Managing the Demand in a Micro Grid Based on Load Shifting with Controllable Devices Using Hybrid WFS2ACSO Technique

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Abstract: Demand Side Management (DSM) is an effective tool for utilities through reducing the demand of peak load and controlling the utilization of the energy of the system. The implementation of DSM provides benefits for utilities and is profitable for the customers who are involved in this process. DSM based on a load shifting strategy is proposed in this paper by employing various devices to minimize the energy consumption pattern in the system. The proposed hybrid strategy is the joint implementation of the Wingsuit Flying Search Algorithm (WFSA) and Artificial Cell Swarm Optimization (ACSO). The searching behavior of WFSA is enhanced by ACSO. Hence, it is named the WFS2ACSO technique. The implementation of this load shifting technique was carried out on three different types of loads, these being residential loads, commercial loads, and industrial loads. Two case studies, over summer and winter, were validated to check the feasibility of the test system. The proposed method aimed to achieve the load demand in an effective way for the minimization of bill electrification, Peak to Average Ratio (PAR), and the consumption of power. The Time-of-Use (TOU) pricing was implemented to calculate the savings in energy bills. The proposed test system of the Micro Grid (MG) was executed on a MATLAB platform with two case studies based on the optimization methods WFSA and WFS2ACSO. Simulation results demonstrated the comparative analysis of electricity cost and peak load with different algorithms and were carried out with and without DSM consideration. The projected DSM methodology achieved considerable savings as the peak load demand of MG decreased. Furthermore, the decrease in PAR levels of 14% in the residential load, 16% in the commercial load, and 10% in the industrial load, with and without the DSM methodology, was presented. The flight length and awareness of probability tuning parameters make the proposed algorithm more effective in obtaining better results. The test results obtained prove the effectiveness of the hybridized algorithm as compared with other trend-setting optimization techniques such as Particle Swarm Optimization (PSO) and Ant Lion Optimization (ALO).

Keywords: Demand Side Management (DSM); Wingsuit Flying Search Algorithm; Micro Grid (MG); residential load; commercial load; industrial load

1. Introduction

Within a country, the principal problem for power systems is the effective utilization of power and its distribution. One of the most severe problems is the blackout of electricity due to inappropriate usage or power wastage. This fault exists in the traditional power system. The issue could be solved with the integration of DSM implementation in a future MG [1]. The major problem of the smart grid is the system that has high peak demand value and low time intervals, resulting in further cost burdens to the generating companies. This problem can be reduced by the concept of DSM [2]. DSM provides a solution in managing the peak demand with existing generation capacity [3]. During the electricity rush hour, electricity is distributed equally and in an efficient manner [4]. Electricity distributors...
charge a minimum amount of money at these maximum times to get users to use electricity during this particular period [5]. The power demand increases during the electricity rush hour [6]. To handle this situation, an additional load exists to increase power potency [7]. DSM is one of the crucial concerns for reducing power consumption, rather than putting pressure on supplementary power generation [8]. DSM is a proactive approach used to manage and shift the load using the same amount of power with less cost per unit of generation in power plants.

Residential customers misuse energy by using the devices in an unorganized manner. Customers must take part in load management to improve the system’s efficacy. Customers of residential areas may use various types of loads, which have different sequences for energy consumption [8].

There are various DSM techniques, as presented in Figure 1. DSM programs consist of planning, implementing, and monitoring activities of electric utilities that are designed to encourage consumers to modify their level and pattern of electricity usage.

DSM is used in the functionalities of an MG in different areas such as electricity market control, the construction of infrastructure and energy resource management, and electric vehicles; therefore, it has a significant impact on MG energy management [9,10]. In [11], the author carried out the scheduling of residential area appliances using a linear programming technique. In [12], the author proposed a heuristic technique to mitigate the integrating issue in the MG by the minimization of the cost of electricity to the customers. Here, the author concentrates on the reduction in cost analysis.

Logenthiran et al. [13] implemented a PSO-based DSM. Bharathi et al. [14] developed a genetic algorithm of DSM (GA-DSM) to achieve a flexible redistribution of loads. The main objective of this research was to diminish energy consumption in the event of an electrical emergency, effectively distributing the power available at a maximum time. Evolutionary techniques pose a solution to DSM-related problems. Khalid et al. [15] provided a Home Energy Management System (HEMS) that is adopted for improving home energy consumption patterns. Here, a Hybrid Bacterial Foraging and Genetic Algorithm were proposed. Furthermore, the Teaching Learning Based Optimization (TLBO) algorithm and other evolutionary algorithms such as flower pollination algorithms are employed in papers [16,17]. The idea of integration between electrical appliances was put forward.

In paper [18], the author implemented the DSM process using Ant Lion Optimization. The simulation results were compared with the PSO algorithm, which provided better results than PSO. Sharma et al. [19] provided a whale optimization heuristic algorithm to reduce the problem. This research demonstrated that on-demand page management approaches depend on planned protection, peak clipping, and load shifting. The simulations were conducted on a test system, which involves the deviation of loads on two service areas. Moreover, the simulation outcomes demonstrated that an advanced demand page management approach provides significant savings by diminishing the peak load requirement of the smart phase.
A new optimal bidding strategy has been developed in [20]. Kumar et al. [20,21] proposed a fish swarm optimization for minimizing the cost of power generation and peak load reduction. Padmini et al. [22–24] implemented the pricing strategy from the supply side. In this work, the authors framed a novel pricing scheme for estimating the cost of generation by the GENCO in the deregulated market. Covic. N et al. [25] developed a new optimization algorithm called WFSA, which was inspired by the popular sport wingsuit flying; it has fewer criteria and converges very quickly. Chaterjee S et al. [26] developed an ACSO algorithm derived through the Artificial Cell Division principle. Latifi, Met al. [27] proposed the integration of renewable energy sources, which effectively address the issues in implementation regarding Demand Side Management. Ahmad et al. [28] implemented a pricing strategy for a comprehensive analysis of DSM. Omar, AI. et al. [29] proposed a hybrid model to reduce the energy consumption in buildings. In papers [30,31], the authors implemented an interrupted charging schedule for the minimization of the charging costs. Biswajit Sarkar et al. [32] developed an optimization model for the minimization of carbon emissions with the simultaneous reduction in bioenergy production cost. Vandana et al. [33] presented a credit policy for the minimization of product cost and carbon emissions.

