. Flying above the Water's Surface

Pelicans lift fish by flapping their wings as soon as they reach the water's surface, then gather them into a pouch around their neck. In the region they have assaulted, pelicans can catch more fish by using this tactic. As the fish approaches the water's surface, the pelicans thrust out their wings to propel them higher, gathering the food into their neck pouch. A greater number of fish are caught by pelicans inside the attacked area when they employ this tactic. Pelicans break the water's surface in the following stage and recover the fish with their pharyngeal bag. POA assesses the figures in the Pelican region's community to come together in search of a good answer.

The proposed POA converges to more favourable spots within the hunting zone by imitating this pelican's activity. This strategy improves POA's local search capability and exploitation possibilities. Mathematically speaking, the method needs to consider the pelican position, and its surrounding points must meet to converge to the best answer. Initially, the proposed POA converges on optimal sites inside the hunting domain by simulating the behaviour of Pelicans. This approach improves POA's local search and exploitation capabilities. The programme should analytically examine the data points surrounding the pelican's precise position in order to get closer to a better outcome. The equation uses a mathematical model to recreate the actions of a pelican while hunting (3).

$$x_{i,j}^{P_2} = x_{i,j} + R.\left(1 - \frac{t}{T}\right).(2.rand - 1).x_{i,j} \quad (3)$$

With R being a constant and R.(1 − t/T) being the neighbourhood radius of $x_{(i, j)}$ = 0.2 established, the pelican's new status is represented in the j[th] dimension as $x_{(i, j)}^{(P_2)}$. Although the iteration counter seemed to be at t, the maximum number of iterations was T. The optimal answer can be found by each member of the population conducting local research on the circumference of the neighbourhood, as indicated by the coefficient "R. (1 − t/T)". This coefficient affects how the POA is used to approach the optimal global solution. A broader region encompassing each member is investigated because the earliest iterations of this coefficient's value are noteworthy. In order to accept or reject the updated pelican position, which would be represented in Equation (4), effective updating was really used at this phase.

$$X_i = \begin{cases} x_i^{P_2}, F_i^{P_2} < F_i; \\ X_i, \quad else \end{cases} \quad (4)$$

The pelican's new status is represented by $x_i^{(P_2)}$, and its objective function value, which depends on stage 2, is exhibited by $F_i^{(P_2)}$.

3.2.4. Pelican Optimization Algorithm

Once they have located their prey, pelicans fly from ten to twenty meters to capture it. Lower altitudes are where certain creatures hunt. So that it would be easier for them to catch and eat the fish, they spread their wings over the water and trick the fish into going into shallower places. The pelican must bend its head forward after swallowing because water gets into its beak as it catches fish.

Pelicans' astute hunting behaviors and strategies have allowed them to develop into expert hunters. The mathematical modelling that was previously described approach served as the primary source of inspiration for the design of the proposed POA. Its recently created Pelican Optimisation Algorithm (POA) is modelled around pelican hunting tactics. Its premature convergence, unequal distribution of resources, and low population diversity persist despite its rapid rate of convergence.

A technique for investigating additional regions of the search space is also included in the POA. This is accomplished by choosing a subset of non-elite pelicans at random, which is then used in the random walk process to produce new candidate solutions. After evaluation, these novel solutions can become a part of the elite club. Until a stopping requirement is satisfied for example, the POA continues iterating during the search process up to a maximum number of iterations or the targeted level of solution quality.

The POA is a promising optimization method that has shown effectiveness in many different optimization tasks, especially multimodal and high-dimensional ones. As with any other metaheuristic algorithm, though, its effectiveness is largely determined by the nature of the problem and the parameter settings selected.

One type of meta-heuristic algorithm is the Pelican Optimisation Algorithm (POA). That draws inspiration from the way pelicans naturally forage for food in bodies of water. They mostly inhabit rivers, lakes, marshes, and coastal areas. Fish is the primary food source for pelicans; frogs, turtles, and crustaceans are infrequently eaten. Its adjustable settings offer advantages like quick convergence and straightforward computations. Through a good balance between exploration and exploitation, POA beats its competitors by providing optimal answers.

Following the first and second stages, when the majority of participants had received updates, with the new population status and the objective function values in mind, the ideal candidate response would be modified. Every time the algorithm iterates after that, the suggested POA based on Equations (3)-(4) is repeated until the algorithm's execution is complete. In the end, the best response that the algorithm iterates over is shown as the ideal solution to the issue. Its pseudo-code is demonstrated in Algorithm 1.

