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Microgrid Demand-Side Management based on Particle Swarm Optimization Technique

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***Abstract*—**Demand Side Management (DSM) is the most important strategy in micro grids. It allows the consumers to consume power in a more controlled manner and also assist the power generation side to balance the demand gap between the consumption and the generation. In this way not only the reliability of the power system and micro grid is increased but also the operational cost of the system gets minimized. Conventionally DSM is system specialized and therefore uses specific techniques and energy conservation system. Moreover, the currently used systems can handle a limited number of controllable appliances and therefore has a limitation. This article present DSM with load shifting technique on micro grids and the strategy is applicable to a large number of appliances. The forecast-ed data is formulated in the form of a minimization problem and Particle Swarm Optimization (PSO), a heuristic algorithm is used to solve the problem. Three different consumption zone have been considered (residential, commercial, and industrial) having different appliance connected to the grid. In the end comparison of the proposed system is done with two other techniques from the literature, which shows that the proposed system has better load shifting technique and has reduced the cost more efficiently.

***Keywords*—** Demand-side management, Microgrid, Load shifting, Particle swarm optimization.

I. Introduction

Increasing technological advancement in the field of power generation and power distribution has led to a new system called microgrid. Microgrid is defined as "a collection of interconnected load as well as Distributed Energy Resources (DER) with plainly characterized electrical boundaries that act as a single, controllable entity for the grid and can be connected and disconnected from the grid to allow it to work in both grid connected and island mode". The electronic interface between the microgrid and more recognizable extensive power system or macro-grid is the main idea of microgrid. The main function of this interface to connect and isolate the two sides electrically [1]- [2]. The US Dept of modern grid initiative report of energy says that a Microgrid has a lot of good things about it: It's customer friendliness, it can handle a lot of different types of generators and storage devices, it can run efficiently, and it has good power quality and optimal assets. Many economic, political, environment, technical, and social issues have led to the improvement of this new grid. DSM is an essential part of future Microgrid energy management because it helps with things like electricity sector control and administrative structure, infrastructure building, and the maintenance of decentralized energy resources and electric cars. Monitoring and manipulating the demand of energy is very easy to moderate peak load demands, changing the demand profile and making grid more sustainable by decreasing whole costs and CO2 emission [3]- [4]. DSM is also effective and can help to avoid the building of underutilized electrical infrastructure such as generation capability, transmission lines, and supply systems.

Microgrid has a unique feature called smart pricing using smart meters for the automated metering infrastructure. When smart pricing tools are used with DSM then it helps to reduce cost of not only consumers but also the suppliers who are part of it. Smart pricing introduces high prices for peak periods and low price for off peak periods. By implementing this there is reduction in utility bill and expensive production of energy, an increase in profit of the utilities [5]- [6]. In power markets DSM is equally important. For each time, step of the following day, the DSM will tell the Microgrid Master contoller (MMC) about the new load schedule and how much load can be shifted from the peak hours. The MMC can then put a bid in the market, which moves some of the peak demand loads away from where they were and therefore the profit generated by the DSM will be returned to the group of consumers.

In literature, various different ways and algorithms are used for managing demand side [7]- [8]. Almost all of them are system-specific, but some of them don't apply to real world systems with a diverse set of independent devices. Different techniques built with dynamic programming and linear programming has been used in [9]. Since real power system has a variety of controllable devices to handle. Each has its own set of calculations and heuristics, so dynamic and linear programing can't handle a lot of them. Apart from these Evolutionary genetic algorithm [1] and bacterial foraging optimization algorithm [2] have been developed to address the problem but these algorithms don't give robust result. The main goal of the strategies in the literature is to cut down system peak load demand operational costs. Although utilities can give various motivations to the consumers for direct control over specific loads by categorizing the customers loads. Most approaches in the literature don't address the criteria and goals separately. Solutions for DSM must handle different types of controllable loads. Additionally, loads might have a variety of properties that changes over time [10]- [11]. As a result, the strategies must be able to handle possible control duration and a wide range of manageable loads.