Table 1 depicts the different contributions from researchers regarding DSM, as shown below.

| Researchers          | Optimization Technique/Mode Used | Achievements or Findings                                    | Contributions                                                                 |
|----------------------|----------------------------------|-------------------------------------------------------------|-------------------------------------------------------------------------------|
| Guelpa, E [1]        | Linear programming               | Thermal scheduling of building                               | The author proposed DSM to control the district heating networks              |
| Tang, R [2]          | Game theory                      | Electricity bill and peak demand reduction                  | An interactive model was developed to communicate between grid and building    |
| Khan, A et al. [3]   | Multiple knapsacks               | Reduction inpeak energy consumption, carbon emissions        | The authors implemented a priority-based DSM strategy by load shifting technique |
| Su, H [4]            | Dynamic pricing strategy         | Forecasting of load demand, customer response analysis       | Development of data-driven DSM                                               |
| Yilmaz, S [5]        | Clustering analysis technique    | To improve electricity demand profiles                      | The authors proposed a novel clustering technique to forecast and enhance the load profiles |
| Walzberg J [6]       | Stochastic approach              | To estimate environmental impact                             | The authors proposed a life cycle assessment to estimate the environmental impacts |
| Luo, X et al. [7]    | Integrated demand and supply management strategy | Reduction inenergy consumption and energy storage | Neglected the PAR and user comfort                                            |
| Pilz, M [8]          | Dynamic game approach            | Reduction in forecasting errors                             | An extensive analysis was developed to reduce the forecasting errors           |
| Rehman, S et al. [9] | Model predictive control         | Reduction in generation cost and emissions                  | Neglected the PAR and user comfort                                            |
| Jha, S [10]          | DSM strategy                     | Voltage control in Micro Grid                                | The author implemented a battery energy storage system for voltage controlling in islanded Micro Grid |
| Qin, H [11]          | Linear programming               | To reduce the power mismatches                               | Proposed a stochastic unit commitment problem to reduce the power mismatches Implementation of renewable energy source to the grid with minimization of issues |
| Surajkumar [12]      | Heuristic technique              | To mitigate the integration issues                          | User comfort not taken into account                                                                                               |
| Logenthiran, T [13] | Particle Swarm Optimization      | Minimization of electricity bill, energy consumption, and PAR| Convergence time was higher and more parameters                                                                                   |
| Bharathi, C et al. [14] | Genetic Algorithm               | Minimization of power consumption                           | User comfort, PAR, and energy saving were neglected                                                                           |
| Khalid, A [15]       | Hybrid Bacterial Foraging and Genetic Algorithm | Energy savings and PAR reduction                           | User comfort neglected                                                          |
| Singh, M.; Jha, R [16] | TLBO technique                  | Peak reduction and usability index                          | User comfort and energy saving were neglected                                  |
Table 1. Cont.

| Researchers          | Optimization Technique/Mode Used                                                                 | Achievements or Findings                                                                 | Contributions                                                                                                                                 |
|----------------------|---------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Padmini, S [17]      | Flower Pollination Technique                                                                     | To reduce the congestion                                                                | The author proposed an optimization technique for rescheduling of generators to reduce the congestion.                                      |
| Venkatesh, B.;       | Ant Lion Optimization                                                                             | Reduction in electricity bill, energy consumption, and PAR                                | The author implemented an Ant Lion Optimization to minimize the electricity bill, energy consumption, and PAR.                              |
| Padmini, S [18]      | Whale Optimization Algorithm                                                                     | Minimization of peak load and energy savings                                              | User comfort and PAR were neglected.                                                                                                                                                                      |
| Sharma, A.; Saxena,  | Artificial Fish Swarm Optimization                                                                | To reduce the cost of power generation                                                   | The author proposed a day-ahead scheduling problem of generation and storage facility.                                                                                                                   |
| Kumar, K [20]        | Artificial Fish Swarm Optimization                                                                | To reduce the energy consumption                                                         | Proposed an algorithm for the reduction in energy consumption patterns.                                                                                                                                  |
| Huang, H [21]        | Locational marginal pricing                                                                       | Maximization of the profit of GENCO                                                      | The author developed an optimal bidding scheme to increase the profits of GENCO.                                                                                                                        |
| Padmini, S [22]      | Evolutionary programming                                                                          | Maximization of the profit of GENCO                                                      | The author developed an optimal bidding scheme to increase the profits of GENCO.                                                                                                                        |
| Padmini, S [23]      | Artificial Cell Swarm Optimization                                                                | Reduction in the optimization criterion                                                   | The author proposed a novel technique for the Wingsuit Flying Search Optimization criterion.                                                                                                             |
| Covic, N [25]        | Artificial Cell Swarm Optimization                                                                | Reduction in the optimization criterion                                                   | The author proposed a novel technique based on Artificial Cell Division process                                                                                                                     |
| Ahmed, E.M et al.    | PSO and Strawberry Optimization Algorithm(SOA)                                                   | Minimization of electricity bill, energy consumption                                     | The author developed a Hybrid Optimization Model to reduce the energy consumption in buildings.                                                                                                        |
| Omar, A.I et al.     | Hybrid Optimization Model                                                                         | To reduce energy consumption                                                              | The author implemented an interrupted charging schedule to minimize the charging costs.                                                                                                                   |
| Mohammed, S.S et al. | Modified placement algorithm                                                                      | Minimization of plug-in electric vehicle charging costs                                   | The author developed an integrated demand response program to maintain the balance between energy supply and demand.                                                                                   |
| Li Y et al. [31]     | CPLEX solver                                                                                      | To maintain the balance between energy supply and demand                                  | Reduction inefficient energy affected the supply chain for biofuels.                                                                                                                                  |
| Sarkar et al. [32]   | Multi-setup-multi-delivery (MSMD) concept                                                          | Development of sustainable biofuel supply chain                                          | To enable the coordination of supply chain successfully with reduced CO₂ emissions. Parameter free and convergence in fewer iterations.        |
| Vandana et al. [33]  | Two-echelon supply chain                                                                          | Energy and carbon dioxide minimization                                                    |
| Proposed method      | Hybrid WFS2ACSO technique                                                                          | Minimization of electricity bill, energy consumption, and PAR                            | Analysis of Demand Side Management with regard to summer and winter seasons considering residential, commercial, and industrial loads with the incorporation of WFSA and hybrid WFS2ACSO optimization technique was formulated. |
|                      |                                                                                                   |                                                                                           | Validation of minimization on bill electrification, Peak to Average Ratio (PAR), and power consumption with and without applying DSM was performed using WFSA and hybrid WFS2ACSO optimization techniques. |
|                      |                                                                                                   |                                                                                           | Comparative efficacy analysis of the proposed WFSA and hybrid WFS2ACSO optimization techniques with the trend-setting optimization techniques such as Ant Lion Optimization and PSO techniques. |

