

# Demand Side Management in Smart Grid using Optimization Technique for Residential, Commercial and Industrial Load

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## Abstract

**Objective:** To minimize the Peak to Average load Ratio (PAR) per day of end users so that the smart grids(SG) efficiency is increased. Set of appliances differentiated as elastic and fixed are considered for optimal scheduling at the user end.

**Methods:** Demand side management (DSM) in smart grid is one which permits customers to reach determinations affecting their energy consumption, and reduces the peak hour demand of the energy providers and reshapes the load profile. Genetic algorithm (GA) is a powerful technique to obtain near optimal solution. Hence GA is used for this load re-scheduling problem for a sample test system to minimize the cost of end user. **Findings:** Economical and environmental advantages can be obtained by time based pricing model compared to currently existing scenario. Especially, the electricity expenditures of the end user can be reduced by responding to pricing which changes with different hours of a day in SG.

**Improvement:** In this work rescheduling of the load curve of a consumer from the existing load curve is performed. The former is done based on time based pricing method that would reduce the PAR of end-user. This scheduling is also based on categorizing the devices used by the user as shiftable and non-shiftable loads.

**Keywords:** Appliance sScheduling, Demand sSide mManagement, Genetic Algorithm, Smart Grid, Energy Management

## 1. Introduction

Since the time human started to use the electricity for lighting purpose, the development of power system has been brought into picture and it is more than 100 years now. But as modernization and need for power increased the existing system is finding change now and then. In the recent years, the degradation of environment, management of utility and security are the issues that is faced by the energy sectors. The people are in need of a radical evolution in the power system sector. The prime most concern of every power sector is to obtain green power generation, more reliable system and intelligent system implementation. That came to be known as the Smart Grid. Dynamic pricing schemes are the unique features of the SG. By usage of smart meters and automatic metering infrastructure, the load can be easily managed according

to dynamic pricing schemes. Some of the commonly used smart grid pricing schemes in DSM programme are Real Time Pricing (RTP), Time of Use (TOU), Critical Peak Pricing (CPP), Day Ahead Pricing (DAP) and Extreme Day Pricing (EDP). When these dynamic pricing schemes are used along with the DSM strategies, penalties and incentives are used to control the customer's energy usage. However, the logic behind DSM is to increase power system security, stability, sustainability and economics by maximizing system capacity without changing the whole physical infrastructure of the power system. The Main focus of this paper is to reduce the Peak to Average Ratio (PAR) and to minimise the cost of the end user, by operating the appliances when the load is less on the grid. For which the time of use can be adjusted. Appliances are classified as shiftable and non-shiftable. For minimizing PAR ratio shiftable appliances plays an important role.

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We propose a work in DSM strategy based on load shifting technique. Several types of shiftable and non shiftable appliances are considered in this work to focus that the heuristic algorithm used can handle more number of appliances in an effective manner. The other part of this paper is organized as follows. A detail explanation of problem formulation is in section 2, section 3.1 deal with SCHEDULING algorithm, details of result obtained is listed in section 4 and section 5 concludes the paper.

## 2. Literature Survey

T. Logenthiran, D. Srinivasan, T. Z. Shun<sup>1</sup> solved the load shifting problem using GA to reduce the cost and PAR. The focus of this work is to schedule the power consumption which is termed as demand side management. In reference<sup>2</sup> the power scheduling is carried out by an convex multioptimization technique. Both centralised and decentralized optimization based on conventional programming has been proposed. However, the optimization framed in<sup>2</sup> would not be suitable for all user appliances. Out of all the appliance used by consumer some are categorized as flexible and some as fixed. The fixed appliance are one which will consume power in the same load pattern without any change. The power scheduling for these appliances cannot be controlled. The flexible appliance are one where the pattern can be changed without the increase of discomfort level of an customer.

DR is defined as the method which is involved to reduce the energy usage from the usual consumption load pattern by using the dynamic pricing schemes<sup>3</sup>. The ultimate objective of price based demand response programs (PBP) is to even out demand fluctuations. Here not only the end user but also the provider is benefited. Viewing in the perspective of customer, the user can get incentives based on reallocating the load from peak hours to non-peak hour<sup>4-5</sup>. On the utility side, DR techniques would be decreasing the risk due to outage, increase the efficiency of the power sector and also increase the reliability factor by reducing the PAR ratio<sup>6</sup>.