Additionally, shifting from main grid to a microgrid unlock new ways to control demand. When it comes to Microgrids, renewable energy sources like wind and solar are likely to make up a big part of the power. Power dispatch operations in a Microgrid are hard because renewable energy sources aren't always predictable and therefor load control strategies are required in such circumstances. Microgrid operation also requires two-way interaction between both the master controller and various parts of the system. So, the communication setup among the microgrid Master controller and manageable loads should be taken care of by the DSM system that is supposed to be used. The designed DSM system should be capable of handling the communication infrastructure between the central controller and controllable loads. The last, decision to make is to select which form of energy is to be used. Renewable energy resources should be used to their full extent, profit is maximized by giving bids to lower demand at peak times, to decrease electricity imported from main grid, or peak load demand reducing some of the criteria that could be used.

This paper present DSM for microgrid using load shifting method to balance the gap between peak and off peak demand. The system is designed to control a large quantity of appliance and therefore play a major role in improving the load shape of the power system. PSO is used to solve the minimization problem and three different consumer zones have been considered on which the designed system would be applied and validated. The organization of the paper is done as; Section II discuss the important features of the smart grid, Section III suggests a Microgrid demand side management strategy, explains how the load shifting mechanism works and sums up the proposed method. Section IV talks about the details of the test microgrid. Section V discusses about the simulation results and compare the proposed system with the literature. Section VI is the conclusion and conclude the whole idea of the paper.

II. Techniques of Demand Side Management

Power consumption of the user changes over time and therefore load profile of the system varies. Power generating companies tries to forecast the load demand and try to reduce the gap in the load demand in peak and off peak hours in a more predictable and smooth way. Instead of adding more power plants or upgrading the transmission and distribution network, DSM emphasis on energy saving, regulating power tariffs and government regulations to cut down peak load demand. Load demand in the peak hours causes an abrupt change in the load demand. Therefore, to control the variation in the load profile and reduce the gap, DSM changes the structure of the load demand curve by lowering load demand of the distribution system during peak times and shift controllable loads to an off-peak time. But this process takes too much communication and a lot of cooperation between network provider's customers to use this method [6]. Conventionally there are six ways to reduce the demand gap i.e., Peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, & load shifting, used in the literature to improve the load profile of daily or seasonal electricity needs of industrial, commercial, and residential customers at peak and off-peak hours. Peak clipping and valley filling tries to reduce the difference between peak and valley load demand in order to lower the peak demand increase the reliability of the Microgrid. Peak clipping [12], [13] is a direct load management approach for reducing peak loads, and valley filling is a direct load control strategy for constructing off-peak demand. In today's modern distribution systems, load shifting [13] is often used as the best load control strategy. Load shifting makes use of the fact that loads can move from peak to off-peak hours. Strategic conservation [12] tries to improve the load shape as much as possible by reducing demand at the consumer's end.

Modern day Microgrid requires a reliable infrastructure for higher load demand. Load shapes are flexible [14]- [15] and are often connected to reliability of Microgrid therefore Microgrid management system looks for clients with adjustable loads who agree to let the system control their devices in critical times in exchange for different incentives. Planning department must foresee Demand-side activities and therefore studies must be done to determine the expected load shape.

III. Proposed Demand Side Management

For future's Microgrid, this paper gives comprehensive day ahead demand side management approach. It uses load shifting as the main technique that the Microgrid Master controller can use. The goal of demand side management could be to take full advantage of renewable energy resources, reduce peak load demand, and reduce the amount of electricity used from the main distribution grid. According to the demand side management goal, the microgrid manager creates an objective load curve. The suggested optimization technique seeks to get the final load curve as close to the objective load curve as possible, achieving the DSM strategy desired goals. For example, if the goal of demand side management is to reduce utility bills, then a load curve that is inversely proportional to the power retail prices will be chosen for this. The objective load curve is fed into the demand side management system, which then analyzes the appropriate load control measures to meet the proposed load consumption. As a result, the suggested approach is adaptable because it is unaffected by the standards used to build the objective load curve.