The above literature survey concludes the following research gap:

- The technique adopted in this paper is proposed with WFSA and the hybrid WFS2ACSO optimization technique, which has not been contributed by other researchers.
Previous researchers have not contributed to the rise in controllable devices in Demand Side Management with regard to summer and winter seasons while considering the methodology of DSM with the incorporation of WFSA and the hybrid WFS2ACSO optimization technique.

Previous studies have not contributed to the comparative analysis of the validation of minimization on bill electrification, Peak to Average Ratio (PAR), and power consumption using the WFSA and the hybrid WFS2ACSO optimization technique with and without applying DSM.

This study highlights the embodiment of a hybrid optimization technique along with a load shifting strategy that can prove beneficial to customers in residential, commercial, and industrial load areas with the inclusion of both shiftable and non-shiftable loads.

The objectives of the proposed work as follows:

- Analysis of Demand Side Management with regard to summer and winter seasons considering residential, commercial, and industrial loads with the incorporation of WFSA and the hybrid WFS2ACSO optimization technique was formulated.
- The validation of minimization on bill electrification, Peak to Average Ratio (PAR), and power consumption with and without applying DSM was performed using WFSA and the hybrid WFS2ACSO optimization technique.
- A comparative analysis of PAR was proposed for both summer and winter.

The rest of the manuscript’s sections are as follows below. Section 2 explains the modeling of DSM in a smart grid with a proposed strategy. Section 3 delineates the proposed hybrid approach of Wingsuit Flying Search Algorithm (WFSA) and Artificial Cell Swarm Optimization (ACSO). Section 4 defines the considered test system. Section 5 provides the clear-cut picture of the proposed approach in terms of result comparison with existing systems.

2. Problem Formulation

Here, the DSM technique is presented for the MG system. DSM acts as a primary technique, known as load shifting. The main aim of DSM is to increase the utilization of RES, increase the economic advantage, and reduce the peak load requirement. Based on the target of DSM, the MG manager configures a goal of a load curve. The main purpose of the work is to adjust the load curve nearest to the possible target load curve. Market price and electricity bill minimization are inversely proportional. Hence, in accordance with this criterion, a suitable objective load curve is chosen. Control methods are required if loads are additionally added. Therefore, the present technique is extensible because it is entirely independent of the criterion used for producing the target load curve. DSM takes place in the initialization of a predefined control period, usually for one day. Figure 2 demonstrates the overview of DSM in an MG.
2.1. Problem Formulation of DSM

DSM approach programs are based on the connection times of every flexible device on a forum that matches the objective curve closer to the target curve. The objective equation is shown in Equation (1) [13].

$$\sum_{m=1}^{H} (P_{\text{Load}}(m) - \text{objective}(m))^2$$  \hspace{1cm} (1)

From the previous equation, the goal curve in time \(m\) is denoted as the value expressed as \(\text{objective}(m)\); the actual usage in time \(m\) is stated as \(P_{\text{Load}}(m)\). The \(P_{\text{Load}}(m)\) is stated as follows:

$$P_{\text{Load}}(m) = \text{forecast}(m) + \text{connect}(m) - \text{disconnect}(m)$$  \hspace{1cm} (2)

From Equation (2), the forecasted consumption time is expressed as \(\text{forecast}(m)\). During the period of load shifting, the amount of connected load and disconnected load in time \(m\) is denoted as \(\text{connect}(m)\) and \(\text{disconnect}(m)\), respectively.

The \(\text{connect}(m)\) is classified into two sections: (1) the increase in load at the connection time of device changed to time \(m\); (2) the increase in load at the connection time of device arranged that proceed on time \(m\). The \(\text{connect}(m)\) is expressed as follows:

$$\text{connect}(m) = \sum_{i=1}^{m-1} \sum_{k=1}^{d} x_{kim} P_{1k} + \sum_{i=1}^{m-1} \sum_{l=1}^{i-1} \sum_{k=1}^{d} x_{li}(m-1) P_{(l+1)k}$$  \hspace{1cm} (3)

Here, the quantity of devices at kind \(k\) is expressed as \(x_{kim}\), which is moved from step time \(i\) to \(m\). The number of types of devices is denoted as \(d\), the power consumptions are
expressed as $P_{1k}$ and $P_{(1+l)k}$. Device type $k$ is expressed as $1+l$, the consumption of total duration for devices $k$ is stated as $j$.