POA Algorithm:

Initiate POA.
1. Enter the problem's optimisation details.
2. Specify the number of iterations (T) and the population size (N) of POA.
3. The objective function was calculated, and the position of the pelican was initialised.
4. Regarding t = 1:T
5. The prey's location is randomly generated.
6. Regarding i = 1:N
7. Phase 1: Approaching the target.
8. Regarding j = 1:m
9. Determine the new status of the j[th] dimension.
10. close.
11. The i[th] member of the population is updated.
12. Phase 2: Winging on the sea surface.
13. Regarding j = 1:m.
14. Assess the j[th] dimension's new status.
15. Close.
16. The population's fifth member was updated.
17. Close.
18. The top contender answer was revised.
19. Close.
20. Provide the best possible outcome.

Close POA.

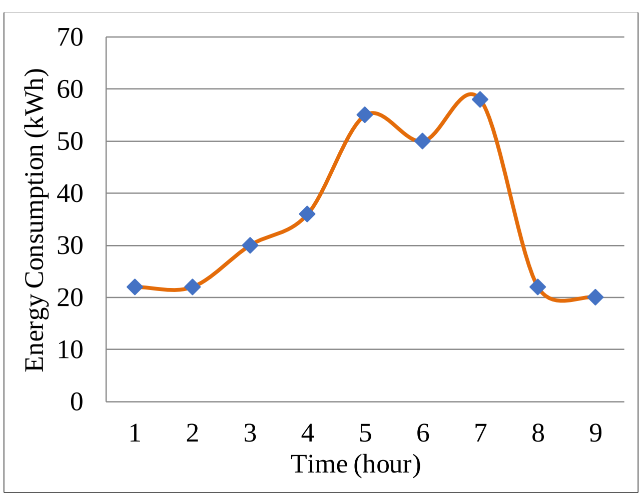
In many scientific fields, optimization is essential to determining the best possible solution out of all the options. The novel idea and contribution of this work is the presentation of the Pelican Optimisation Algorithm (POA), a brand-new optimization technique for handling a range of optimization problems. A mathematical simulation of solving a pelican in an evolutionary optimizer forms the core of the suggested POA's design.

Following a description of each stage in the POA process, the mathematical model is shown. The primary advantage and characteristic of the suggested POA is that parameter setting is not necessary because it lacks control parameters. The suggested POA's effectiveness is evaluated using 23 distinct objective functions. Additionally, the efficacy of POA in optimization is examined by contrasting its outcomes with those of eight other optimization techniques.

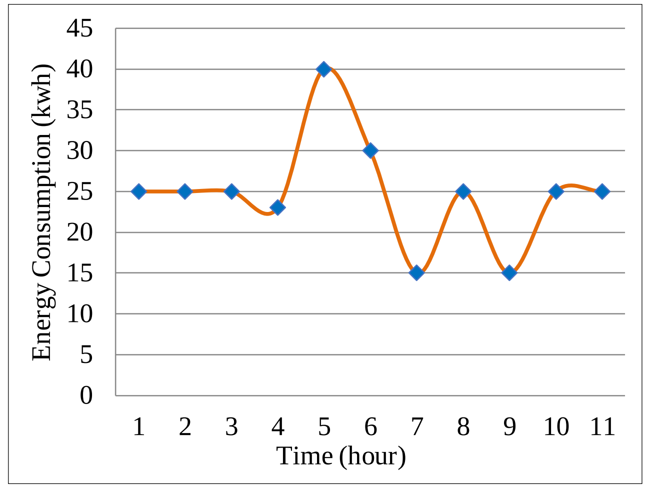
The optimization findings show that the suggested POA has a high and respectable capacity to resolve optimization issues. Furthermore, the simulation results demonstrate that compared to the eight optimization methodologies under comparison, the suggested POA is significantly superior and more competitive.

4. Results and Discussions

The simulation results that were obtained with MATLAB/Simulink are covered in this part. The simulation results show how well the proposed DSM technique manages a large number of controlled loads. The recommended algorithm modifies the load to lower expenses and the PAR. The optimal candidate solution up to this point will be updated after updating each member of the population in accordance with the values in the objective function, the population's new status, and the first and following stages. Simulation findings indicate that our proposed power consumption scheduling system can reduce peak load demand, save power consumption expenses, and improve customer satisfaction.

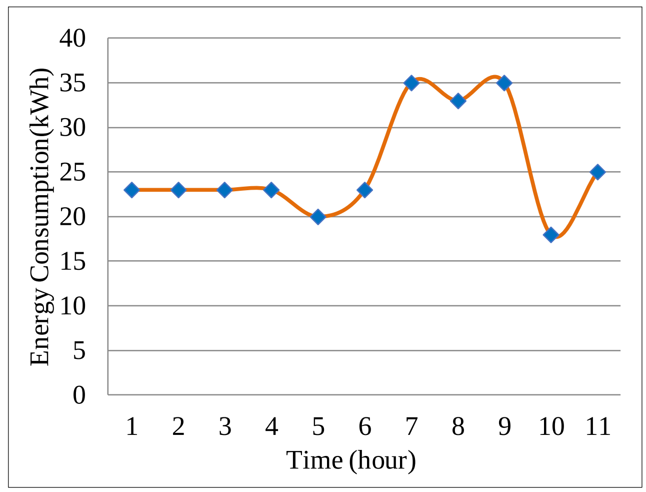


(a)

