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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

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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.

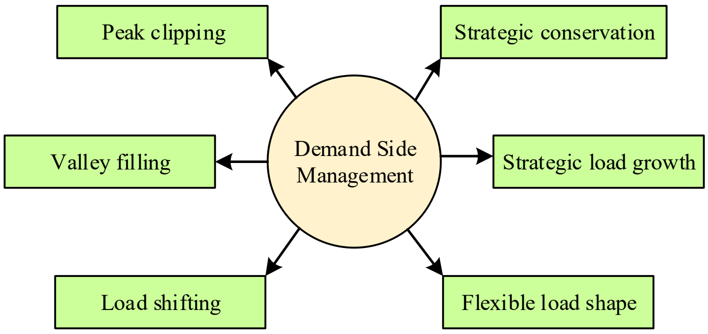

Figure 1. Basic Demand Side Management approaches.

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 wasinspired bythe 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 regardingDSM, as shown below.

Table 1. Contributions from various researchers.

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 wasdeveloped 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	Forecastingof 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 inforecasting errors	An extensive analysis was developed to reduce the forecasting errors
Rehman, S et al. [9]	Model predictive control	Reduction ingeneration 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
Surajkumar [12]	Heuristic technique	To mitigate the integration issues	Implementation of renewable energy source to the grid with minimization of issues
Logenthiran, T [13]	Particle Swarm Optimization	Minimization of electricity bill, energy consumption, and PAR	User comfort not taken into account Convergence time washigher and more parameters
Bharathi, C et al. [14]	Genetic Algorithm	Minimization of power consumption	User comfort, PAR, and energy saving wereneglected
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 wereneglected

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.; Padmini, S [18]	Ant Lion Optimization	Reduction inelectricity bill, energy consumption, and PAR	The author implemented an Ant Lion Optimization to minimize the electricity bill, energy consumption, and PAR
Sharma, A.; Saxena, A [19]	Whale Optimization Algorithm	Minimization of peak load and energy savings	User comfort and PAR wereneglected
Kumar, K [20]	Artificial Fish Swarm Optimization	To reduce the cost of power generation	The author proposed a day-ahead scheduling problem of generation and storage facility
Huang, H [21]	Artificial Fish Swarm Optimization	To reduce the energy consumption	Proposed an algorithm for the reduction inenergy consumption patterns
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]	Locational marginal pricing	Maximization of the profit of GENCO	The author developed an optimal bidding scheme to increase the profits of GENCO
Covic, N [25]	Wingsuit Flying Search	Reduction inthe optimization criterion	The author proposed a novel technique for the Wingsuit Flying Search Optimization criterion
Chatterjee, S [26]	Artificial Cell Swarm Optimization	Reduction inthe optimization criterion	The author proposed a novel technique based on Artificial Cell Division process
Ahmed, E.M et al. [28]	PSO and Strawberry Optimization Algorithm(SOA)	Minimization of electricity bill, energy consumption	The author proposed a joint implementation of PSO snd SOA to minimize the electricity bill and energy consumption
Omar, A.I et al. [29]	Hybrid Optimization Model	To reduce energy consumption	The author developed a Hybrid Optimization Model to reduce the energy consumption in buildings
Mohammed, S.S et al. [30]	Modified placement algorithm	Minimization of plug-in electric vehicle charging costs	The author implemented an interrupted charging schedule to minimize the charging costs
Li Y et al. [31]	CPLEX solver	To maintain the balance between energy supply and demand	The author developed an integrated demand response program to maintain the balance between energy supply and demand
Sarkar et al. [32]	Multi-setup-multi-delivery (MSMD) concept	Development of sustainable biofuel supply chain	Reduction inefficient energy affectedthe supply chain for biofuels
Vandana et al. [33]	Two-echelon supply chain	Energy and carbon dioxide minimization	To enable the coordination of supply chain successfully with reduced CO_2 emissions.
Proposed method	Hybrid WFS2ACSO technique	Minimization of electricity bill, energy consumption, and PAR	Parameter free and convergence in fewer iterations • Analysis of Demand Side Management with regard to summer and winter seasonsconsidering residential, commercial, and industrial loads with the incorporation of WFSA and hybrid WFS2ACSO optimization technique wasformulated • 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 providesthe 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 additionallyadded. 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.

