# Fuzzy Based Demand Side Management in Smart Grid

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**Abstract.** Demand Side Management (DSM) utilizes customer choices and helps to reduce overall cost and burden of energy demand. When implemented in smart grid, the use of information sharing and flow of electricity in bidirectional manner makes the system self-healing, optimized and energy efficient. In this paper, a DSM strategy based on Fuzzy Logic is proposed for cost reduction and load shifting. In proposed scheme, the load is scheduled to the best time of day to make the system most cost effective. Proposed strategy is demonstrated in two different load scenarios namely industrial and residential. For both scenarios, multiple prosumers are considered for demonstrating proposed DSM technique in large network. The results show the straightforwardness and easy application of the proposed methodology.

## INTRODUCTION

The Demand Side Management (DSM) includes two-way communication between the grid utility as well as customer end for sharing real time information regarding demand and tariffs. The information sharing has to take place either real time or at least at a regular time interval. The first and basic task in making the system enhanced is to study the various methods by which this information is being utilized [1]. In every electric utility grid, there is always a need to have some stored energy as a backup to ensure the reliability of power supply during peak hours. In most of the power systems energy backup is provided by the battery energy storage system (BESS). In order to maximize the efficiency and to optimize battery-based storage system, Glow Swarm and Support vector machine are implemented [2]. The various case studies have been addressed for renewable energy using wind power with different techniques in [3]. A Fuzzy based algorithm has been proposed in order to ensure the reliability of grid tied photovoltaic system with different load conditions in [4]. In [5], a price-based cost optimization technique has been proposed for grid connected solar photovoltaic system under different consumer load conditions. In the literature, various Artificial Intelligence (AI) based cost optimization techniques have been proposed by the researchers as cited in [6]. In order to address the importance of environmental impact of various optimization techniques, an Artificial Intelligence based strategy has been proposed in [7] for residential load. An energy consumption scheduling based strategy has been proposed for DSM for an autonomous system in order to provide the access to the consumers so as to estimate their future load demands [8]. A highly efficient and robust system has been proposed using Game Theory for Cardinality Optimization for Sparse Load Shifting in DSM system in [9], the optimization to be minimization of peak to average ratio [10] and network evolutionary game based strategy has been reported in [11] and [12]. A highly efficient state feedback control of DSM has been designed and implemented successfully in [13]. In [14], the symbiotic organisms search algorithm has been addressed to reduce- user bill or cost to the consumers, as well as the peak demand. The uncertainty and unpredictability of information is taken care of in [15] for an efficient DSM system by using Distributed Stochastic Linear Proposed methodology Management (DSLPM) algorithm. In [16], the highly useful approach of particle hopping algorithm is used. The case specific to demand response in China is encountered using Deviation algorithm to establish a day ahead load peak shedding/ shifting scheme [17]. In general, the cost estimation is done and that itself serves the purpose of load scheduling or shifting. But in [18], the system maximized the profit of the energy load, alleviates the supply-demand imbalance and reduces the bills of other market participants by using Finite horizon Markov decision process algorithm. The action of simply reversing the schedule according to the demand brings the problem of rebound peak [19] which was encountered using cost minimization algorithm for optimal management system.

In [20], an intelligent scheduling solution based on a stochastic optimization algorithm is designed and tested for the use in batteries of plug-in electric vehicles. In [21], Internet of Things (IoT) based hardware implementation of solar photovoltaic system is achieved for microgrid. In [22], progressive demand side response is proposed and implemented using the Multi Agent System (MAS) for solar microgrid. A detailed analysis of optimization of power consumption and DSM strategies is done in [23]. In order to address IEEE reliability indices in [24] and [25] statistical assessment of cost benefit analysis has been done on seven different power sectors to assess generating capacity adequacy assessment of DSM applications. The problems of water storage tank and a building thermal mass were addressed by the use of peak load shifting to minimize the real-time pricing tariffs [26]. An autonomous two-tier cloud-based system has been proposed and cost reduction using genetic algorithm have been discussed in [27] and [28] respectively. In [29], a multiperiod generation and transmission expansion is addressed using Fixed Series Compensations (FSC). Likewise in order to address the reduction of both- the peak hour demand and consumer cost, particle swarm algorithm and grasshopper algorithm have been tested in [30]. The active power and reactive power are addressed for voltage profile improvement, by load shifting for voltage regulation within tolerance limits [31]. In [32], a DSM strategy is proposed based on reinforcement learning and fuzzy reasoning to reduce user cost in residential load management. However, the above said swarm passed optimization techniques are giving very promising results in terms of efficiency and an effective load scheduling but still found very tedious to implement in practical as compared to Fuzzy based systems. So, in this paper fuzzy rule-based load shifting has been proposed for a smart grid consisting of rooftop solar array. The shifting of load demand on the system is performed using fuzzy rules and the whole strategy is implemented using MATLAB simulation. There are two scenarios will be taken to validate the proposed methodology through simulation results. Thus, a highly robust system is developed and tested successfully, giving the scope for new research.