The $\text{disconnect}(m)$. is also classified into two sections: (1) the decrease in load based on the connection of delay time devices and start to consumption at time $m$; (2) the decrease in load for delaying at connection times of devices, which is predicted to begin its consumption at time steps that precede $l$. The $\text{disconnect}(m)$. is expressed as follows [31]:

$$\text{disconnect}(m) = \sum_{q=m+1}^{1+m} \sum_{k=1}^{d} x_{ktq}P_{1k} + \sum_{i=1}^{j-1} \sum_{k=1}^{l} x_{ki}(m-1)P_{(1+l)k}$$

(4)

From the above equation, the quantity of devices is expressed as $x_{ktq}$ at type $k$, the highest amount of delay is expressed as $m$.

2.2. Minimization Function

The load $i$ is the initial load curve. This curve should be modified as per the objective curve after submission of DSM evaluated as the load curve provided from the load. Then, the goals are as below:

$$\text{Min } F_1 = \text{Max} \left( \text{Load}_i \right)$$

(5)

$$\text{Min } F_2 = \sum_{h=1}^{h} \text{Load}_{fh}P_h$$

(6)

where the highest peak of the final load curve is expressed as $F_1$ and is necessary to be reduced with function $F_2$. The function $F$ is represented to update the final load curve and to rectify the reduction issues.

$$\text{Min } F_h = |\text{RLM}_h| - |\Delta\text{Load}_h|$$

(7)

Here, RLM refers to the Reducible Load Margin calculated at each hour.

$$\text{RLM}_h = \text{forecast}_h - \text{obj}_h$$

(8)

From the previous equation, the marginal load is deducted or added in whole or in part to the predicted load curve in diverse times, bringing it as near as possible to the target curve [32].

$$\text{RLM}_h = \begin{cases} \geq 0, & \text{forecast}_h < \text{obj}_h \\ \leq 0, & \text{forecast}_h \geq \text{obj}_h \end{cases}$$

(9)

2.3. Constraints

From the above minimization function, the following constraints are developed, which are expressed as follows.

At any moment, the number of devices of any kind to be moved will forever be positive.

$$x_{kt} > 0 \quad \forall k, h$$

(10)

At any moment, the number of devices to be moved cannot be greater than the available number of controllable devices of that exacting device.

$$\sum_{k=1}^{h} x_k \leq \text{controllable}(k)$$

(11)

From the above equation, the total number of the devices accessible for the control of type misstated as $\text{controllable}(k)$.

The consumers require a reduction in electricity bill costs. The goals of different groups should be in conflict, and a better way for providing them to fulfill the objective
with optimal solutions. Furthermore, the decisions of the decision-maker also should be taken into consideration [13].

2.4. Calculation of Controllable Devices

In DSM, the total number of controllable devices is one of the utmost valuable things. Based on the duration time, the devices are connected to operate what are known as non-shiftable devices such as refrigerators, TVs, and so on. Devices that are flexible over the time duration are known as shiftable devices, such as the washing machine, dryer, dishwasher, and so on. Based on three areas, shiftable devices were used for DSM performance.

According to several controllable devices in the MG, the three areas’ devices were evaluated, expressed as follows:

1) Residential area: In the residential area, controllable devices are very low for load control based on the ratings of power consumption, and the load of home appliances is very low, such as for the washing machine, dishwasher, EV home charger, and so on.

2) Commercial area: Here, the equipment is quite high in comparison with the residential load. This includes devices such as the coffee maker, water dispenser, and so on.

3) Industrial area: In the industrial area, the load of power consumption are at maximum, with a minimum number of controllable devices, such as the welding machine, water heater, etc. In this area, the operating conditions are also high compared to other areas.

3. Proposed WFS2ACSO Technique Approach

In this research paper, a DSM approach for MG is proposed. This approach depends on a load shifting system that can deal with a huge number of devices of various methods. All devices request the central programmer to run the job, and the programmer creates the decision regarding the status of devices in a definite time.

The Wingsuit Flying Search Algorithm (WFSA) [25] is a metaheuristic algorithm with free parameters, practically speaking. It depends on lean technology in the execution of reaching the perfect output globally.

The Artificial Cell Swarm Optimization (ACSO) [26] is a robust and powerful metaheuristic swarm-based optimization approach. It is inspired by biological, living cells. It can easily identify a cell organization in the ways that the transport of dissimilar parts among cells is reduced.

The proposed hybrid system is the joint implementation of WFSA and ACSO. The searching behavior of WFSA is enhanced by ACSO, and hence it is named the WFS2ACSO technique for the minimization of electricity bills, power consumption, and PAR. The algorithm mimics a flyer’s intention to land as low as probable on the Earth’s surface in range. It has virtually few parameters, such as the size of the population and the maximum representation of iterations. The proposed model was implemented on MATLAB/Simulink and simulation studies were conducted in the MG that had dissimilar types of clients through many loads.

WFS2ACSO Algorithm Steps

Step 1: Initialization of dimensions, number of search agents, max iterations, upper boundary, lower boundary, awareness probability, and flight length.

Step 2: Random generation of population or positions for the parameters at the input are arbitrarily created using below matrix $X$.

$$X = \begin{bmatrix}
p^{11}(m) & p^{12}(m) & \cdots & p^{1q}(m) \\
p^{21}(m) & p^{22}(m) & \cdots & p^{2q}(m) \\
\vdots & \vdots & \ddots & \vdots \\
p^{n1}(m) & p^{n2}(m) & \cdots & p^{nq}(m)
\end{bmatrix} \quad (12)$$
From the above equation, the Demand Side Management is represented as $P_{11}(t)$.