Scheduling of load for DR is an optimization problem and frequently solved by classical linear programming(LP) techniques. Reallocation of load for DR is an typical optimization problem and generally solved by using LP, MILP etc. De La Torre S has solved profit maximization problem in pool based electric market by using MILP programming<sup>7</sup>. For co-generation facilities on the user end, cost and energy opti-

mization problem are solved in reference<sup>8,9</sup>. All the reference used the dynamic pricing system for evaluation. Shifting of the load pattern would always increase the discomfort level of the user, but considering this and the reduction of the cost of electricity bill is addressed by many authors as stated in papers<sup>10,11</sup>. Therefore, considering waiting time of the user will make an multiobjective optimization of two differently varying variables. Similarly authors have put forward various techniques for rescheduling the load patterns such as load shedding, clipping the loads, filling the load in valley point etc<sup>12-14</sup>. Peak clipping reduces the peak demand and valley filling increases the demand at off-peak reducing the difference between peak load and valley load by filling the valley from a curtail load from the peaks to reduce the load burden. While, strategic conversation<sup>12</sup> reduce the peak load demand at customer premises. Strategic load growth<sup>12-14</sup> introduce large demand in the valley in off-peak to produce optimized load curve. Flexible load shape<sup>12-14</sup> only modifies the demand curve of the customers which are willing to take part in the DSM program in exchange for incentives. Whereas, load shifting<sup>14</sup> is generally used to shift load from on-peak to off-peak in order to minimize the cost. Genetic algorithm a global search method and its priority to be used in cost minimization problem is enumerated by authors in reference listed<sup>15,16</sup>.

## 3. Problem Formulation

In this section, the formulation of cost minimization is performed. Due to the electricity market being sporadic in nature, here it is assumed that the RTP signal change on slot time basis and its value is constant within that particular slot hour. Our objective is to minimize the consumer bill price for end user as well as to reduce the PAR so that smart grid efficiency is increased. The minimization problem is formulated as follows.

Minimize

$$\sum_{t=1}^{24} \sum_{a=1}^n \sum_{b=1}^m X_{ab}(t) \times E_{ab}(t) \times E_p(t) \tag{1}$$

Subjected to

$$\sum_{t=1}^a \sum_{a=1}^n \sum_{b=1}^m X_{ab}(t) * E_b(t) \leq P(t) \tag{2}$$

$$M_a = \mathbb{Z} - \mathbb{h}_a$$

t - Time slots.

- a - Number of appliances.
- b - Type of appliance.
- $E_{ab}$  - Energy consumption of appliance a of type b.
- $E_p(t)$  - Electricity price at time slot t.
- $X_{ab}$  - ON/OFF State of appliance a of type b.
- PL(t) - Maximum power limit at time slot t
- $M_a$  - Maximum allowable delay of the equipment.
- $Lh_a$  - length of operating time.

In the above constrain equation the energy consumption at time slot t is less than maximum limit to reduce the PAR. Furthermore, the number of appliances a of type b, shifted cannot be greater than the number of controllable appliances at time slot t. Schedule controllable devices are only controlled by DSM controller.

### 3.1 Algorithm for Dsm

GA is a heuristic global search method that mimicks the general theory of natural selection and survival of the fittest. GAs operates on three operators to exploit the unfit gene and carry out the optimization using fit gene so that better optimal solution would be reached. This optimization technique is generally an maximization problem which can be used for minimization by taking the reciprocal of the cost fitness function. This global search algorithm can manage more number of controllable appliances compared to other conventional methodologies adapted for SG. Also it will reduce the complexity yielded by Game theory technique. Each type of load has different consumption pattern and different length of operation time. Therefore, the design scheme should be able to tackle all these involutions. Evolutionary algorithm such as GA has potential to solve these types of complex problems. GA provide near optimal solution of the given problem. Hence we use GA based scheduling algorithm to solve cost optimization problem.