During demand side management, things are done at before certain amount of time, which is generally a day. Actions are then taken in real time depending on the outcomes. This makes use of the Microgrid ability to communicate. When client press (ON) button on appliances, the DSM controller gets a request to connect to the appliance from the customer. The DSM controller responds depending on the outcomes of a DSM method that was done before. The connection is either allowed or a new time is given as a response.

A. PARTICLE SWARM OPTIMIZATION ALGORITHM

Particle swarm optimization (PSO) is a swarm based evolutionary computational technique. This technique was settled by Eberhart and Kennedy in 1995 inspired from the technique, living organisms use to search food and better living place [16]- [17]. Each particle will move across the search zone to find a solution, to achieve local best (Pbest) and global best (Gbest) result.

Let x1, x2, x3, ..., xn be the coordinates or positions of particles in the swarm and v1, v2, v3, ..., vn be the velocities of particles in the swarm. After each iteration the velocity of particle in the swarm is update and can be calculated by: where k represents the increment or increase in time, represent the best position or location of the particle, represent the global best position or location and w represent the inertial weight of the particle whose value ranges from 0.9 to 1.2. For lower inertial weight particle will perform local search and for higher value it will perform global search. $r1$ and "$r2$" are any random number between 0 and 1. The cognitive and social components are represented by $c1$ and $c2$. The values of cognitive and social components in this article is such that $c1 = c2 = 2$. when $c1$ and $c2$ are multiplied with $r1$ and $r2$, the average value becomes 1. Below Fig. 1 shows the updating of particle's velocity and position in a two-dimensional space and Fig. 2 shows a flow chart of the proposed model in which PSO algorithm has been implemented.

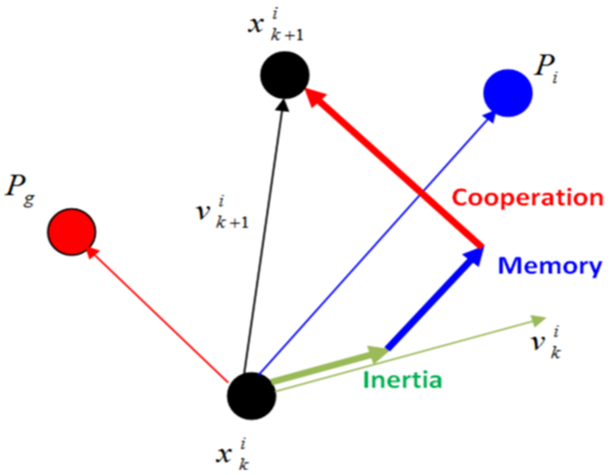

Figure 1 Updated position and velocity of PSO

B. IMPLEMENTATION OF PARTICLE SWARM OPTIMIZATION (PSO)

From
Ref [1]

$$Diff(t) = Lmm(t) - Obj(t) \quad (3)$$

Where:
$Diff(t)$ = Difference of two quantities at time "t"
$Lmm(t)$ = Optimal load profile at time "t"
$Obj(t)$ = Main objective function at at time "t"

The term Lmm(t) is actually an optimize load array in which the current optimized results are stored and after the process is completed the final optimized result will be stored in it. The Lmm(t) will follow the main Obj(t) and try to reached to the main objective function Obj(t) [16]- [18]. Lmm(t) will move in the direction of main Obj(t). Now the required function is given as:

$$Minimize\ F_h = [\mid Diff_h \mid - \mid \Delta load_h \mid] \quad (4)$$

Diffh is calculated from Eq. 3. The value of Diffh can be positive or negative. If the value of Diffh" is positive, the Δloadh will show disconnected load. It means that some load should be disconnect to minimize the result or Fh value. If the value of Diffh have negative number, the Δloadh will show the connected load. It means that some load would be connected to minimize the result or Fh value. So,

$$\Delta load_h = \begin{cases} Disconn_h & if\ Diff_h > 0 \\ Conn_h & if\ Diff_h < 0 \end{cases} \quad (5)$$