**Step 3:** Objective function relates to an evaluation of fitness as expressed in Equation (1).

**Step 4:** Position updating using ACSO

After the calculation of the fitness function, update the positions of the cell swarms using Equation (13):

$$X_{new} = X + fl \times r \times (X_k - X).$$  \hspace{1cm} (13)

where $X_{new}$ is the new position, $X$ is the current position, $X_k$ is the best position in the local search, $fl$ is the flight length, and $r$ is the random number between $[0, 1]$.

**Step 5:** Calculation of successor distance

After the calculation, the successor distance is evaluated in order to divide the range of parent cells. The successor distance will be changed at each generation.

For where the $(i + 1)$th cell yields a superior assessment with regard to the preceding propagation.

$$\delta_{i+1} = \delta_i - r_d \text{ and } S_{i+1} = S_i - \delta_{i+1}$$ \hspace{1cm} (14)

For where the $(i + 1)$th cell yields a superior assessment with regard to the preceding propagation.

$$\delta_{i+1} = \delta_i + r_i \text{ and } S_{i+1} = S_i + \delta_{i+1}$$ \hspace{1cm} (15)

where $\delta_i$ is the successor distance change, $r_d$ is the decrement rate, and $r_i$ is the increment rate.

**Step 6:** Calculation of life of cell

The child cell of the next generation will move into parent life, then, the parent cell suffers based on fitness value and their life will stay as equal or it will be reduced per unit.

For where the $(i + 1)$th cell yields a superior assessment with respect to the preceding propagation.

$$life_{i+1} = life_i$$ \hspace{1cm} (16)

For where the $(i + 1)$th cell yields a superior assessment with respect to the preceding propagation.

$$life_{i+1} = life_i - 1$$ \hspace{1cm} (17)

**Step 7:** Stopping criteria

If $iter < iter_{\text{max}}$, then return the best achievement of the population as the optimal solution. A flowchart mimicking this algorithm is shown in Figure 3.

A simple numerical illustration of WFS2ACSO (hybrid of Wingsuit Flying Search Algorithm (WFSA) and Artificial Cell Swarm Optimization (ACSO)) is presented.

Consider the simple objective function $f(x) = x_1^2 + x_2^2$ subject to $x_{hi} = (0.4, 0.4)$. The fitness value obtained is $f(x_{hi}) = 0.32$. Now, the above fitness function of WFS2ACSO is applied as $X_1 = 0.4$ and $X_2 = 0.4$, rand is 0.5, and $fl$ is 2. Then, $f(x_{hi}) = 0.4$. Then, the updated value is taken as $x_{hi} = (0.3, 0.4)$. Thus, the new fitness value is $f(x_{hi+1}) = 0.25$. Thereafter, from the fitness function of WSF2ACSO, $x_{hi+1} = 0.2$. Therefore $f(x_{hi+1}) < f(x_{hi})$. This implies that the new fitness value is replaced with the old fitness value.

In the case of the Ant Lion algorithm, the disorderly walk of the ants leads to multiple local minima instead of global minima. The WFSA algorithm proves its validity by the incorporation of a minimum tuning parameter of flight length. Therefore, this mutation process is further enhanced by the awareness of probability in Artificial Cell Swarm Optimization. Thus, this WFS2ACSO hybridization yields a better result when compared with the other trend-setting algorithms such as PSO and Ant Lion algorithm, as portrayed in the literature.
The proposed experimental system is a test case of an MG [13] comprising residential, commercial, and industrial loads. The forecasted load demands of all three areas are shown in Figure 4. In this paper, the daily load plan was taken from 8 o’clock in the morning of the present day while considering the adjacent day for analyzing the active peak load changing process. The details of all the three area loads are provided in Tables 2–4. Table 5 shows the tariff for all three areas.

![Flow chart for WFS2ACSO algorithm](image)

**Figure 3.** Flow chart for WFS2ACSO algorithm.

### 4. Details of the Test System

The proposed experimental system is a test case of an MG [13] comprising residential, commercial, and industrial loads. The forecasted load demands of all three areas are shown in Figure 4. In this paper, the daily load plan was taken from 8 o’clock in the morning of the present day while considering the adjacent day for analyzing the active peak load changing process. The details of all the three area loads are provided in Tables 2–4. Table 5 shows the tariff for all three areas.

![Forecasted load demands of all three areas](image)

**Figure 4.** Forecasted load demands of all three areas.
Table 2. Details of the residential load.

| S. No. | Name of the Device  | Rating of the Device (Watts) |
|--------|---------------------|-------------------------------|
| 1      | Light               | 40                            |
| 2      | Fan                 | 75                            |
| 3      | TV                  | 100                           |
| 4      | Charger             | 7                             |
| 5      | Washing machine     | 400                           |
| 6      | Mixie               | 500                           |
| 7      | Iron box            | 750                           |
| 8      | Grinder             | 300                           |
| 9      | Motor               | 740                           |

Table 3. Details of the commercial load.

| S. No. | Name of the Device         | Rating of the Device (Watts) |
|--------|----------------------------|-------------------------------|
| 1      | Water dispenser            | 450                           |
| 2      | Dryer                      | 230                           |
| 3      | Kettle                     | 650                           |
| 4      | Oven                       | 750                           |
| 5      | Coffeemaker                | 180                           |
| 6      | Fan                        | 300                           |
| 7      | Air conditioner            | 500                           |
| 8      | Lights                     | 2000                          |
| 9      | EV charging                | 700                           |

Table 4. Details of the industrial load.

| S. No. | Name of the Device        | Rating of the Device (Watts) |
|--------|---------------------------|-------------------------------|
| 1      | Water heater              | 500                           |
| 2      | Welding machine           | 1600                          |
| 3      | Fan/AC                    | 750                           |
| 4      | Air furnace               | 1100                          |
| 5      | Induction motor           | 1500                          |
| 6      | DC motor                  | 1000                          |
| 7      | Water pump                | 720                           |
| 8      | Boiler                    | 470                           |
| 9      | Chilling plant            | 1200                          |