Rest of the paper is organized as: Section 2 discusses problem statement. In section 3 the proposed cost reduction-fuzzy based strategy has been described. In section 4, proposed methodology is implemented for two different scenarios in the MATLAB environment. In section 5, results are discussed to validate the proposed cost-effective model. In the later stage (section 6), the results have been concluded in order to show that proposed model has outperformed as compared to the scenario such as the case without load scheduling.

## PROBLEM STATEMENT

To shift the load of consumer with satisfying the constraints of schedulable load in DSM for the Time-of-Day (ToD) tariff between utility and prosumers to make the smart grid most cost effective and energy efficient. The objectives of this work include:

The reduction of peak demand by shifting the load demand to off-peak hours.

Flattening the load curve during the 24-hour ToD.

Consequently, these objectives will lead in reduction of electricity usage cost for prosumers.

The mathematical formulation of the proposed methodology is given as below:

$$F = M \qquad (P^t) \tag{1}$$

$$P^t = a_1(P_i^t - P_s^{t-1}) + a_2 P_0^t \tag{2}$$

Where, $P^t$: average power consumed by prosumer between time (t-1) and t.

$P_i^t$: power consumed between (t-1) and t by prosumer.

$P_s^{t-1}$: average demand on the system.

$P_0^t$: average demand of prosumer.

$a_1$, $a_2$: constants which will be integers satisfying $a_1 + a_2 = 1$ (3)

The overall cost function for ToD tariff is as follows:

$$C_T = N_m{*}C_m + N_a{*}C_a + N_e{*}C_e \tag{4}$$

Where, $C_T$: Total cost of energy use in the day

$C_m$: Tariff for load used in morning hours

$C_a$: Tariff for load used in afternoon hours

$C_e$: Tariff for load used in evening hours

$N_m$: Total demand in morning phase
$N_a$: Total demand in afternoon phase
$N_e$: Total demand in evening phase

## PROPOSED METHODOLOGY

The proposed methodology processes the demand of prosumer $P^t$ by the use of Fuzzy Logic System (FLS). This follows ToD approach for its evaluation of demand and its cost. As the user provides the predicted demand for the day, for the upcoming day, week, month, or even a year, the system identifies the time when the demand is high and when it is low. System also takes into account of the fact that some of the loads are schedulable, also called as flexible load, while some of them are non-schedulable, also called as fixed load. Few examples of schedulable and non-schedulable loads are listed in Table 1.

**TABLE 1.** Examples of schedulable and non-schedulable loads

| | |
|---|---|
| **Schedulable load** | Washing machine, Mobile chargers, Laptop charger, Dishwasher, Vacuum cleaner |
| **Non-schedulable load** | Refrigerator, air conditioner, toaster, mixer, water heater |

### Load Shifting Strategy

The steps for applying proposed methodology are given below:

**Step 1:** Set the number of prosumers to be assessed.

**Step 2:** Collect information about electrical appliances at consumer end and categorise them as schedulable and non-schedulable loads.

**Step 3:** Divide complete 24 hours into 3 ToD zones namely morning, afternoon and evening.

**Step 4:** Find the best suitable Time-of-Day (ToD) for each schedulable load.

**Step 5**: Map low as well as schedulable loads to peak load enabling the system to operate under wide range of operation.

**Step 6:** Set Fuzzy rules and apply Fuzzy Logic for proposed objective given in eqn. (1).

**Step 7:** Step 3 shifts schedulable load at best suitable time. Then, calculate ToD tariff as per eqn. (4).

The proposed DSM strategy is robust and could be used to shift the schedulable load and results into a cost-effective scheme for prosumers.