Where,

$$Discon(t) = \sum_{q=t+1}^{t+m} \sum_{j=1}^{D} X_{j+q} P_{1j} + \sum_{t=1}^{j-1} \sum_{q=t+1}^{t+m} \sum_{j=1}^{D} X_{qj(t-1)} P_{(i+t)j} \quad (7$$

where Xjit is the number of j type controllable device which are delayed from time i to t. D is the total number of devices.P1j and P(1+t)j shows the power consumption at time 1 to (1 + t) respectively for j type of devices. k is the total duration of usage of j types of devices.

$$Conn(t) = \sum_{i=1}^{t-1} \sum_{j=1}^{D} X_{jit} P_{1j} + \sum_{t=1}^{k-1} \sum_{i=1}^{t-1} \sum_{j=1}^{D} X_{ij(t-1)} P_{(i+t)} \quad (7)$$

where, X_{j+q} us the number of controllable devices which are delayed from t to q. m is the maximum allowable delay.

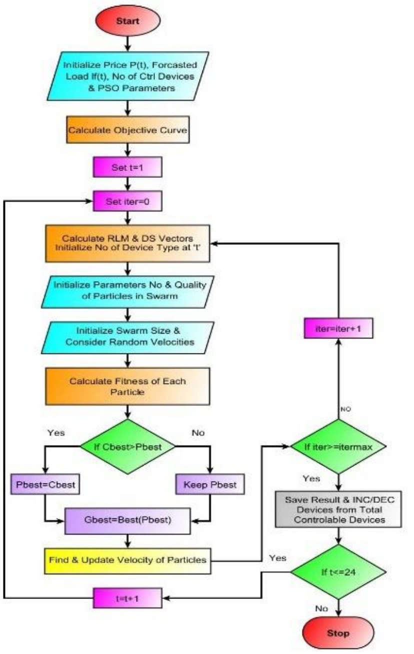

Figure 2 Flowchart of proposed Algorithm

Table 1 Hourly data of forecasted load

Time-(Hrs)	Wholesale price (Cost/Unit)	Hourly Forecasted Load (kW)		
		Residential Load	Commercial Load	Industrial Load
08 – 09	12.00	729.4	923.5	2045.5
09 – 10	9.19	713.5	1154.4	2435.1
10 – 11	12.27	713.5	1443	2629.9
11 – 12	20.69	808.7	1558.4	2727.3
12 – 13	26.82	824.5	1673.9	2435.1
13 – 14	27.35	761.1	1673.9	2678.6
14 – 15	13.81	745.2	1673.9	2678.6
15 – 16	17.31	681.8	1587.3	2629.9
16 – 17	16.42	666	1558.4	2532.5
17 – 18	9.83	951.4	1673.9	2094.2
18 – 19	8.63	1220.0	1818.2	1704.5
19 – 20	8.87	1331.9	1500.7	1509.7
20 – 21	8.35	1363.6	1298.7	1363.6
21 – 22	16.44	1252.6	1096.7	1314.9
22 – 23	16.19	1046.5	923.5	1120.1
23 – 24	8.87	761.1	577.2	1022.7
24 – 01	8.65	475.7	404	974
01 – 02	8.11	412.3	375.2	876.6
02 – 03	8.25	364.7	375.2	827.9
03 – 04	8.10	348.8	404	730.5
04 – 05	8.14	269.6	432.9	730.5
05 – 06	8.13	269.6	432.9	779.2
06 – 07	8.34	412.3	432.9	1120.1
07 – 08	9.35	539.1	663.8	1509.7

IV. INFORMATION OF TEST MICROGRID

The proposed DSM method is tried out on microgrid considered in [2] where there are three different places in a Microgrid, with the different type of customers, such as commercial, residential, and industrial customers.

The whole network is energized by a 410 V power source. The major goal of this case study is to lower consumers' utility bills in these areas. So, an objective load curve that is inversely proportional to power marketplace prices was chosen. All areas of the Microgrid were subjected to the same market prices. A duration period of 12hr was selected for the simulation to check the efficiency of the proposed design since working capability of the system increases with the time as more loads can be moved to off peak hours and the working capabilities of the system cannot be judged. Table I shows the expected hourly wholesale power costs and hourly load consumption for each Microgrid area. Maximum load demands of the three focused areas for this study are as follow Residential 1.36MW, commercial 1.82MW, and industrial regions 2.73MW.