Table 5. Hourly TOU tariff.

| Time (h) | Tariff(USD/Wh) |
|----------|----------------|
| 24–1     | 0.0865         |
| 1–2      | 0.0811         |
| 2–3      | 0.0825         |
| 3–4      | 0.0810         |
| 4–5      | 0.0814         |
| 5–6      | 0.0813         |
| 6–7      | 0.0834         |
| 7–8      | 0.0935         |
| 8–9      | 0.12           |
| 9–10     | 0.0919         |
| 10–11    | 0.1227         |
| 11–12    | 0.2069         |
| 12–13    | 0.2682         |
| 13–14    | 0.2735         |
| 14–15    | 0.1381         |
Table 5. Cont.

| Time (h) | Tariff(USD/Wh) |
|----------|----------------|
| 15–16    | 0.1731         |
| 16–17    | 0.1642         |
| 17–18    | 0.0983         |
| 18–19    | 0.0863         |
| 19–20    | 0.0887         |
| 20–21    | 0.0835         |
| 21–22    | 0.1644         |
| 22–23    | 0.1619         |
| 23–24    | 0.0887         |

5. Results and Discussions

In this section, a DSM approach proposed for an MG is presented. The proposed hybrid approach is the joint implementation of the Wingsuit Flying Search Algorithm (WFSA) and Artificial Cell Swarm Optimization (ACSO). The searching behavior of WFSA is enhanced by ACSO and, hence, it is named the WFS2ACSO technique. The WFS2ACSO technique is used for the reduction in electricity bills, power consumption, and PAR. The proposed model is implemented with the MATLAB-Simulink software package. Simulation studies were carried out for an MG with two case studies, during summer and winter, which consisted of dissimilar kinds of clients with a huge number of loads.

Case 1: Performance of system parameters for residential area, commercial area, and industrial area under summer conditions.

Here, the energy bill of utility, peak load, and PAR was reduced using the proposed WFS2ACSO applied on three different areas of the MG.

The demand curves of the different individual areas are shown in Figures 5–7. In the residential area, during the morning hours, the peak demand was 2000 Watts, and demand was reduced during afternoon hours. In the commercial area, during the morning hours, peak demand was around 1500 Watts, and many of the loads were operating during morning hours. In the industrial area, the peak demand was around 800 Watts, and the operating hours of the loads varied throughout the day.

Figure 5. Demand curve of residential load.
The ON/OFF period of individual devices of all three areas is shown in Figures 8–10. From Figure 8, the fan operated for a maximum duration and the iron box operated for a minimum duration, while the rest of the devices operated according to the requirement of the user in the residential area. From Figure 9, the air conditioner operated during the nights in the summer, while the rest of the devices operated according to the requirement of the customer in the commercial area. From Figure 10, the fan/AC had the maximum operating hours and the DC motor had the minimum operating hours.

**Figure 6.** Demand curve of commercial load.

**Figure 7.** Demand curve of industrial load.

**Figure 8.** ON/OFF period of individual appliances for residential area.
The different load curves of the forecasted objective and load that shifted after DSM with peak load reduction are shown in Figures 11–13. In the residential area, the peak load was deviated from 2400 W to 2300 W after shifting some of the devices to the off-peak hours to optimize the system; there was a peak reduction of 4.16% of the load. In the commercial area, the load was reduced from 4985 W to 4290 W by shifting the shiftable loads, such as the dryer, kettle, and oven, to off-peak hours; there was a peak reduction of 14.01% of the load. In the industrial area, the load was reduced from 6868 W to 5487 watts by shifting the shiftable loads, such as the welding machine, water heater, and boiler to the off-peak hours; there was a peak reduction of 20.1% of the load.

Figure 9. ON/OFF period of individual devices for commercial area.

Figure 10. ON/OFF period of individual devices for industrial area.

Figure 11. DSM results of residential load under summer conditions.
The utility electricity bill curves of the three areas compared with various algorithms are shown in Figures 14–16. By the proposed technique, the reduction in the single-day electricity bill of the residential zone was from USD 2689.32 to USD 2427.32; there was a substantial cost saving of 9.74% in the summer. The reduction in the single-day electricity bill of the commercial zone was from USD 11,853.43 to USD 10,259.82; there was a cost saving of 13.44%.

The reduction in the single-day electricity bill of the industrial zone was from USD 13,579.11 to USD 11,853.43; there was a cost saving of 13.74%.
Figure 15. Cost comparison of various techniques for commercial area.

Figure 16. Cost comparison of various techniques for industrial area.

Case 2: Performance of system parameters for residential area, commercial area, and industrial area under winter conditions.

Here, the electricity bill cost, peak load, and PAR were reduced with the proposed WFS2ACSO, which was tested on three zones of the smart grid.

The demand curve of the different individual areas is shown in Figures 17–19. In the residential area, during morning hours, the peak demand was 1000 Watts, and the demand was reduced during afternoon hours. In the commercial area, the peak demand was around 4000 Watts, and many of the loads were operating during morning hours. In the industrial area, the peak demand was around 6000 Watts, and the operating hours of the loads varied throughout the day.