### Cost Reduction Strategy

The cost calculation of the proposed methodology by the system is explained as follows:

Total hours in a day: 24 hours

For an industrial sector scenario/ day time scenario, the demand would, in general, be such that

$$C_a > C_m > C_e \tag{5}$$

For a residential sector scenario/ night time scenario, the demand would, in general, be such that

$$C_m > C_e > C_a \tag{6}$$

**Step 1:** Let the 24 hours be divided into three parts: morning, afternoon and evening. Each phase will have equal duration. Let morning range from 00:00 to 08:00 hours; afternoon from 08:00 to 16:00 hours; evening from 16:00 to 00:00 hours (in 24-hour format).

**Step 2:** In case of industrial sector scenario/ day time load, the total cost of energy use in a day would be minimum if total cost equals

$$N_m{*}C_m + N_e{*}C_a + N_a{*}C_e \tag{7}$$

**Step 3:** Similarly, in case of residential sector scenario/ night time load, the total cost of energy use in a day would be minimum if total cost equals

$$N_a{*}C_m + N_m{*}C_a + N_e{*}C_e \tag{8}$$

The aim would be to schedule a typical load in one of the three categories depending on the demand present the three categories.  Thus, if there is a heavy load, it should ideally be scheduled at a phase where there is less demand that is already present. On the other hand, if there is a light load, it may be scheduled to a phase in which heavy demand exit. This minimum cost case is found by the system. Thus, the result has minimum cost and reduced peak of electricity demand.

As an input, the user gives the electrical load in each ToD/ phase in the form of flexible and fixed load. The system analyses it, processes it to find the new schedule of each load such that there is reduction in peak and minimum cost, and provides the output about the best suitable ToD for each flexible load.

## APPLICATION OF PROPOSED METHODOLOGY

The proposed methodology is elaborated for different load conditions which represents industrial scenario and residential scenario. In industrial scenario, the demand of electricity is high from 8 am to 4 pm, less during morning and evening hours as shown in Fig. 1. In residential scenario, the demand of electricity is higher in morning and evening hours, than during afternoon time, as shown in Fig. 2.

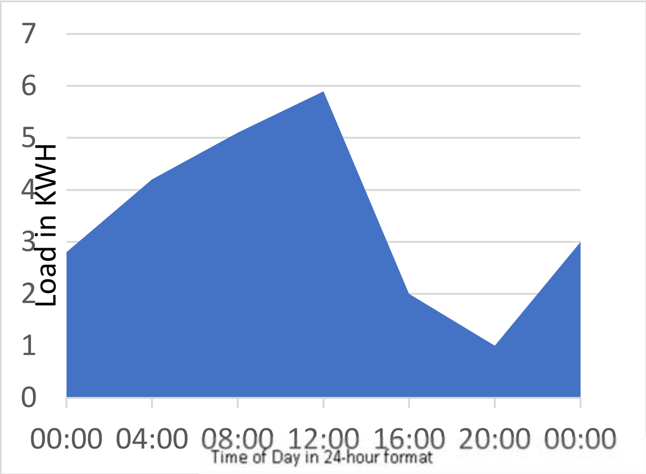


**FIGURE 1.** User demand for industrial load

In industrial scenario, because of switching on of a large number of machines including high energy demanding motors, cooling tower operation, lightening devices, air conditioning, computers and other industrial machinery, load demand is high during 8 am to 4 pm. In residential scenario, load curve variation depends on use of televisions in the evening, air conditioners and coolers, or heaters in the night, and geysers, toasters, mixture-grinders in the morning, charging of electronic gadgets, etc.

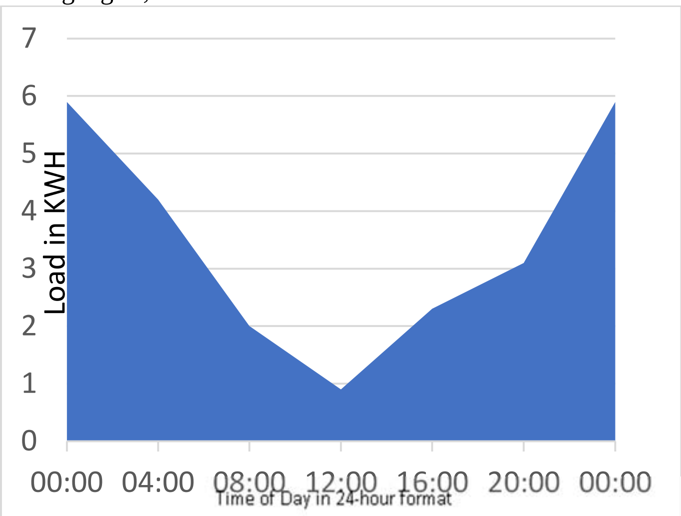


**FIGURE 2.** User demand for residential load

Two different scenarios have been discussed here based on when the peak demand is likely to occur. The proposed methodology has been applied in two different scenarios and results are discussed in subsequent section.