A. RESIDENTIAL ZONE

The gadgets that are controlled in a residential zone use consume less electrical energy and run for very short period. Table II shows the categories of devices that are subject to load control, as well as how much energy they consume. A total of 2604 devices are considered from 14 different types of devices.

Table 2 Controllable load data in the residential zone

Device Type	Hourly Consumption of Device (KW)			Number of Devices
	1st hrs	2nd hrs	3rd hrs	
Dryer	1.2	-	-	189
Dish Washer	0.7	-	-	288
Washing Machine	0.5	0.4	-	268
Oven	1.3	-	-	279
Iron	1.0	-	-	340
Vacuum Cleaner	0.4	-	-	158
Fan	0.2	0.2	0.2	288
Kettle	2.0	-	-	406
Toaster	0.9	-	-	48
Rice Cooker	0.85	-	-	59
Hair Dryer	1.5	-	-	58
Blender	0.3	-	-	66
Frying Pan	1.1	-	-	101
Coffee Maker	0.8	-	-	56
Total				2604

B. COMMERCIAL ZONE

People in the commercial zone use more electricity than people in the residential zone, but the difference isn't much. Table 3 shows the consumption patterns of the loads that are under control, as well as how much electricity they use. In this section, there are about 808 controlled devices from 8 different types of devices.

Table 3 Controllable load data in commercial zone

Device Type	Hourly Consumption of Device (KW)			Number of Devices
	1st hrs	2nd hrs	3rd hrs	
Water Dispenser	2.5	-	-	156
Dryer	3.5	-	-	117
Kettle	3.0	2.5	-	123
Oven	5.0	-	-	77
Coffee Maker	2.0	2.0	-	99
Fan	3.5	3.0	-	93
AC	4.0	3.5	3.0	56
Lights	2.0	1.75	1.5	87
Total				808

C. *INDUSTRIAL ZONE*

It has the smallest number of control devices in all the three categories, however the devices consume more energy and run for a longer period. Table IV-C presents the usage of all the devices in this area. Industrial loads seem to be critical or uncontrollable. Therefore, there are only 106 controlled devices from six groups. This is why there are only a few devices that can be controlled. Device control times are same for all the three categories.

Table 4 Controllable load data in industrial zone

Device Type	Hourly Consumption of Device (KW)			Number of Devices
	1st hrs	2nd hrs	3rd hrs	
Water heater	12.5	12.5	12.5	39
Welding Machine	25	25	25	35
Fan/AC	30	30	30	16
Arc Furnace	50	50	50	8
Induction Motor	100	100	100	5
DC Motor	150	150	150	6
Total				109

V. SIMULATION RESULTS AND DISCUSSION

In all three scenarios, simulation results show that the proposed demand side management method was successful in bringing final consumption near to the goal load curve. The suggested method has successfully handled a large number of controllable loads of various types and incorporates all of the Microgrids heuristics. Fig. 3 depicts the simulation results obtained for the residential area. With demand side management, the residential area's utility bill for the day drops from $2302.90 to $2136.64, resulting in a 7.22% reduction in utility bill.

Fig. 4 shows the results achieved in the commercial area. With demand side management, the commercial area's daily power bill drops from $3636.60 to $3320.22, resulting in a 8.7% reduction in utility bill.

Fig. 5 shows the results obtained for the industrial area. The utility bill for the industrial area without demand side management approach is $5712.00 per day; however, with demand side management strategy, the bill is $4940.88 per day, resulting in a 13.5% reduction in utility bill. The simulation results from the suggested demand side management technique for these three sectors of the Microgrid are summarized in Table V. The technique has been successful in achieving the goal in all three areas, with significant utility bill reductions. When the number of devices accessible for control rises, demand side management results usually improve [19]- [20]. Despite the fact that the industrial sector has the minimum quantity of devices accessible for control, the percentage decrease in utility bill is the largest of all regions in this case study.