In a utility company, DSM is a platform to avoid or delay the need to increase the generating capacity to a new value by reducing the load or shifting the load of the consumer. Also, for non-commercial, commercial or industrial consumer, DSM favours to save money by reducing their electricity consumption cost and also provide incentives(utility) based on the reallocation. Commonly, the DSM is introduced to curb the power consumption of the user at his side. and many approaches are introduced to solve it as an optimization problem with proper objective function. The minimization of the peak-to-average ratio of the total energy demand is considered

as a desire objective function for utility and the minimization of the energy cost is considered for consumer. The solution of this problem is user energy consumption schedules which satisfy the mentioned objective function. The proposed DSM can be implemented easily on a smart grid with the smart metering component which can communicate with control system of utility/power Company and other consumers through a local area network (LAN). The DSM controller cumulatively deals with the appliances in each time slot, and gives a complete pattern by solving the minimization problem. The DSM is carried out at the beginning of the day, and when an appliance sent a request to DSM controller; it takes action on the basis of DSM technique results which carried out in advance.

The chromosomes pattern of GA represents the solution. In this work, chromosomes are considered as an array of bits which represent the ON/OFF state of appliances. Thus, the length of chromosomes depends on the number of controllable appliances. N is the number of controllable loads in each area. The population of chromosomes is randomly initialized after that a fitness function is evaluated. In this case, a fitness function is evaluated by using the eq. 1. The steps of GA for solving minimization problem are show below. In each iteration new population of chromosomes are produced by crossover and mutation. Single point crossover and binary mutation are used in this work. The convergence of the algorithm depends upon the crossover and mutation rate. Larger crossover rate means faster the convergence and larger mutation rate means loss of good solution, and cause premature convergence of the algorithm. Sometimes, near optimal solution is found early on in GA but get missed by crossover and mutation. One best solution is remembered from the population consumption cost and the secondary objective is to reduce the PAR. Each area of the SG has different types of controllable loads, details of these areas is given as follows.

#### 3.1.1 Algorithm

The proposed algorithm for this problem is given below.

##### DSM Algorithm

- 1: Initialize  $t=0$ .
- 2: Randomly initialize the population which represents the patterns of appliances.
- 3: Evaluate the fitness

4: Choose pattern from the population in which best fitness is achieved by satisfying the constraints, this pattern is chromosome that represent solution.

5: Check all the appliances status in chromosome

6: for  $k = 1$  to population size

7: Select randomly two pairs of chromosomes.

8: If  $P_c > \text{rand}$ , crossover this pair.

9: If  $P_m > \text{rand}$ , select next generation by mutation.

10:  $t = t + 1$ , go to step 3, till  $t = 24$ .

### 3.1.2 Residential Area

For minimization of the cost, here three end user with ten electrical appliances are considered. But the time of use of all the appliance varies depends on the need of the user. The KVA ratings for all the appliances are considered as the same. But main role is played by the shiftable loads for those the time of use can be shifted to the time when the load on the grid is less. The table 1 gives the input data for residential load appliances.

**Table 1.** Residential Load input

S.No.	Name Of Appliances	Type Of Appliance	Power Consumption (KWH)
1	Iron	Shiftable Load	0.16
2	Toaster	Shiftable Load	2.3
3	TV	Shiftable Load	1.2
4	Washing Machine	Shiftable Load	3.2
5	Fan	Shiftable Load	0.33
6	Fridge	Non- Shiftable Load	2.5
7	Air Conditioner	Non- Shiftable Load	3.6
8	Geyser	Non- Shiftable Load	5.2
9	Aquarium Pump	Non- Shiftable Load	0.21
10	Water Cooler	Non- Shiftable Load	1.6

### 3.1.3 Commercial Area

In this category of appliances we are considering three users for which different appliances with similar KVA ratings are taken. For the duration of 24 hours. Main role is

played by the shiftable loads which are operated when the load is minimum on the grid. The appliances for commercial area with its input KVA rating is listed in Table 2.