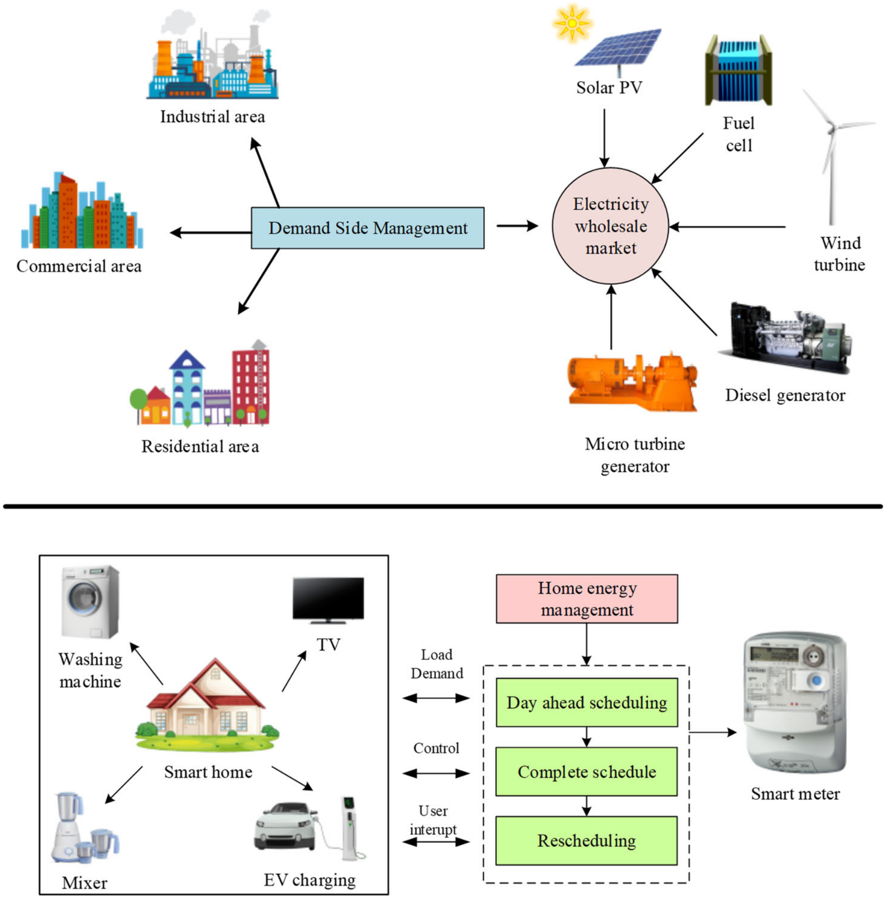

Figure 2. Overview of Demand Side Management in MG.

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].

$$\sum_{m=1}^{n}(P_{Load}(m)-objective(m))^{2} \tag{1}$$

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

$$P_{Load}(m)=forecast(m)+connect(m)-disconnect(m) \tag{2}$$

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

The *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 *connect* (m) is expressed as follows:

$$connect(m)=\sum_{i=1}^{m-1}\sum_{k=1}^{d}x_{kim}P_{1k}+\sum_{l=1}^{j-1}\sum_{i=1}^{m-1}\sum_{k=1}^{d}x_{ki}(m-1)P_{(1+l)k} \tag{3}$$

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 $disconnect(m)$. 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 inload for delaying at connection times of devices, which is predicted to begin its consumption at time steps that precede t. The $disconnect(m)$. is expressed as follows [31]:

$$disconnect(m) = \sum_{q=m+1}^{t+m} \sum_{k=1}^{d} x_{ktq} P_{1k} + \sum_{l=1}^{j-1} \sum_{i=1}^{t+m} \sum_{k=1}^{d} x_{ki}(m-1) P_{(1+l)k} \tag{4}$$

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:

$$Min\ F_1 = Max(Load_i) \tag{5}$$

$$Min\ F_2 = \sum_{H=1}^{h} Load_{fh} P_h \tag{6}$$

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.

$$Min\ F_h = [|RLM_h| - |\Delta Load_h|] \tag{7}$$

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

$$RLM_h = forecast_h - obj_h \tag{8}$$

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].

$$\boldsymbol{RLM_h} = \begin{cases} \geq \mathbf{0},\ \boldsymbol{forecast_h} < \boldsymbol{obj_h} \\ \leq \mathbf{0},\ \boldsymbol{forecast_h} \geq \boldsymbol{obj_h} \end{cases} \tag{9}$$

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.

$$x_{kh} > 0\ \forall k, h \tag{10}$$

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

$$\sum_{k=1}^{h} \boldsymbol{x_k} \leq \boldsymbol{controllable}(\boldsymbol{k}) \tag{11}$$

From the above equation, the total number of the devices accessible for the control of type misstated as *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 ratings 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 candeal 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 meta-heuristic 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.

$$X = \begin{bmatrix} P^{11}(m) & P^{12}(m) \cdots P^{1q}(m) \\ P^{21}(m) & P^{21}(m) \cdots P^{2q}(m) \\ \vdots & \vdots \quad \cdots \quad \vdots \\ P^{n1}(m) & P^{n2}(m) \cdots P^{qn}(m) \end{bmatrix}. \tag{12}$$

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):

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

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.

$$\delta_{i+1} = \delta_i - r_d \text{ } and \text{ } S_{i+1} = S_i - \delta_{i+1} \tag{14}$$

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

$$\delta_{i+1} = \delta_i + r_i \text{ } and \text{ } S_{i+1} = S_i + \delta_{i+1} \tag{15}$$

where δ_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.

$$life_{i+1} = life_i \tag{16}$$

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

$$life_{i+1} = life_i - 1 \tag{17}$$

Step 7: Stopping criteria

If *iter* < *iter_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 $\boldsymbol{f(x) = x_1^2 + x_2^2}$ subject to $\boldsymbol{x_{h,i} = (0.4, 0.4)}$. The fitness value obtained is $\boldsymbol{f(x_{h,i}) = 0.32}$. Now, the above fitness function of WFS2ACSO is applied as X_l = 0.4 and X_u = 0.4, rand is 0.5, and *fl* is 2. Then, $\boldsymbol{f(x_{h,i}) = 0.4}$. Then, the updated value is taken as $\boldsymbol{x_{h,i} = (0.3, 0.4)}$. Thus, the new fitness value is $\boldsymbol{f(x_{h+1,i}) = 0.25}$. Thereafter, from the fitness function of WSF2ACSO, $\boldsymbol{x_{h+1}^t =}$. 0.2. Therefore $\boldsymbol{f(x_{h+1,i}) < f(x_{h,i})}$. This infers 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.

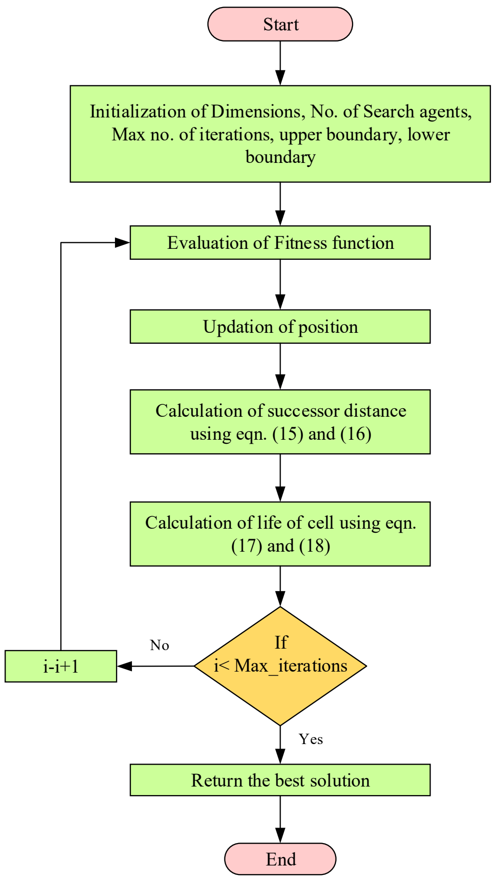

Figure 3. Flow chart for WFS2ACSO algorithm.