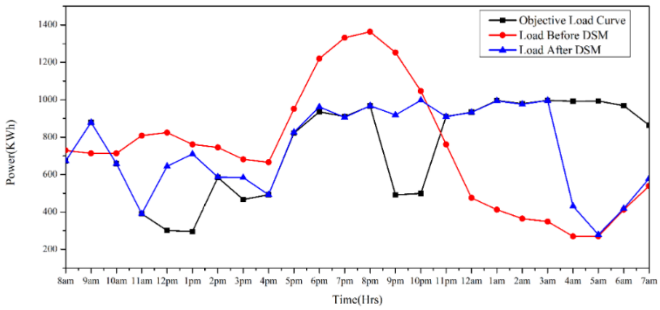

Figure 3 Residential Load Output

The number of controllable devices majorly depend on the consumer interest in saving the bill and how much inconvenience he is willing to tolerate. Since in residential system controlling of the device is generally easier compared to

the other two regions because the inconvenience caused by controlling is very low compared to the other two sectors. Residential sector has the greatest quantity of devices accessible for control in terms of number and diversity, but the utility bill reduction is not as significant as projected.

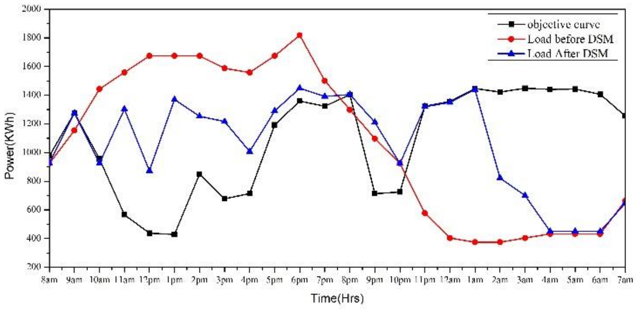

Figure 4 Commercial Load Output

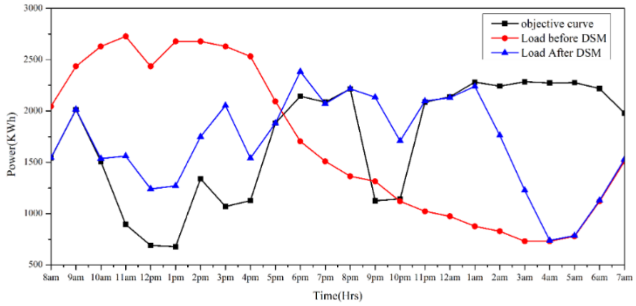

Figure 5 Industrial Load Output

This is due to the high-power consumption of devices in the industrial sector versus the much minor consumption of devices in the residential sector. Furthermore, even minor load shifting of high-power devices results in significant cost savings for clients. End customers and power supplier both can take advantage of effective demand side management. The reduction in peak load demands is one of the most significant benefit. Table V illustrates the peak load demands for the three areas with and without the suggested demand side management technique. It can be seen that the proposed demand side management technique minimizes the peak load demand for each area.

Table 5 Comparison of cost with previous work

Refer ence	Method s Area Type	Cost Before DSM ($)	Cost After DSM ($)		Reducti on (%)
[1]	EGA	Residential Commercial Industrial	2302.90 3636.60 5712.00	2188.30 3424.30 5141.60	4.97 5.56 9.98
[2]	BFOA	Residential Commercial Industrial	2211.05 3211.28 5067.78	2047.67 3020.60 4556.34	7.4 5.93 10.1
Propo sed	PSO	Residential Commercial Industrial	2302.90 3636.60 5712.00	2136.64 3320.22 4940.88	7.22 8.70 13.5

Reduced peak load demand enhances grid sustainability by lowering overall costs and peak load demands. Additionally, this will prevent the creation of underutilized electrical infrastructure, such as generation capacity, transmission lines, and distribution networks.