**Table 2.** cCommercial Load input

sS.no	Name of appliances	Type of appliances	Power consumption (KWH)
1	Coffee Maker	Non-shiftable	0.4
2	Filter pump (Swimming Pool)	shiftable	1.5
3	Electric heater (Spa)	shiftable	5.5
4	Oven	shiftable	2.3
5	AC	Non-shiftable	3.2
6	Washing Machine( Hot wash, warm rinse)	Shiftable	6.3

### 3.1.4 Industrial Area

For industrial monitoring purpose we have considered three different user and five different appliances with the same power of KVA rating. The operation time for industrial load is taken for a span of 24 hours, and for this the output is obtained. The table 3 shows input data of the industrial appliances in KVA ratings.

**Table 3.** Small industrial load input data

S.no	Name of appliances	Type of appliances	Power consumption (KWH)
1	oven	shiftable	30
2	lights	shiftable	24
3	hot water storage	Non-shiftable	18
4	space heaters	Shiftable	55
5	Induction Motor	shiftable	100

## 4. Simulation Results

This section figures out the results obtained by coding done in MATLAB are discussed. Results show that

the technique used for DSM scheme efficiently manage large number of controllable loads in all three areas. The proposed algorithm shifts the load to minimize the cost and PAR. Fig 1 shows the load demand from residential loads without scheduling. Fig 2 shows the result from residential load with scheduling. This clearly depicts after scheduling reduces the demand which in turn reduces the cost of residential load as shown in Fig 3. Similarly Fig 4, 5, 6, shows the result from commercial load and Fig 7, 8 shows the result from industrial load.

The graphs shown in Fig 10-14 are generated with the help of MATLAB software for single users first without scheduling and later after applying scheduling. In SG if the load curve of the user is scheduled according to the algorithm proposed peak to average load ratio is reduced. This reduction will further reduce the cost of consumption since they are directly related parameters.

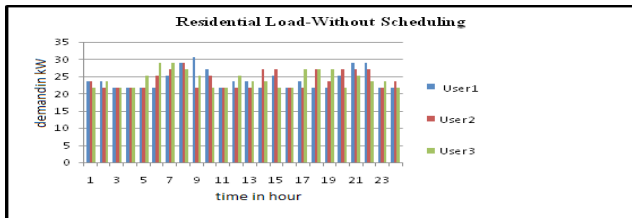


Figure 1. Residential load without scheduling.

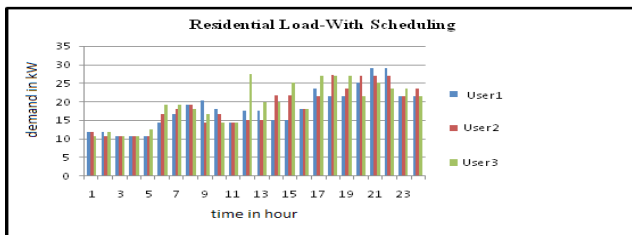


Figure 2. Residential load with scheduling.

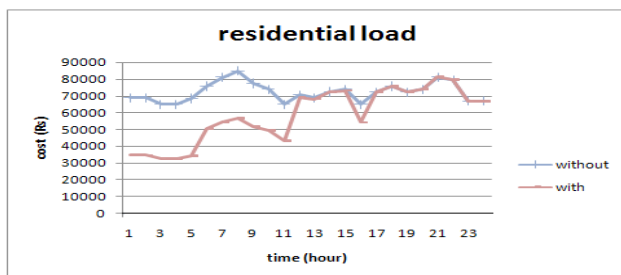


Figure 3. Cost of residential load for all user.

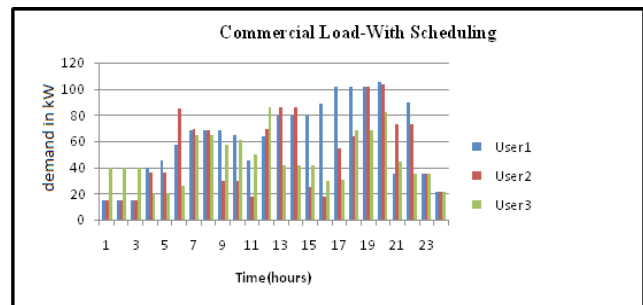


Figure 4. Commercial load without scheduling.