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.

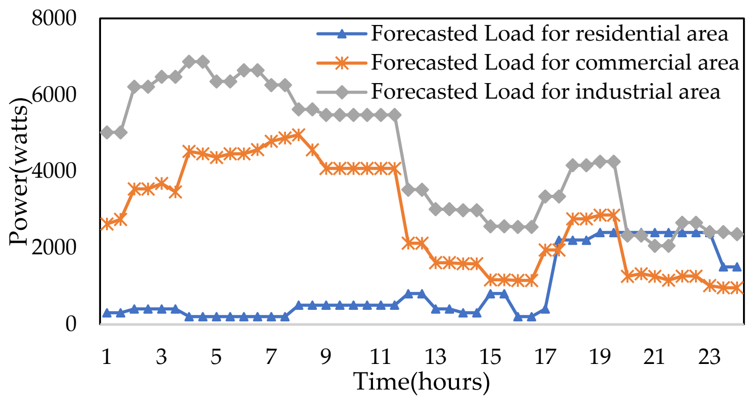

Figure 4. Forecasted load demands of all three areas.

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 was2000 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.

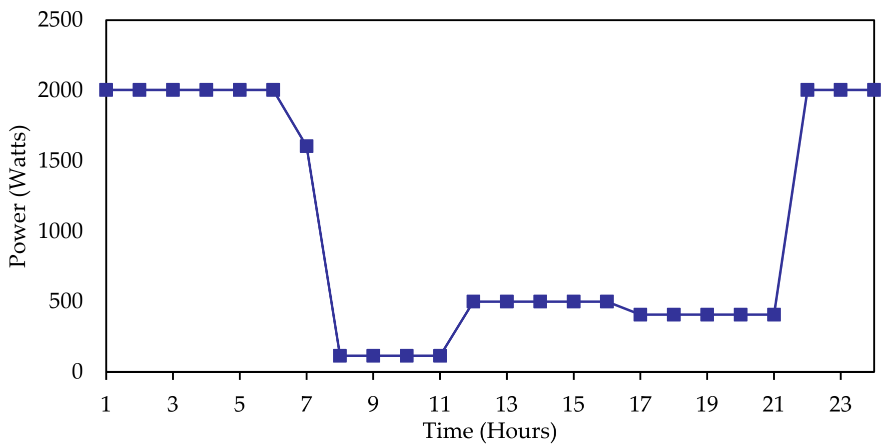

Figure 5. Demand curve of residential load.

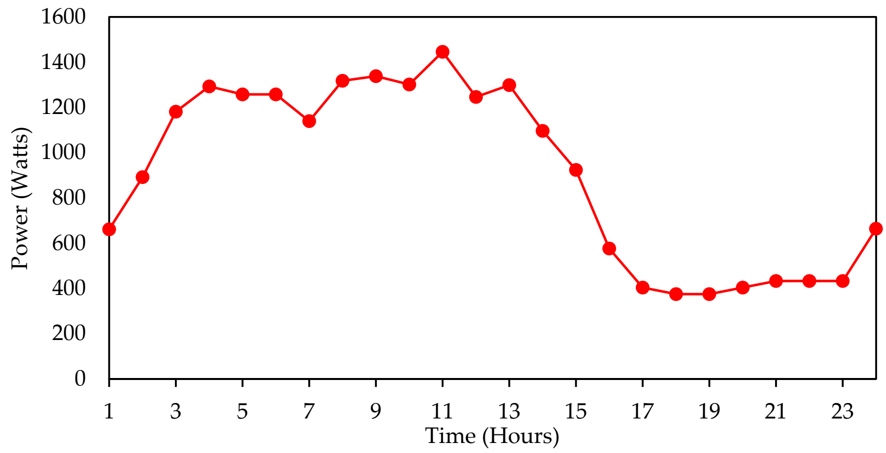

Figure 6. Demand curve of commercial load.

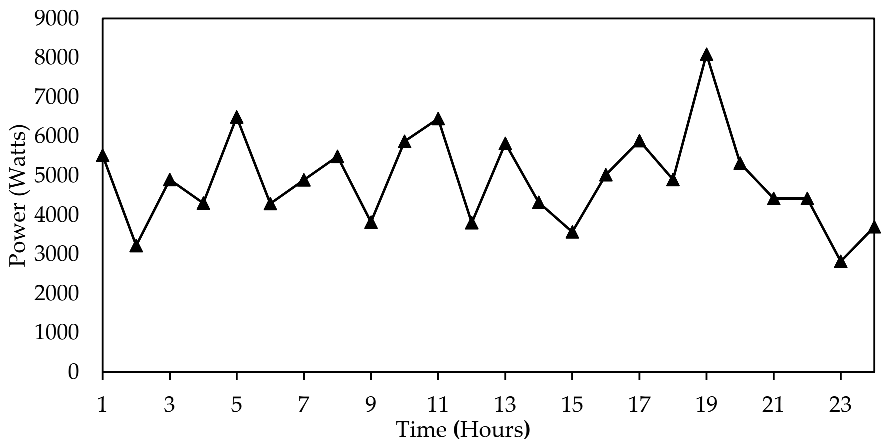

Figure 7. Demand curve of industrial load.

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.