### 4.1 Case I: Peak in afternoon (Industrial scenario for single prosumer)

**Step 1:** The user enters fixed demand in following steps:

- From midnight to 8:00 am: 3 KW
- From 8:00 am to 4:00 pm: 5 KW
- From 4:00 pm to midnight: 2 KW

**Step 2:** The user enters flexible demand in following steps:

- From midnight to 8:00 am: 4 KW
- From 8:00 am to 4:00 pm: 6 KW
- From 4:00 pm to midnight: 1 KW

**Step 3:** An array of rules which confirms that a Fuzzy Logic System has been successfully developed based on the given data.

**Step 4:** The proposed methodology tells the user the best time to schedule each flexible load in following parts:

- The demand of 4 KW should be scheduled at 7:30 pm.
- The demand of 6 KW should be scheduled at 10:00 am.
- The demand of 1 KW should be scheduled at 9:50 pm.

**Step 5:** The initial and final cost to the user is displayed in Rupees as follows:

- Initial cost was Rs. 142.50.
- Final cost is Rs. 63.

**Step 6:** The plot of the Fuzzy Logic System, shown in Fig. 3 is generated by the software.

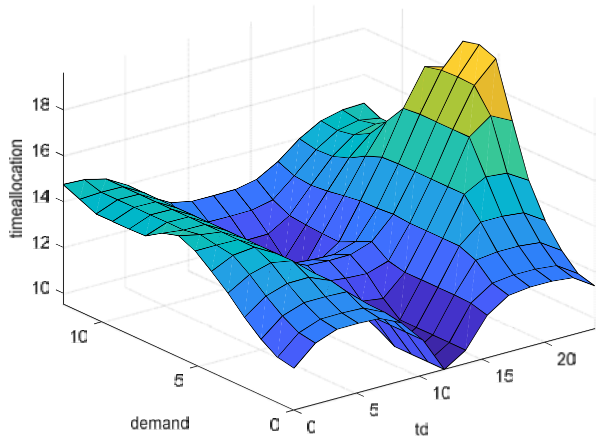


**FIGURE 3.** Plot of the FLS implemented in case I

### 4.2 Case II: Peak in morning and evening (Residential Scenario for single prosumer)

**Step 1:** The user enters fixed demand in following steps:

- From midnight to 8:00 am: 4 KW
- From 8:00 am to 4:00 pm: 1 KW
- From 4:00 pm to midnight: 3 KW

**Step 2:** The user enters flexible demand in following steps:

- From midnight to 8:00 am: 5 KW
- From 8:00 am to 4:00 pm: 2 KW
- From 4:00 pm to midnight: 4 KW

**Step 3:** The array of rules which confirms that a Fuzzy Logic System has been successfully developed based on the given data.

**Step 4:** The proposed methodology tells the user the best time to schedule each flexible load in following parts:

- The demand of 5 KW should be scheduled at 2:20 pm.
- The demand of 2 KW should be scheduled at 10:30 am.
- The demand of 4 KW should be scheduled at 2:05 pm.

**Step 5:** The initial and final cost to the user are displayed in Rupees as follows:

- Initial cost was Rs. 168.67.
- Final cost is Rs. 76.

**Step 6:** The plot of the Fuzzy Logic System, shown in Fig. 3 is generated by the software.

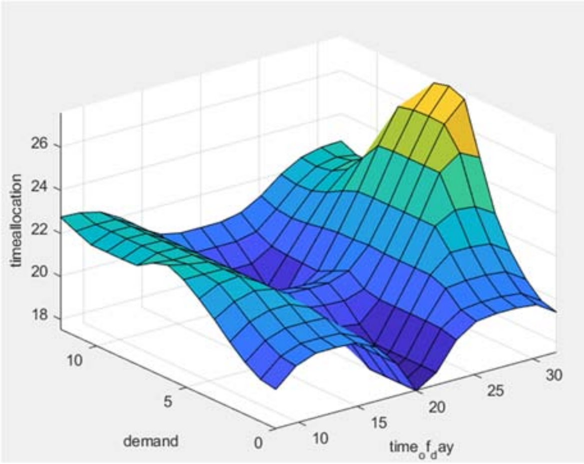


**FIGURE 4.** Plot of the FLS implemented in case II

From the results shown in Fig. 3 and Fig. 4, it can be observed that the proposed methodology shifts schedulable load to a particular ToD from peak hour. The allocation of each load as given by the user, modified and rescheduled to its best time possible, depending upon its load capacity, and the total demand during its use.