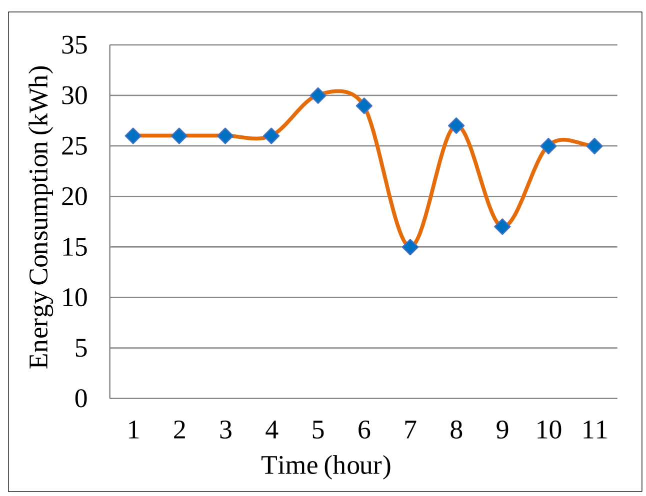


(b)

Fig. 2 Energy use with and without scheduling (a) Energy Consumption without scheduling, and (b) Energy Consumption with scheduling.



(a)



(b)

Fig. 3 POA both with and without scheduling based on energy use (a) POA based energy consumption without scheduling, and (b) POA based energy consumption with scheduling.

Regardless of scheduling, Figure 3 depicts the POA-based energy usage over 24 hours. Figure 4 illustrates, both with and without scheduling, the percentage load of each household appliance during peak hours. The load increases to 30 kwh during peak hours. If we set up the appliances according to our recommended strategy, we could be able to spread the load throughout the day evenly. Using 15% less energy. The simulation's findings show that when energy-use units are excluded from smart meters, the percentage load increases. When scheduling is not present, the energy consumption unit plans the power consumption more effectively, which leads to a peak load of 25%. Thanks to more effective energy consumption unit planning, the peak load is lowered to 20%.

Table 1. Input of residential load

Sl. No	Appliance Name	Type of Appliance	Power Consumption
1	Iron	Adjustable Weight	0.15
2	Washing Machine	Adjustable Weight	3.3
3	Toaster	Adjustable Weight	2.4
4	Fridge	Non-Adjustable Weight	2.6
5	Air Conditioner	Non-Adjustable Weight	3.5

By controlling the load with our efficient power consumption scheduling method, the cost is lower. Figure 4 displays the proportion of users at peak load times. The cost of energy is lowered by 22% when every subscriber and user of smart meters with ECC units makes effective use of the energy.

By planning energy use, each user can lower their monthly expenditure. Figure 5, which shows the decrease in bills for each user, demonstrates how scheduling appliances can reduce each customer's monthly utility costs. Table 2 displays a comparison of several DSM approaches using different algorithms.