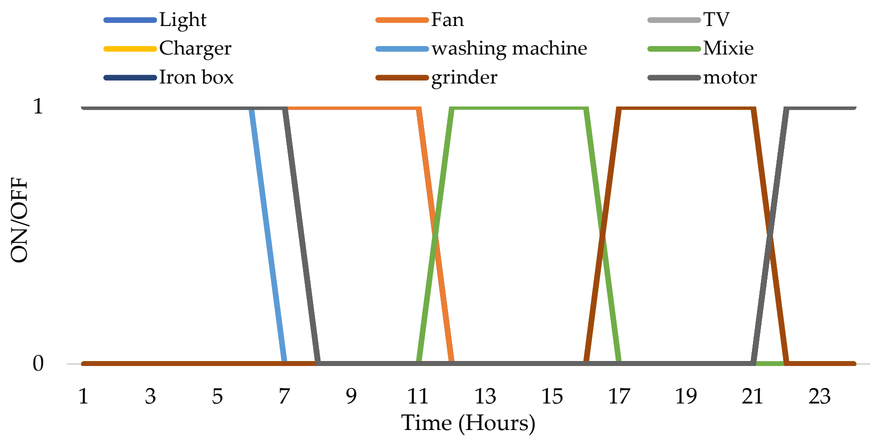

Figure 8. ON/OFF period of individual appliances for residential area.

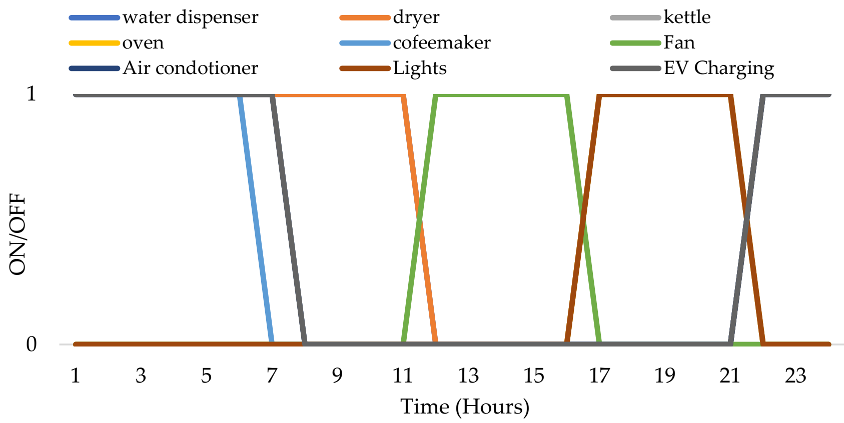

Figure 9. ON/OFF period of individual devices for commercial area.

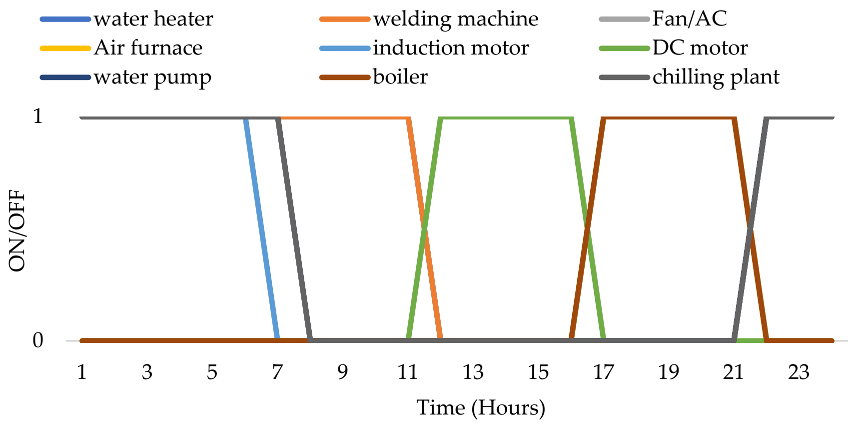

Figure 10. ON/OFF period of individual devices for industrial area.

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 welding machine, water heater, and boiler to the off-peak hours; there was a peak reduction of 20.1% of the load.

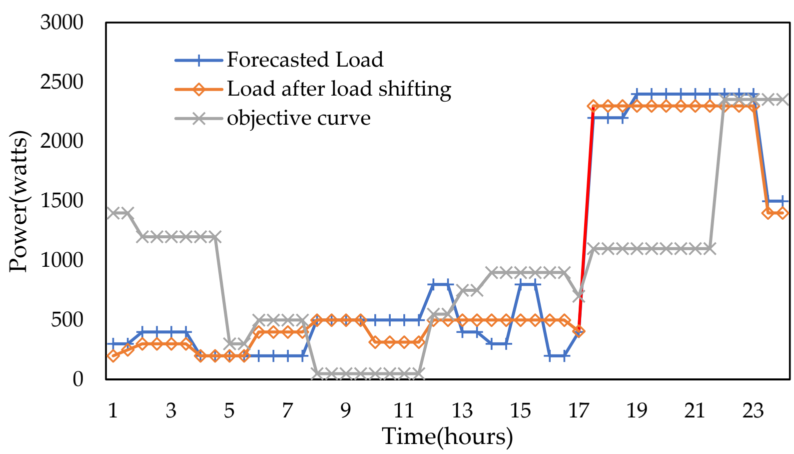

Figure 11. DSM results of residential load under summer conditions.