Figure 17. Demand curve of residential load.
The ON/OFF period of individual devices of all three areas is shown in Figures 20–22. From Figure 20, in the residential area, the fan operated for the maximum duration and the iron box operated for the minimum duration, while the rest of the devices operated according to the requirement of the user. From Figure 21, in the commercial area, the air conditioner operated during the nights in the summer, while the rest of the devices operated according to the requirement of the customer. From Figure 22, the fan/AC had the maximum operating hours and the DC motor had the minimum operating hours.
The different load curves of the forecasted objective and load that shifted after DSM with peak load minimization are shown in Figures 23–25. In the residential area, the peak load was deviated from 2400 W to 2200 W after shifting some of the devices to the off-peak hours to optimize the system; there was a peak reduction of 9.09% of the load. In the commercial area, the load was reduced from 4985 W to 4290 W by shifting the shiftable loads, such as the dryer, kettle, and oven, to off-peak hours; there was a peak reduction of 14.01%. In the industrial area, the load was reduced from 6524 W to 5120 W by shifting the shiftable loads, such as the boiler, to off-peak hours; there was a peak reduction of 21.52%.
The utility electricity bill curves of three areas were compared with various algorithms, as shown in Figures 26–28. By the proposed technique, the reduction in the single-day electricity bill of the residential zone was from USD 2663.19 to USD 2297.02; there was a substantial cost saving of 13.74% in the winter. The reduction in the single-day electricity bill in the commercial zone was from USD 7034.23 to USD 6159.59 in the winter with a cost saving of 12.43%. The reduction in the single-day electricity bill of the industrial zone was from USD 10,796.65 to USD 9144.54; there was a cost saving of 15.30%.

Figure 24. DSM results of commercial load under winter conditions.

Figure 25. DSM results of industrial load under winter conditions.

Figure 26. Cost comparison of various techniques for residential area.
Table 6 shows the comparison of the percentage cost reduction for different optimization methods for the residential load. Table 7 shows the comparison of the percentage cost reduction for different optimization methods for the commercial load. Table 8 shows the comparison of the percentage cost reduction for different optimization methods for the industrial load.

Table 6. Comparison of percentage cost reduction for different optimization methods for residential load.

| Method       | Sunny Season | Winter Season |
|--------------|--------------|---------------|
|              | Without DSM (USD) | With DSM (USD) | Percentage Reduction (%) | Without DSM (USD) | With DSM (USD) | Percentage Reduction (%) |
| WFS2ACSO (proposed) | 2689.32 | 2427.32 | 9.74 | 2663.19 | 2297.02 | 13.74 |
| WFSA         | 2689.32 | 2516.90 | 6.43 | 2663.19 | 2386.15 | 10.40 |
| ALO [18]     | 2689.32 | 2530.59 | 5.90 | 2663.19 | 2447.66 | 8.09 |
| PSO [13]     | 2689.32 | 2568.22 | 4.50 | 2663.19 | 2478.64 | 6.92 |

Table 7. Comparison of percentage cost reduction for different optimization methods for commercial load.

| Method       | Sunny Season | Winter Season |
|--------------|--------------|---------------|
|              | Without DSM (USD) | With DSM (USD) | Percentage Reduction (%) | Without DSM (USD) | With DSM (USD) | Percentage Reduction (%) |
| WFS2ACSO (proposed) | 2689.32 | 2427.32 | 9.74 | 2663.19 | 2297.02 | 13.74 |
| WFSA         | 2689.32 | 2516.90 | 6.43 | 2663.19 | 2386.15 | 10.40 |
| ALO [18]     | 2689.32 | 2530.59 | 5.90 | 2663.19 | 2447.66 | 8.09 |
| PSO [13]     | 2689.32 | 2568.22 | 4.50 | 2663.19 | 2478.64 | 6.92 |

Table 8. Comparison of percentage cost reduction for different optimization methods for industrial load.

| Method       | Sunny Season | Winter Season |
|--------------|--------------|---------------|
|              | Without DSM (USD) | With DSM (USD) | Percentage Reduction (%) | Without DSM (USD) | With DSM (USD) | Percentage Reduction (%) |
| WFS2ACSO (proposed) | 2689.32 | 2427.32 | 9.74 | 2663.19 | 2297.02 | 13.74 |
| WFSA         | 2689.32 | 2516.90 | 6.43 | 2663.19 | 2386.15 | 10.40 |
| ALO [18]     | 2689.32 | 2530.59 | 5.90 | 2663.19 | 2447.66 | 8.09 |
| PSO [13]     | 2689.32 | 2568.22 | 4.50 | 2663.19 | 2478.64 | 6.92 |
Table 7. Comparison of percentage cost reduction for different optimization methods for commercial load.

| Method                  | Sunny Season | Winter Season | Sunny Season | Winter Season |
|-------------------------|--------------|---------------|--------------|---------------|
|                         | Without DSM (USD) | With DSM (USD) | Without DSM (USD) | With DSM (USD) | Without DSM (USD) | With DSM (USD) | Without DSM (USD) | With DSM (USD) |
| WFS2ACSO (proposed)     | 7301.20      | 6465.81       | 13.74        | 7034.23       | 6159.59       | 12.43           |
| WFSA                    | 7301.20      | 6579.92       | 9.88         | 7034.23       | 6235.39       | 11.35           |
| ALO [18]                | 7301.20      | 6894.50       | 6.94         | 7034.23       | 6305.18       | 10.36           |
| PSO [13]                | 7301.20      | 6976.63       | 4.44         | 7034.23       | 6476.16       | 7.97            |

Table 8. Comparison of percentage cost reduction for different optimization methods for industrial load.

| Method                  | Sunny Season | Winter Season | Sunny Season | Winter Season |
|-------------------------|--------------|---------------|--------------|---------------|
|                         | Without DSM (USD) | With DSM (USD) | Without DSM (USD) | With DSM (USD) | Without DSM (USD) | With DSM (USD) | Without DSM (USD) | With DSM (USD) |
| WFS2ACSO (proposed)     | 11,853.43    | 10,259.82     | 13.44        | 10,796.65     | 9144.54       | 15.30           |
| WFSA                    | 11,853.43    | 10,748.99     | 9.31         | 10,796.65     | 9613.93       | 10.95           |
| ALO [18]                | 11,853.43    | 11,211.69     | 5.41         | 10,796.65     | 9995.45       | 7.42            |
| PSO [13]                | 11,853.43    | 11,425.10     | 3.61         | 10,796.65     | 10,174.85     | 5.75            |

Table 9 shows the comparison of electricity bill reductions using various techniques. According to the simulation results, the results obtained from the WFS2ACSO algorithm are the best when compared to WFSA, ALO, and PSO. In comparison with the proposed technique, the reduction in the single-day electricity bill of the residential zone was 9.74% in the summer and 13.74% in the winter. The reduction in the single-day electricity bill of the commercial zone was 11.44% in the summer and 12.43% in the winter. Similarly, the reduction in the single-day electricity bill in the industrial zone was 13.44% in the summer and 15.30% in the winter.