### 4.3 Case III: Peak in afternoon (Industrial scenario for multiple prosumers)

For applying proposed methodology, 10 residential prosumers are considered simultaneously. For different prosumers fixed and flexible loads connected in the system for different time slots of day are assumed and shown below in Table 2.

**TABLE 2.** Assumed fixed and flexible loads of each time slot for residential scenario

| Prosumer No. | Morning fixed load | Afternoon fixed load | Evening fixed load | Morning flexible load | Afternoon flexible load | Evening flexible load |
|---|---|---|---|---|---|---|
| 1 | 4 | 5 | 4 | 4 | 6 | 5 |
| 2 | 4 | 6 | 5 | 4 | 6 | 5 |
| 3 | 5 | 6 | 4 | 4 | 6 | 3 |
| 4 | 5 | 6 | 2 | 5 | 5 | 3 |
| 5 | 4 | 6 | 3 | 4 | 5 | 4 |
| 6 | 5 | 5 | 3 | 3 | 6 | 3 |
| 7 | 5 | 5 | 3 | 4 | 6 | 2 |
| 8 | 4 | 6 | 3 | 3 | 6 | 3 |
| 9 | 4 | 6 | 2 | 3 | 5 | 3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 10 | 3 | 6 | 3 | 4 | 5 | 3 |

The results after applying proposed DSM methodology for 10 residential prosumers are listed in Table 3.

**TABLE 3.** Load shifting for residential scenario

| Prosumer No. | Morning flexible load | Shifted ToD for Morning flexible load | Afternoon flexible load | Shifted ToD for Afternoon flexible load | Evening flexible load | Shifted ToD for Evening flexible load |
|---|---|---|---|---|---|---|
| 1 | 4 | 7:50PM | 6 | 8:11PM | 5 | 6:50PM |
| 2 | 4 | 7:50PM | 6 | 8:19PM | 5 | 6:53PM |
| 3 | 4 | 6:52PM | 6 | 8:19PM | 3 | 5:52PM |
| 4 | 5 | 6:41PM | 5 | 8:11PM | 3 | 5:15PM |
| 5 | 4 | 7:50PM | 5 | 8:11PM | 4 | 5:52PM |
| 6 | 3 | 7:50PM | 6 | 8:11PM | 3 | 5:31PM |
| 7 | 4 | 6:52PM | 6 | 8:11PM | 2 | 5:15PM |
| 8 | 3 | 8:35PM | 6 | 8:19PM | 3 | 5:31PM |
| 9 | 3 | 8:35PM | 5 | 8:11PM | 3 | 5:15PM |
| 10 | 4 | 8:35PM | 5 | 8:11PM | 3 | 5:31PM |

It can be observed from the results of Table 3, that the proposed methodology suggests to shift the load of 3 KW from morning slot to 8:35pm, the load of 5 KW to 8:11pm, the load of 3 KW from evening slot to 5:15pm for Prosumer No. 9.

The proposed DSM methodology also performs cost analysis for each prosumer which is presented in Table 4. In all the cases, the percentage change has been calculated as

Percentage change in cost = ( (Initial Cost – Final Cost)/Initial Cost ) * 100 (9)

**TABLE 4.** Cost analysis for residential scenario

| Prosumer No. | Initial cost | Final cost | Percentage change in cost |
|---|---|---|---|
| 1 | 127.5 | 58.5 | 54.11 |
| 2 | 137 | 63 | 54.01 |
| 3 | 135.75 | 60 | 55.8 |
| 4 | 128 | 55.5 | 56.64 |
| 5 | 124.5 | 55.5 | 55.42 |
| 6 | 123 | 54 | 56.09 |
| 7 | 124.75 | 54 | 56.71 |
| 8 | 127.75 | 55.5 | 56.55 |
| 9 | 118.25 | 51 | 56.87 |
| 10 | 119.75 | 52.5 | 56.15 |

As elaborated in Table 4, after application of DSM, electricity cost for each prosumer has been decreased by a significant amount. As observed in Table 4, for prosumer No. 9, percentage cost of electricity reduced is 56.87%.