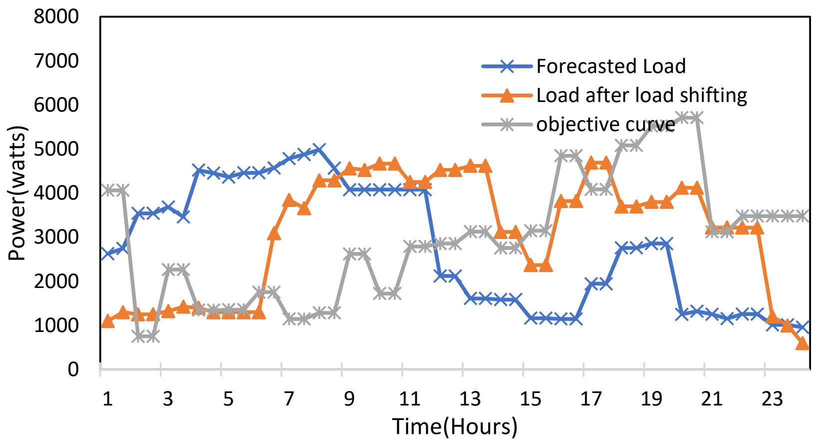

Figure 12. DSM results of commercial load under summer conditions.

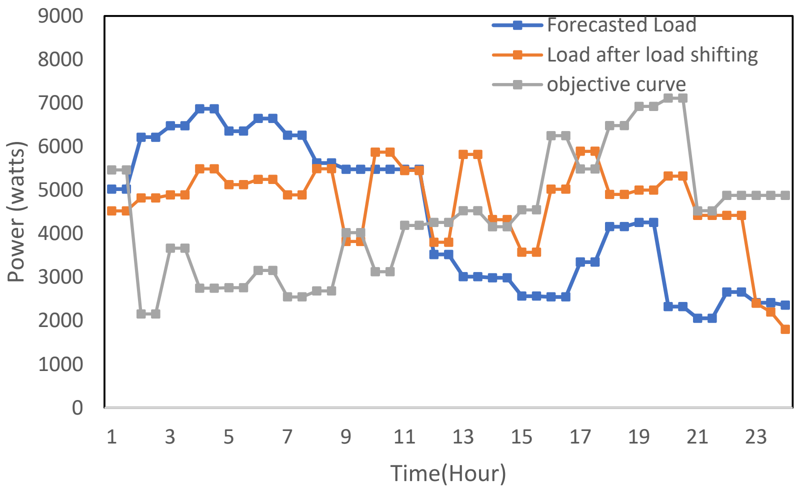

Figure 13. DSM results of industrial load under summer conditions.

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 7301.2 to USD 6465.81 during the summer, with a cost saving of 13.74%. The reduction in the single-day electricity bill of the industrial zone was from USD 11,853.43 to USD 10,259.82; there was a cost saving of 13.44%.

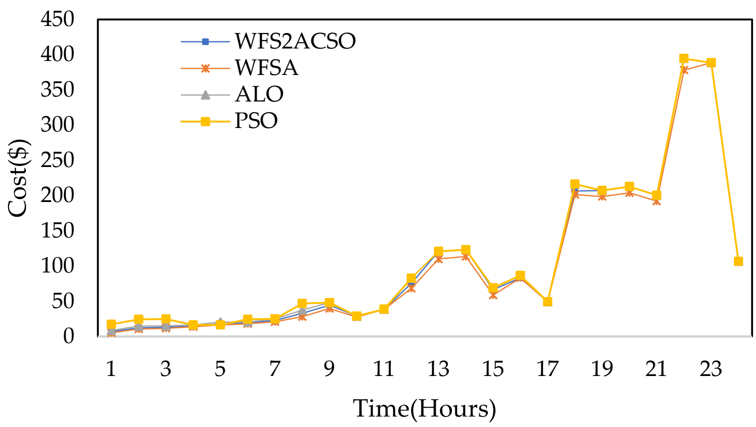

Figure 14. Cost comparison of various techniques for residential area.

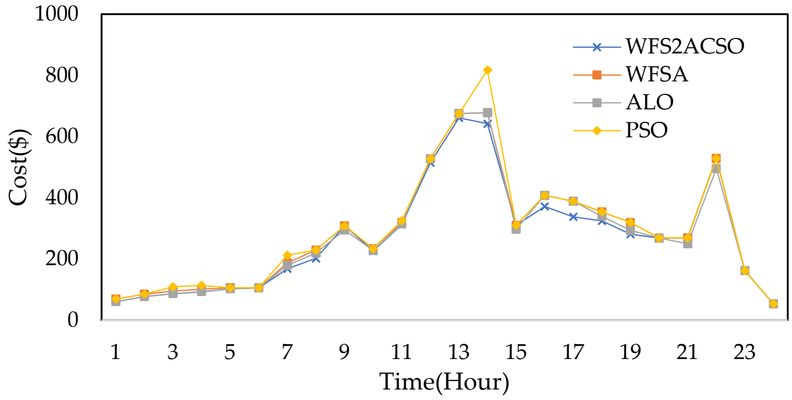

Figure 15. Cost comparison of various techniques for commercial area.

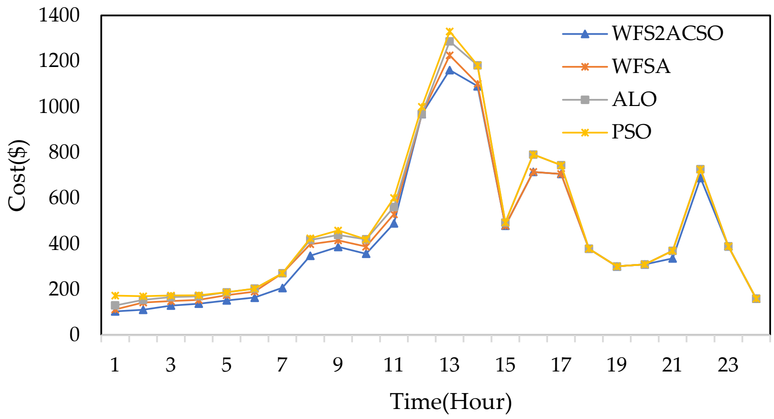

Figure 16. Cost comparison of various techniques for industrial area.

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 was1000 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.