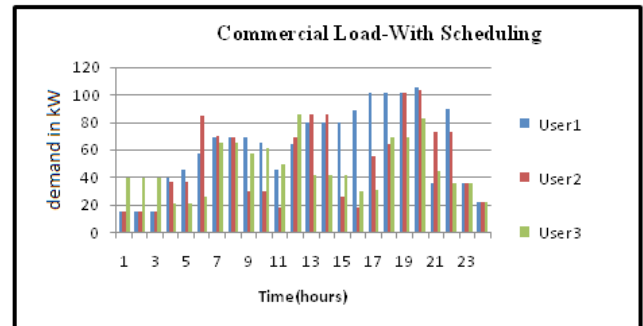


Figure 5. Commercial load with scheduling.

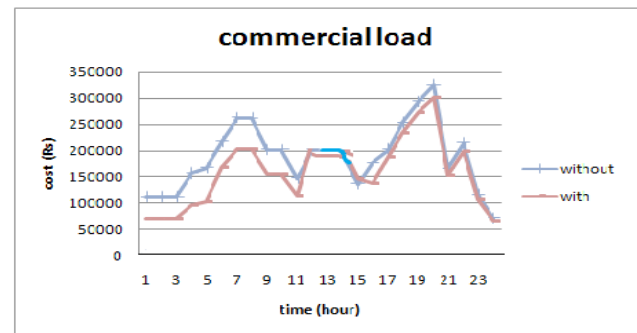


Figure 6. Cost of Commercial load.

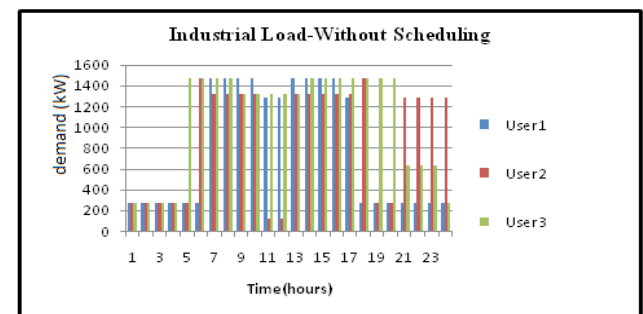


Figure 7. Industrial load without scheduling.



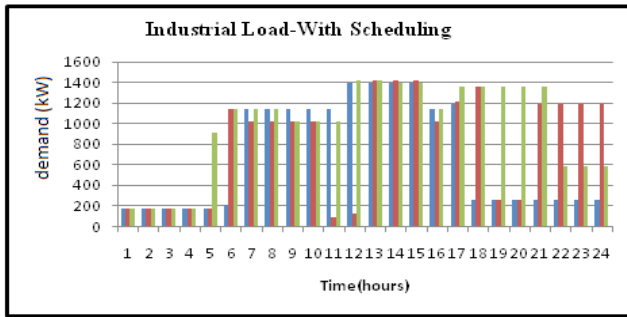


Figure 8. Industrial load with scheduling.

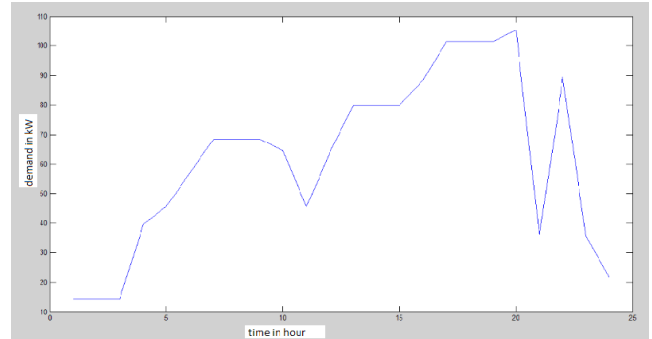


Figure 12. With scheduling graph for commercial load.