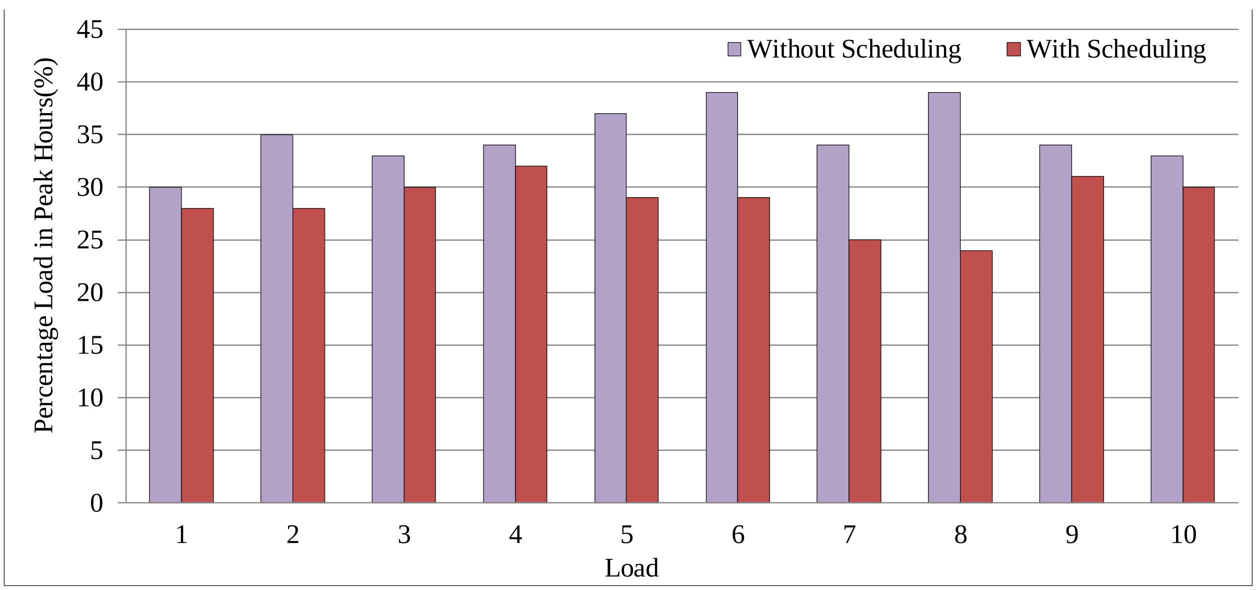


Fig. 4 Percentage of users at peak use times

Table 2. Comparison of the suggested and existing approaches for energy cost reduction

Sl. No	Methods	Energy Cost Reduction
1	Game Theoretic Approach	18%
2	Genetic Algorithm	20%
3	Data-Driven Framework	37%
4	Pelican Optimization Algorithm	54.25%

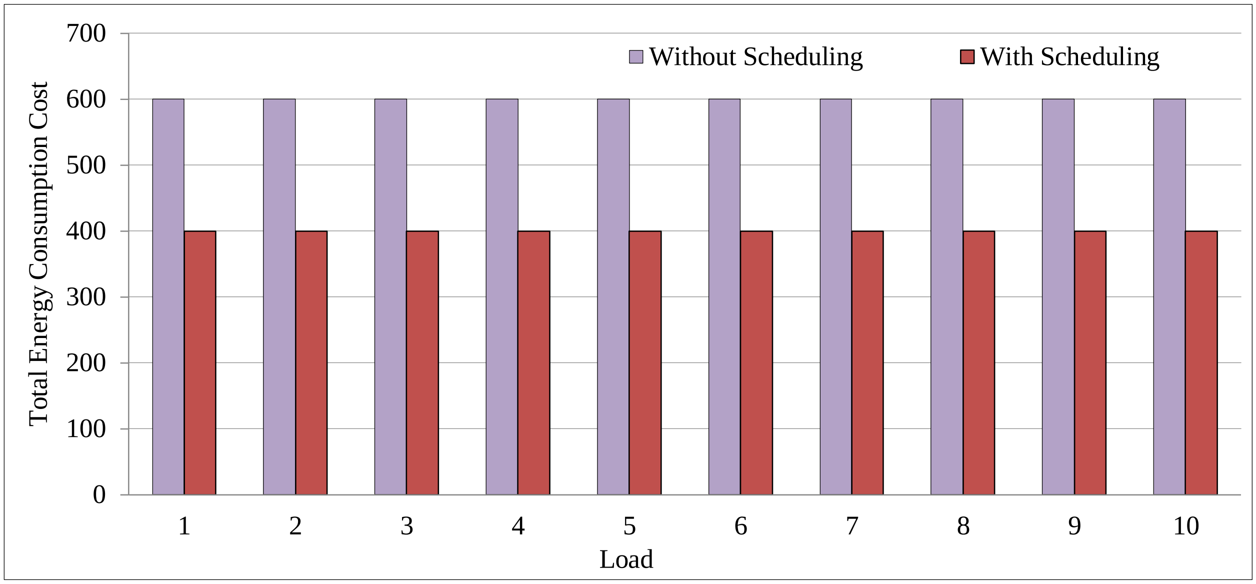


Fig. 5 Estimated costs associated with each user, with and without scheduling

5. Conclusion

This study proposes the DSM algorithm for residential loads using the Pelican Optimization Algorithm (POA) Method. To that end, a load scheduling problem involving both shiftable and non-shiftable devices is considered for the users mentioned above and is handled with the Pelican Optimization Algorithm (POA). A MATLAB simulation's result shows that every user minimizes the daily cost and efficiently consumes energy. This recommended method also helps the entire SG, particularly at the distribution network level. A decline in peak load demand increases the distribution network's capacity and dependability. Lastly, the results show that the recommended method effectively reduces the user's PAR ratio, consequently, the cost of consuming electricity is reduced. The findings demonstrate that each user's daily power prices, PAR, and overall energy costs are decreased by the suggested DSM model with the POA Algorithm. The simulation's findings indicate that the DSM model minimizes energy expenses by 22% and lowers the PAR of a single user by 20%. PAR and total energy costs have decreased by 54.25%, respectively. When there are many users in the future, this model may be updated to take user-side energy production such as fuel cells, solar power, and wind into consideration.

Acknowledgments

The supervisor provided invaluable direction and unflinching support throughout the research, for which the author is truly grateful.

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