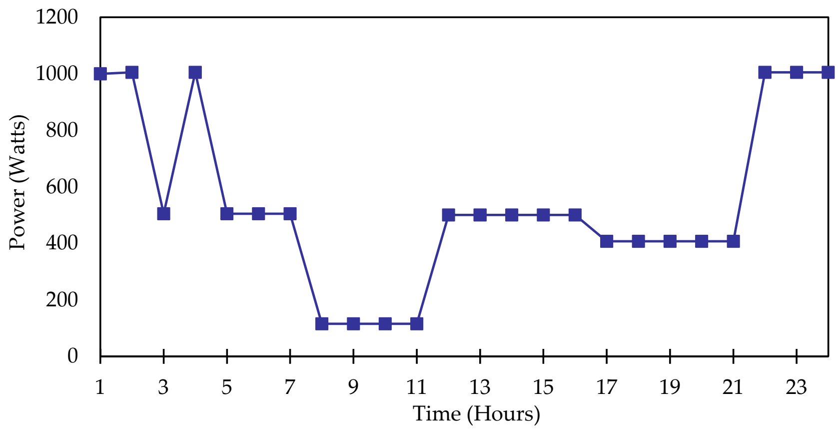

Figure 17. Demand curve of residential load.

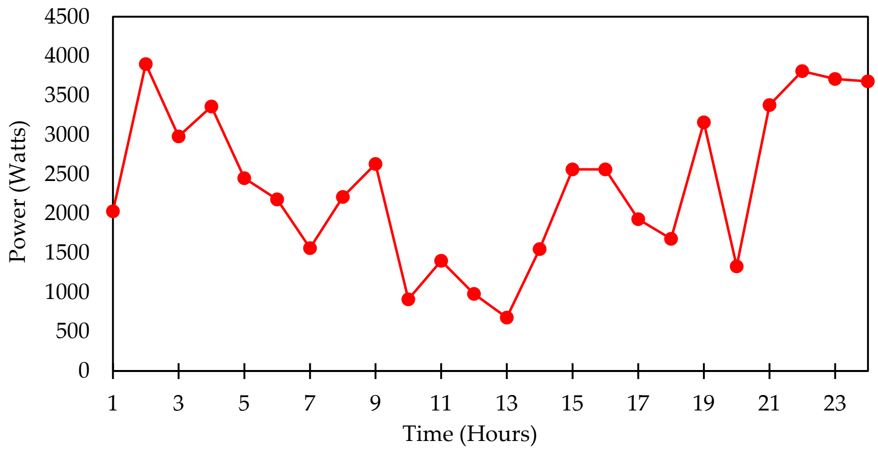

Figure 18. Demand curve of commercial load.

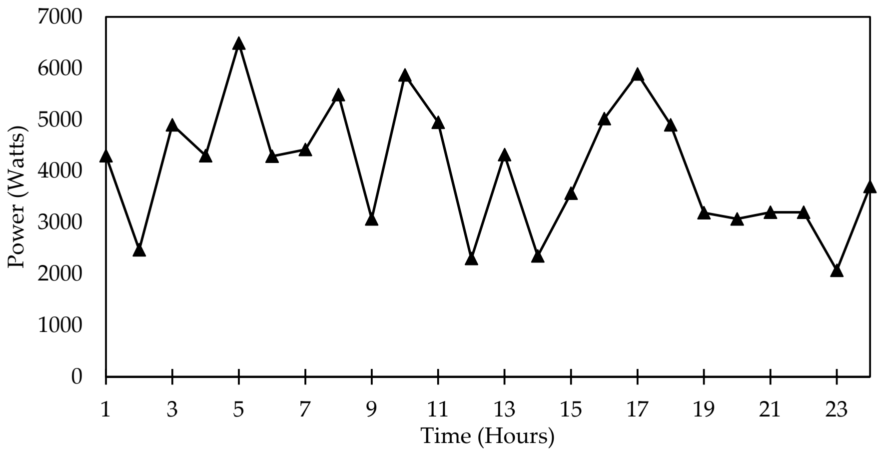

Figure 19. Demand curve of industrial load.

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.

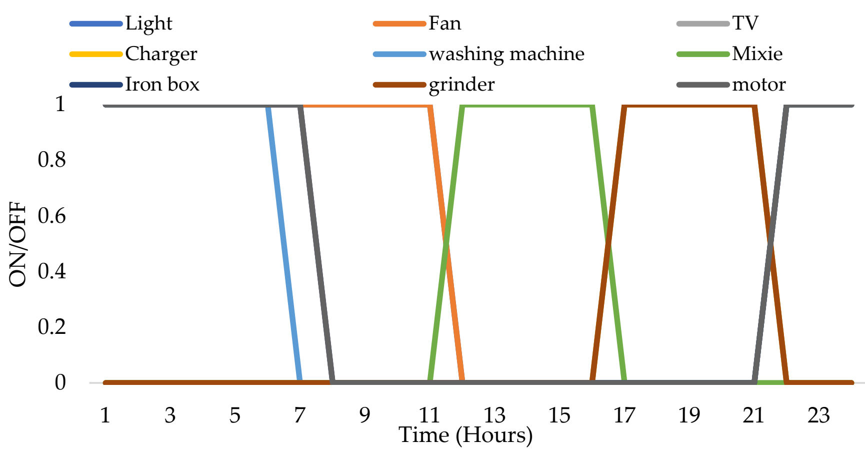

Figure 20. Individual power of home appliances.