## 4. 4 Case IV: Peak in morning and evening (Residential scenario for multiple prosumers)

For applying proposed methodology, 20 residential prosumers are considered simultaneously. For different prosumers fixed and flexible loads connected in the system for different time slots of day are assumed and shown below in Table 5.

**TABLE 5.** Assumed Fixed and Flexible load of each time slot for industrial scenario

| Prosumer No. | Morning fixed load | Afternoon fixed load | Evening fixed load | Morning flexible load | Afternoon flexible load | Evening flexible load |
|---|---|---|---|---|---|---|
| 1 | 6 | 5 | 4 | 6 | 5 | 5 |
| 2 | 5 | 4 | 3 | 6 | 6 | 5 |
| 3 | 5 | 5 | 4 | 6 | 5 | 3 |
| 4 | 6 | 5 | 2 | 5 | 4 | 4 |
| 5 | 6 | 4 | 3 | 6 | 5 | 5 |
| 6 | 6 | 4 | 4 | 6 | 5 | 3 |
| 7 | 5 | 4 | 2 | 5 | 4 | 3 |
| 8 | 6 | 5 | 2 | 5 | 4 | 4 |
| 9 | 6 | 4 | 4 | 6 | 5 | 3 |
| 10 | 4 | 3 | 2 | 6 | 2 | 2 |
| 11 | 6 | 2 | 2 | 4 | 3 | 2 |
| 12 | 6 | 5 | 3 | 5 | 5 | 2 |
| 13 | 4 | 3 | 3 | 6 | 4 | 2 |
| 14 | 5 | 3 | 2 | 6 | 5 | 3 |
| 15 | 6 | 4 | 3 | 4 | 3 | 2 |
| 16 | 4 | 3 | 2 | 6 | 4 | 3 |
| 17 | 6 | 5 | 4 | 4 | 3 | 3 |
| 18 | 6 | 5 | 5 | 6 | 3 | 2 |
| 19 | 6 | 4 | 3 | 6 | 2 | 2 |
| 20 | 5 | 3 | 3 | 4 | 3 | 2 |

The results after applying proposed DSM methodology for 20 residential prosumers are listed in Table 6.

**TABLE 6.** Load shifting for industrial scenario

| Prosumer No. | Morning flexible load | Shifted ToD for Morning flexible load | Afternoon flexible load | Shifted ToD for Afternoon flexible load | Evening flexible load | Shifted ToD for Evening flexible load |
|---|---|---|---|---|---|---|
| 1 | 6 | 2PM | 5 | 12 NOON | 5 | 4PM |
| 2 | 6 | 2PM | 6 | 11AM | 5 | 4PM |
| 3 | 6 | 2PM | 5 | 11:52AM | 3 | 4PM |
| 4 | 5 | 2PM | 4 | 11:52AM | 4 | 4PM |
| 5 | 6 | 2:01PM | 5 | 12:05PM | 5 | 4:05PM |
| 6 | 6 | 2:04PM | 5 | 12:05PM | 3 | 4:05PM |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7 | 5 | 2PM | 4 | 11:35PM | 3 | 4PM |
| 8 | 5 | 2PM | 4 | 11:52AM | 4 | 04:01PM |
| 9 | 6 | 2PM | 5 | 12:05PM | 3 | 4:05PM |
| 10 | 6 | 2PM | 2 | 11:35PM | 2 | 4PM |
| 11 | 4 | 2PM | 3 | 11:35PM | 2 | 4PM |
| 12 | 5 | 2PM | 5 | 11:52AM | 2 | 4PM |
| 13 | 6 | 2PM | 4 | 11:35PM | 2 | 4PM |
| 14 | 6 | 2PM | 5 | 11:52AM | 3 | 4PM |
| 15 | 4 | 2PM | 3 | 11:35PM | 2 | 4PM |
| 16 | 6 | 2PM | 4 | 11:35PM | 3 | 4PM |
| 17 | 4 | 2PM | 3 | 11:35PM | 3 | 4PM |
| 18 | 6 | 2PM | 3 | 12:05PM | 2 | 04:01PM |
| 19 | 6 | 2:04PM | 2 | 12:05PM | 2 | 4PM |
| 20 | 4 | 2:07PM | 3 | 12:33PM | 2 | 2:07PM |

It can be observed from the results of Table 6, that the proposed methodology suggests to shift the load of 4 KW from morning slot to 2:07pm, the load of 3 KW to 12:33pm, the load of 2 KW from evening slot to 2:07pm for Prosumer No. 20.