Table 10 shows the output results of the comparison of peak demand reduction in residential, commercial, and industrial areas in the summer. In the residential area, there was a deviation of the load from 2400 W without DSM to 2300 W with DSM after shifting the required number of devices to the off-peak hours. In the commercial area, the load was reduced from 4985 W without DSM to 4290 W with DSM, and in the industrial area, the load was reduced from 6868 W without DSM to 5487 watts with DSM.
Table 10. Comparison of peak demand reduction during summer.

| Area       | Peak Load Without Applying DSM (Watts) | Peak Load With Applying DSM (Watts) | Peak Deviation (Watts) | Percentage Deviation (%) |
|------------|----------------------------------------|------------------------------------|------------------------|--------------------------|
| Residential| 2400                                   | 2300                               | 100                    | 4.16                     |
| Commercial | 4985                                   | 4290                               | 695                    | 14.01                    |
| Industrial | 6868                                   | 5487                               | 1381                   | 20.10                    |

Table 11 shows the output results of the comparison of peak demand reduction in three different zones of the MG in the winter. The load reduction in the residential zone was minimized from 2400 W to 2200 W. The load reduction in the commercial zone was minimized from 4985 W to 4290 W, and in the industrial area, the load was reduced from 6524 W to 5120 W.

Table 11. Comparison of peak demand reduction during winter.

| Area       | Peak Load Without Applying DSM (Watts) | Peak Load With Applying DSM (Watts) | Peak Deviation (Watts) | Percentage Deviation (%) |
|------------|----------------------------------------|------------------------------------|------------------------|--------------------------|
| Residential| 2400                                   | 2200                               | 200                    | 9.09                     |
| Commercial | 4985                                   | 4290                               | 695                    | 14.01                    |
| Industrial | 6524                                   | 5120                               | 1404                   | 21.52                    |

Table 12 shows the Peak to Average Ratio comparison of the three areas. In the residential area, the reduction in PAR was from 1.924 to 1.657; in the commercial area, the PAR reduction was from 1.854 to 1.564; and in the industrial area, the PAR was reduced from 1.754 to 1.587. Decreasing the peak load demand enhances grid sustainability by reducing the overall cost and carbon emission levels.

Table 12. Peak to Average Ratio (PAR).

| Method                  | Residential Load | Commercial Load | Industrial Load |
|-------------------------|------------------|-----------------|-----------------|
|                         | Without Incorporation of DSM | Incorporation of DSM | Without Incorporation of DSM | Incorporation of DSM | Without Incorporation of DSM | Incorporation of DSM |
| Peak to Average Ratio   | 1.924            | 1.657           | 1.854           | 1.564           | 1.754           | 1.587           |
| (summer)                | 1.684            | 1.485           | 1.784           | 1.486           | 1.871           | 1.658           |

According to the above simulation results, the WFS2ACSO algorithm provides the best results when compared to WFSA, ALO, and PSO for minimizing the electricity bills, peak load reduction, and PAR. In the residential area, there was a cost saving of 9.74% in the peak load reduction of 100 Watts in the summer, and there was a cost saving of 13.74% in the peak load reduction of 200 Watts in the winter. In the commercial area, there was a cost saving of 11.44% in the peak load reduction of 695 Watts in the summer, and there was a cost saving of 12.43% in the peak load reduction of 695 Watts in the winter. In the industrial area, there was a cost saving of 13.44% in the peak load reduction of 1381 Watts in the summer, and there was a cost saving of 15.30% in the peak load reduction of 1404 Watts in the winter.

6. Conclusions

The DSM strategy in the MG system using the WFS2ACSO technique was presented in this paper. At the distribution grid level, DSM has the possibility of providing numerous advantages to all MGs. The proposed technique in a global system depends on
load displacement created mathematically for reduction issues. Thus, the WFS2ACSO technique was found to be very effective for the reduction in electricity bills, PAR, and power consumption. The daily load change method presented in this manuscript was mathematically created from reduction issues. The WFS2ACSO technique was utilized for defusing the minimization issues. The proposed method performed in an MG had several loads at three service areas: a residential area, commercial area, and industrial area. The simulation outcomes demonstrated that the DSM approach reaches substantial savings by decreasing the peak load demand of the MG. The proposed model was executed on a MATLAB/Simulink platform based on two case studies using an existing system. By using the proposed methodology, the performance of the system increased due to the coordinating demand-side load of the MG and was successfully and efficiently utilized.

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Abbreviations

\( P_{load}(m) \) Actual usage in time m
\( X_{kim} \) Quantity of devices of kind k
\( L_{load} \) Highest peak of final load curve
\( P_h \) Power consumption in hour h
\( RLM_h \) Reducible load margin in hour h
\( \Delta Load_h \) Change in load deviation
\( obj_h \) Objective curve in hour h
\( x_{kh} \) Number of devices of kind k in hour h
\( P^{11}(t) \) Position of the particle
\( X_{new} \) New position
\( X \) Current position
\( X_k \) Best position
\( DSM \) Demand Side Management
\( MG \) Micro Grid
\( WFSA \) Wingsuit Flying Search Algorithm
\( ACSO \) Artificial Cell Swarm Optimization
\( PSO \) Particle Swarm Optimization
\( ALO \) Ant Lion Optimization
\( HEMS \) Home Energy Management Systems
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