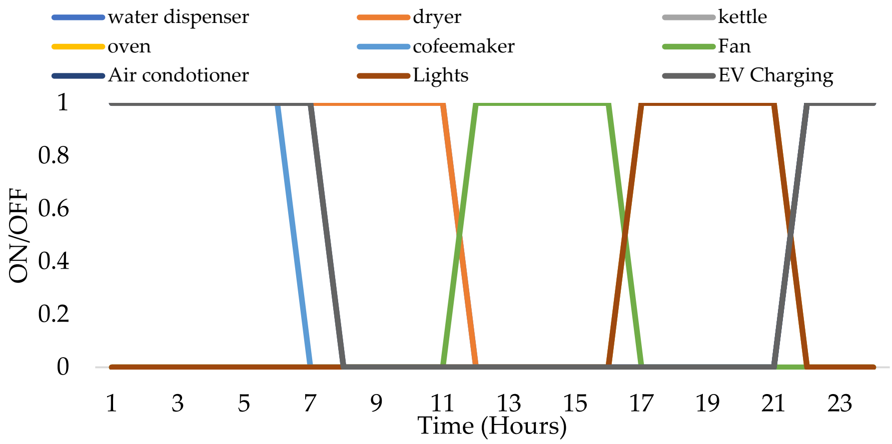

Figure 21. ON/OFF period of individual devices.

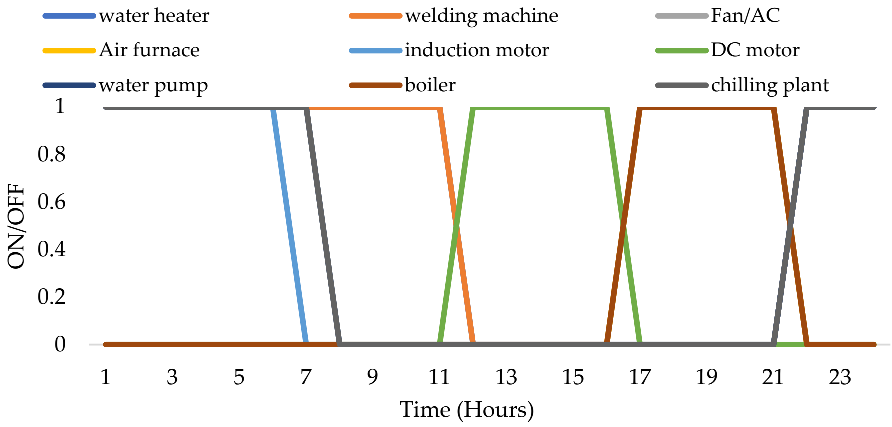

Figure 22. ON/OFF period of individual devices.

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 shift able loads, such as the boiler, to off-peak hours; there was a peak reduction of 21.52%.

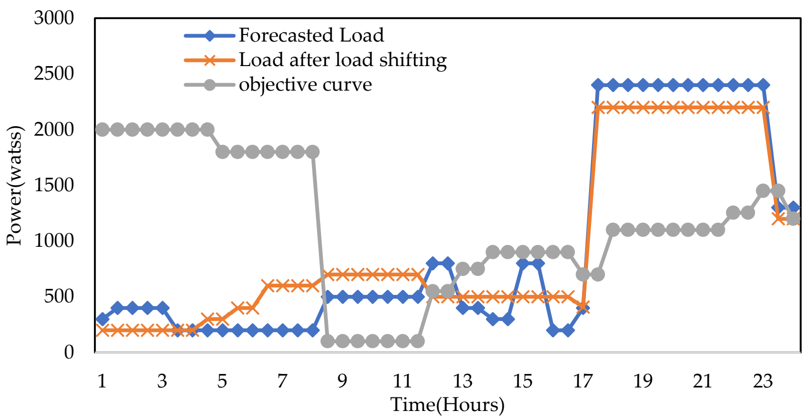

Figure 23. DSM results of residential load under winter conditions.

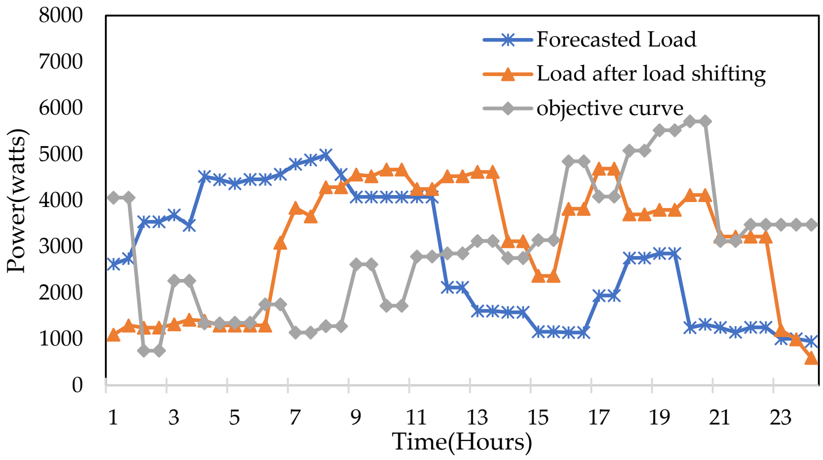

Figure 24. DSM results of commercial load under winter conditions.

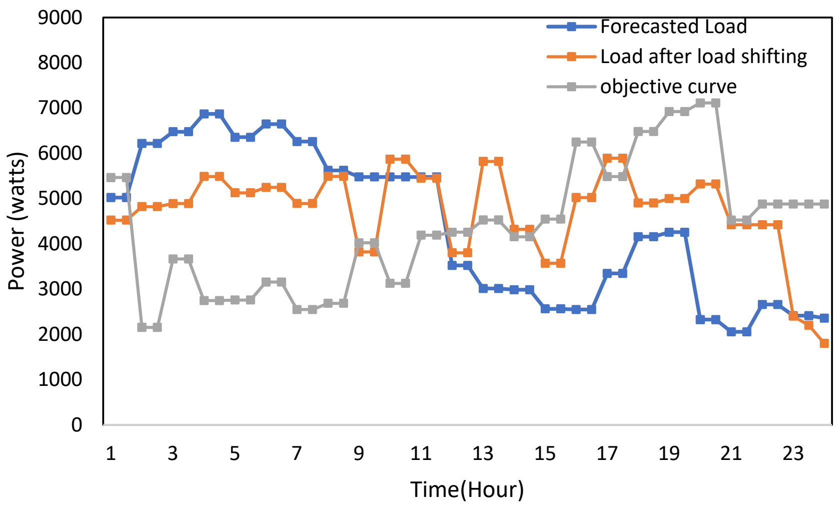

Figure 25. DSM results of industrial load under winter conditions.