Table 6 Comparison of peak load reduction with previous work

Refer ence	Method s	Area Type	Peak Load Before DSM	Peak Load After DSM	Reduc tion (%)
[1]	EGA	Residential Commercial Industrial	1363.6 1818.2 2727.3	1114.4 1485.2 2343.6	18.27 18.31 14.06
[2]	BFOA	Residential Commercial Industrial	1363.6 1812.2 2727.3	1106.3 1462.5 2338.6	18.86 19.29 14.25
Propo sed	PSO	Residential Commercial Industrial	1363.6 1818.2 2727.3	997.05 1448.18 2284.37	26.88 20.35 16.24

Demand side management also benefits power supplier since it reduces peak load demand, which results in significant cost savings because expensive generators that are generally turned on to produce power during peak load demand are no longer required. When the system's peak load demand decreases, the cost of operating generators decreases significantly. This would also result in the system's reserve generation capacity being increased.

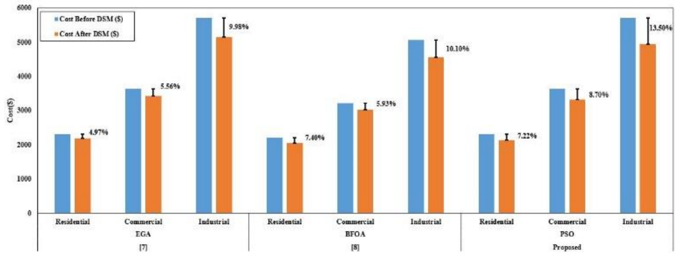

Figure 6 Percentage Peak load reduction by three different methods

Comparing the proposed model to literature in which [1] uses genetic algorithm and [2] uses bacterial foraging optimization algorithm to decrease peak load and overall cost, it can be observed that the results of the proposed design are relatively improved. The proposed method based on PSO is far better than other two methods to reduce peak load and utility bill in all three areas of the smart city. Table V compares the peak load reduction of each method and how much effective they are in each sector of the smart city. It can be observed that GA has reduced the residential load by 18.27%, commercial load by 18.31%, and industrial load by 14.06% while the BFOA model reduces the residential load by 18.86%, commercial load by 19.29%, and industrial load by 14.25%. The proposed model has more impact on the peak load reduction with 26.88% of reduction in residential,20.35% in the commercial and 16.24% in industrial peak load demand. Fig. 6 represent the percentage difference in the profits gained by the three optimizations techniques.

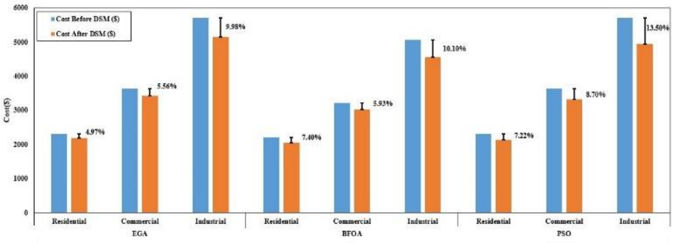

Figure 7 Percentage cost reduction by three different methods

Table VI shows the cost reduction comparison of all the three method it can be observed that the proposed method is better than the rest of the two methods used in literature. In case of GA, residential cost is reduced by 4.97%, commercial by 5.56% and industrial by 9.98%. BFOA has reduced the cost of resident by 7.4%, commercial by 5.93% and industrial by 10.1%. The proposed method has performed better as compared to the other two methods by reducing cost of residential sector by 7.22%, commercial by 8.70% and industrial by 13.5%. Fig.7 represent the percentage difference of each model in the considered sectors.

CONCLUSION

Demand side management has numerous advantages in a Microgrid, mostly at the distribution linkage level. This article present a Demand Side Management technique for future Microgrid operations by using load shifting technique and PSO to optimize the operations. The proposed solution employs a generalized load shifting technique that involves changing loads and is theoretically expressed as an optimization problem. This challenge is resolved using a particle swarm optimization algorithm that takes into account three different sorts of client areas. Comparison of the proposed model is done with the [1], uses GA for optimization, and [2] which uses BFOA for optimization. It is observed that the proposed model reduces the peak load and operational cost more efficiently than the other two methods. Comparison of the three methods is done considering three different types of consumers. The simulation results suggest that the proposed method may be utilized to grip a large number of different types of controlled devices in order to meet the goal of increased savings by decreasing the Microgrids peak load demand.

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