The proposed DSM methodology also performs cost analysis for each prosumer which is presented in Table 7.

**TABLE 7.** Cost analysis for industrial scenario

| Prosumer No. | Initial cost | Final cost | Percentage change in cost |
|---|---|---|---|
| 1 | 107.25 | 77.25 | 27.97 |
| 2 | 100 | 72.5 | 27.5 |
| 3 | 96.75 | 69.25 | 28.42 |
| 4 | 90.5 | 63 | 30.38 |
| 5 | 101 | 71 | 29.7 |
| 6 | 97.75 | 67.75 | 30.69 |
| 7 | 80.25 | 55.25 | 31.15 |
| 8 | 90.5 | 63 | 30.38 |
| 9 | 97.75 | 67.75 | 30.69 |
| 10 | 68 | 43 | 36.76 |
| 11 | 68 | 43 | 36.76 |
| 12 | 90.25 | 62.75 | 30.47 |
| 13 | 77.25 | 52.25 | 32.36 |
| 14 | 84.25 | 56.75 | 32.64 |
| 15 | 77.25 | 52.25 | 32.36 |
| 16 | 77.25 | 52.25 | 32.36 |
| 17 | 86.75 | 61.75 | 28.81 |

| | | | |
|---|---|---|---|
| 18 | 94.75 | 64.75 | 31.66 |
| 19 | 82.25 | 52.25 | 36.47 |
| 20 | 135.66 | 64 | 52.82 |

As elaborated in Table 7, after application of DSM, electricity cost for each prosumer has been decreased by a significant amount. As observed in Table 7, for prosumer No. 20, percentage cost of electricity reduced is 52.82%.

## RESULTS AND DISCUSSION

The proposed methodology generates a fuzzy logic system based on the data entered by the user. It provides the user with the best appropriate ToD for each of the schedulable load to be rescheduled as to create minimum cost burden.

The plot shown in Fig. 5 shows the allotted time to the user load, on y-axis as a function of the quantity of load demand in KW, on x-axis. The system successfully supresses the peaks during the afternoon hours. The plot shown in Fig. 6, for industrial load, shows graph between allotted time on y-axis and ToD on x- axis. Careful observation to the system plots in Fig. 5 and Fig. 6 reveals that allotted time goes beyond 24 hours. It means that the allotted time above 24 hour is an extension and have to be taken by subtracting it from 24. For example, if allotted time is 26 hours, it means that load is scheduled at 26 – 24 = 2 am. The same criteria has been applied in ToD calculation in this system. But the user does not need to compute this manually, as the proposed methodology computes the result out of the correct readings for the user automatically. The majority of load is intentionally allocated in 4 pm to 12 midnight so as to minimize the peak load in afternoon.