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%.

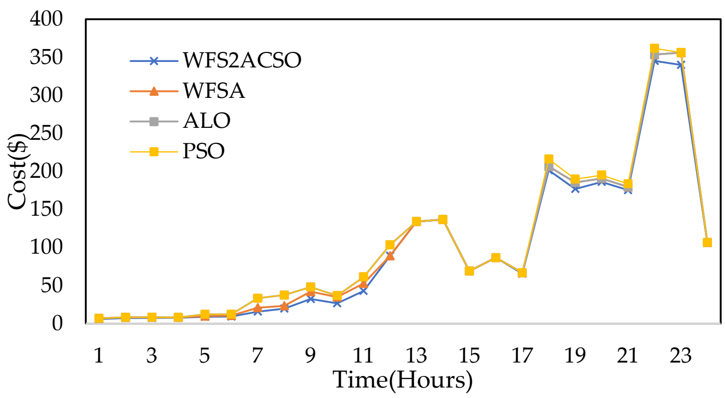

Figure 26. Cost comparison of various techniques for residential area.

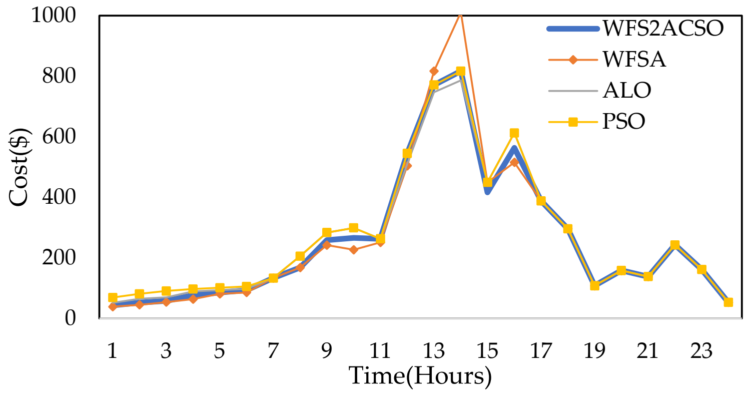

Figure 27. Cost comparison of various techniques for commercial area.

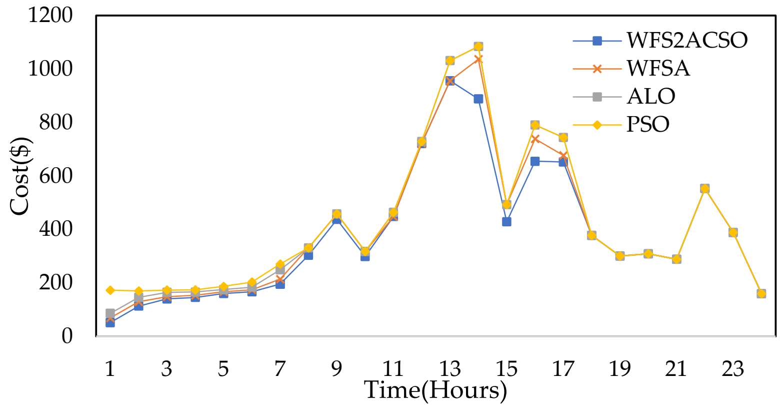

Figure 28. Cost comparison of various techniques for industrial area.

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	Cost of Residential Load					
	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	Cost of Commercial Load					
	Sunny Season			Winter Season		
	Without DSM (USD)	With DSM (USD)	Percentage Reduction (%)	Without DSM (USD)	With DSM (USD)	Percentage Reduction (%)
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	6794.50	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	Cost of Industrial Load					
	Sunny Season			Winter Season		
	Without DSM (USD)	With DSM (USD)	Percentage Reduction (%)	Without DSM (USD)	With DSM (USD)	Percentage Reduction (%)
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 9. Percentage reduction of operational cost comparison of various methods.

Method	Residential Load Cost		Commercial Load Cost		Industrial Load Cost	
	Sunny Season in %	Winter Season in %	Sunny Season in %	Winter Season in %	Sunny Season in %	Winter Season in %
WFS2ACSO (proposed)	9.74	13.74	11.44	12.43	13.44	15.30
WFSA	6.43	10.40	9.88	11.35	9.31	10.95
ALO [18]	5.90	8.09	6.94	10.36	5.41	7.42
PSO [13]	4.50	6.92	4.44	7.97	3.61	5.75

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)	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)	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 (summer)	1.924	1.657	1.854	1.564	1.754	1.587
Peak to Average Ratio (winter)	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 thewinter. 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 thewinter. 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 ofthe MG and was successfully and efficiently utilized.

Author Contributions: Conceptualization, B.V. and P.S.; methodology, B.V.; software, B.V.; validation, P.S., B.C. and L.M.-P.; formal analysis, P.S., B.C. and L.M.-P.; investigation, B.V.; resources, B.V.; data curation, B.V.; writing—original draft preparation, B.V. and P.S.; writing—review and editing, B.V. and P.S.; visualization, B.V. and P.S.; supervision, P.S.; project administration, P.S., B.C. and L.M.-P.; funding acquisition, B.C. All authors were involved in developing the concept, simulation, and validation and making the article an error-free technical outcome for the set investigation work. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

P_{load} (m)	Actual usage in time m
X_{kim}	Quantity of devices of kind k
$Load_f$	Highest peak of final load curve
$\boldsymbol{P_h}$	Power consumption in hour h
$\boldsymbol{RLM_h}$	Reducible load margin in hour h
$\boldsymbol{\Delta Load_h}$	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
MG	Micro Grid
HEMS	Home Energy Management Systems

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