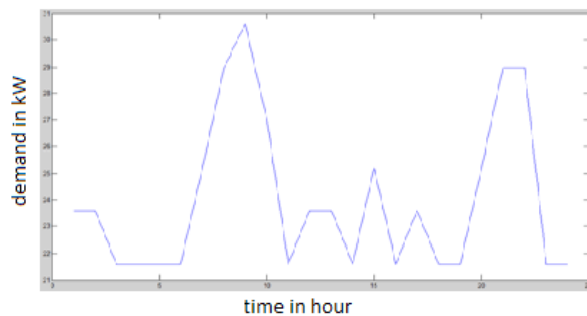


Figure 9. Without scheduling graph for residential load.

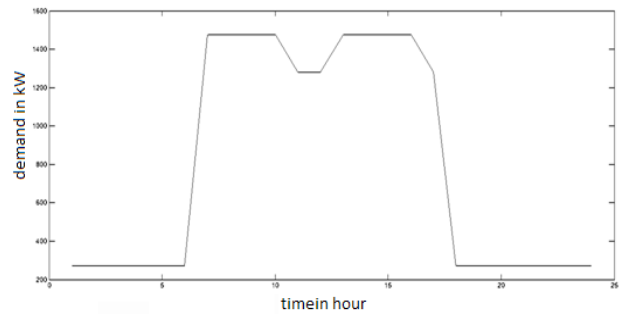


Figure 13. Without scheduling graph for industrial load.

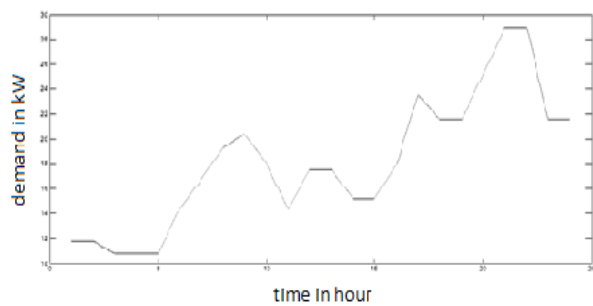


Figure 10. With scheduling graph for residential load.

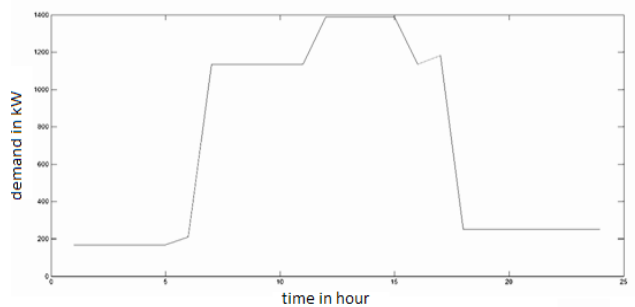


Figure 14. With scheduling graph for industrial load.

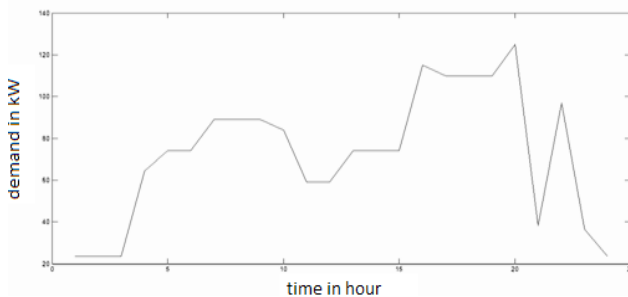


Figure 11. Without scheduling graph for commercial load.

## 5. Conclusion

In this research work, DSM algorithm for industrial, commercial and residential loads are proposed using GA. In this regard, a load scheduling problem is considered by involving shiftable and non-shiftable devices for the above mentioned users and solved by using GA. Result obtained from simulation using Matlab shows that each user efficiently utilizes the energy and minimizes its total expense in a day. Moreover, this proposed strategy is beneficial for entire SG, particularly at distribution network level. By reduction in peak load demand the

distribution network capacity and reliability is increased. This strategy can be employed in the future SG. Finally, the results show that the algorithm proposed, effectively reduces the PAR ratio of the user and there by electricity consumption cost is also reduced.

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