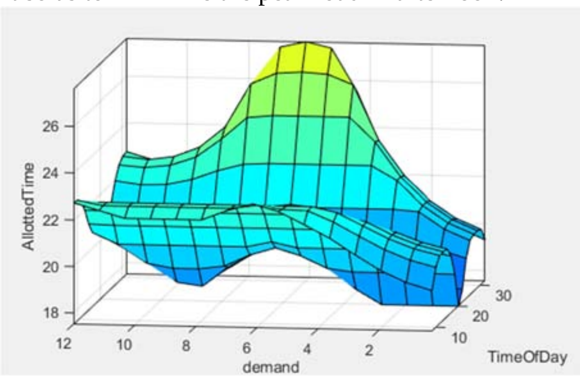


**FIGURE 5.** Allotted time vs demand graph of FLS Case I

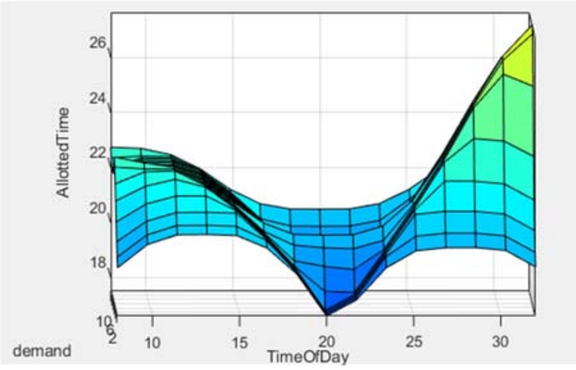


**FIGURE 6.** Allotted time vs time of day graph of FLS Case I

The plot shown in Fig. 7 is for residential load. It shows the allotted time to the user load, on y-axis as a function of the load demand in KW, on x-axis. The system aims to reduce the peak load to afternoon when the load is current very low. The plot shown in Fig. 8, for industrial load, shows graph between allotted time on y-axis and ToD on x-axis. Unlike in Fig. 6, the scale for allocated time is from 0 to 24 hours. Here, no time extension is not required. The majority of load is intentionally allocated in 8 am to 4 pm to minimize the peak load in the morning.

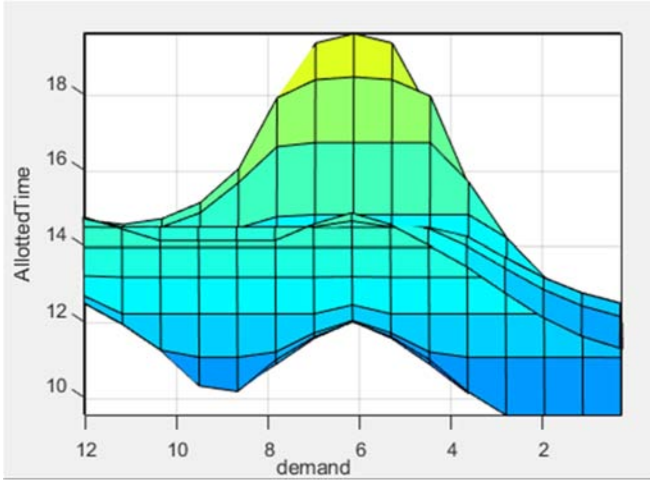


**FIGURE 7.** Allotted time vs demand graph of FLS Case II

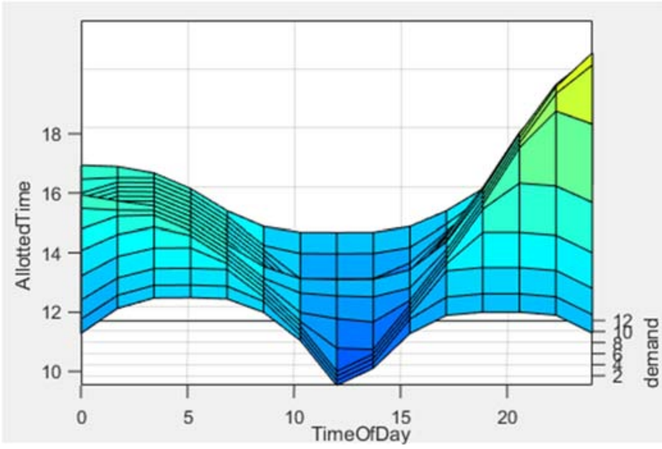


**FIGURE 8.** Allotted time vs time of day graph of FLS Case II

The proposed methodology also calculates the cost of electricity usage before and after the shifting based on DSM. The cost is reduced and the loads are scheduled to the best time of day possible. This process of verification makes according to use for ToD tariff calculation is presented in Indian scenario and in Indian Rupees (INR). The rules of tariff calculation can be further modified depending on the sector of demand, as proposed in the future scope of the paper. Here a system that can take a total of 6 h demand for flexible load and 6 h demand for fixed load is used. It also works with loads lighter that. Thus this system in its current state can solve the problems that have a total of 12 h demand or less. For higher demand, the system method can be used to easily modify the system. This may be needed for a smart grid of a much wider range of operation.

## CONCLUSIONS

In this paper, DSM scheme is proposed that can easily be implemented to each household/ factory in a smart grid. The use of Fuzzy Logic makes the system to decide if a load is to be scheduled or not, and if it has to be, then the best appropriate time of day. In this paper, two general scenarios of demand have been tested which shows that the system makes the grid much more efficient and cost effective.

The proposed DSM technique is demonstrated for multiple residential and industrial prosumers and results shows its effectiveness for larger network also.

It can be implemented in various energy demand sectors making it robust and practical. A loop-based algorithm can be added in future to this system so that the power demand of higher order can also be mapped into the system, as the lower order power has been already mapped in it.

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