Priority based Scheduling of Residential Users Devices in Smart Grid Including WaitingTime

R. Rajarajeswari, D. Suchitra, J. Vijay Krishna, Joydeep Das Gupta

Abstract--- ***Demand side management (DSM) is an intiative taken by the utility to allow the consumer to optimize the power demand. To curb the energy consumption at the consumer end DSMprograms are developed and implemented by utility companies. The peak-to-average(PAR) load ratio onthecustomer side is reduced by reshaping the consumer's power demand from peak hour to base load period. Due to this the electric power consumed during peak hour is reduced, by implementing dynamic pricing the the cost for power consumption is also decreased. DSM leads to improve system efficiency, cost reduction, and increase system reliability.The usage of electricity during peak times leads to increase in the price of energy usage which is a loss for both customers as well as for the utility companies. This paper suggests a remedy for this inadequacy by means of minimizing the electricity payment cost by consideringminimumwaiting time for each appliance. By rescheduling the loads to non-peak period, the PAR ratio of the demand curve reduces, further causing the cost to be minimum. Time-of-use (TOUP), Incline-block rate (IBR) andReal-time pricing (RTP)arethe demand response strategy considered for a sample system which has both shiftable and fixed devices. By implementing the load shifting algorithm, PAR ratio is minimized which results in reduction of stress in the utility end during peak hours anda ample amount of cost saving .***

Keywords--- ***Demand Side Management (DSM), Waiting Time, Pricing Methodologies, Load Shifting,Priority based Scheduling.***

I. INTRODUCTION

The modern world is going beyond the innovation of new technologies to improve the lifestyle of the society i.e., everything becomes smarter and smarter.As the system getting smarter the use of electricity is also increasing rapidly. Since the energy is a non-storable one we need to use it carefully. The utility is under stress when there is a increase in demand day-by-day and the utility is forced to supply the demand on the system. Usually, the energy from the conventional sources has a limit for its generation. So utility companies need to find the solution for the efficient utilization of energy or harvest and use the energy from the renewable energy sources. DSM plays a mandatory role for achieving an efficient management of power both in demand and generation end . Demand side management is the programs implemented by the utility company on end user. It controls and reshapes the energy consumption profile of the end user in an efficient manner. For the implementation of such programs, the communication between user and utility is necessary and can be achieved with communication technologies available in smart grid and the smart meters. The main problem faced by the utility is the high demand for energy during peak times. In that case, the generators needtobe operated in its full capacity, this may increase the stress on utility. On the other hand, during off-peak hours the demand is low, only less amount of power generation is needed to meet the electricity demand ontheconsumer end. So it is important to reduce load fluctuations in order to minimize the pressure of utility during the day. This is the importance of smooth or constant load pattern. The main aim of DSM programs is to smoothen the load pattern.

Smoothening of the load pattern is done by so many methods like load shifting, peak clipping, and valley filling etc. This paper proposes the load shifting DSM program to reduce peak hour electricity consumption of end users. Reduction in load leads to the reduced electricity cost for the end users. Reduced cost will attract more users to take part in DSM programs there by both utility and end users get benefited. Load shifting is done by shifting the loads from peak hours to off-peak hours, where we have less cost per unit.The cost of electricity can also be reduced by adopting various time differentiated pricing models like RTP , DAP, TOUP, Critical Peak Pricing (CPP) etc. The pricing models encourages the customers to shift the controllable devices at home,during the shifting process the Maximum Allowable Power Limit (MAPL) for each hour is set. The shifting of load to a particular time is allowed only when MAPL is not exceeded by including the non shiftable loads at that time period.

II. RELATED WORK

SeveralDSM strategies areadopted in recent days.The prime most function of DSM program is to minimize the cost of generation, the power consumed and reduce the stress on the uutility.Mohsenian-Rad et.al., proposed a residential load control method based on a price predictor [1]. It schedules the operation oftheappliance based on the load and cost information available from the smart meters. RTP pricing model is used in this work. A DSM program using Evolutionary Algorithm a heuristic technique for load shifting is performed. The DAP scheme isinvolved in the calculation of cost [2].

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A Genetic algorithm based DSM technique by considering three different types of load namely lightly loaded residential demand, a commercial demanded load data which has considerable amount of load and a heavily loaded industrial demand. For achieving the objective of minimization of cost , the shifting is done based on framing a objective load curve . Then the optimization algorithm brings the final load curve as close to the objective curve [3]. It aims to reduce the electricity cost and also the PAR of the load. Load scheduling based on integer programming algorithm is described in [4]. This scheme is based on postponement of load fromheavily loaded hours tonon-peak hours to minimize the electricity cost and to reduce peak load.

A choice based model, dependent on Mixed Integer Linear Programming (MILP) and assignment based heuristic algorithm for residential energy management was proposedbyPeizhong et.al. in [5]. Consumer adjusts the daily consumption according to the signal received by the aggregator. A self-governing energy management strategy for household devices for real-time application was proposed in [6]. The scheme aims at the reduction in energy consumption cost and peak load. TOUP methodwas described in this model by NaveedUl, et al., that gives an outline of various home appliances scheduling techniques to exploit the demand side management in smart grid to reduce the cost and PAR [7]. In [8] author consider the energy consumption scheduling (ECS) devices in smart meters for the sovereign demand side management within an area. The ECS devices run a distributed algorithm to achieve the optimal energy consumption schedule and interact automatically. It aims the reduction in PAR in load demand. Game theory techniques were used for DSM using TOUP in the paper [14]. Communication techniques used along with load shifting using Game theory algorithm is used in reference[13].

III. DEMAND SIDE MANAGEMENT

Electricity is an essential inputin all sectors of any country, hence we need to focus on the effective utilization of available energy. As the developing countries like India, the requirement of electrical energy increases significantly. It is impossible to meet the requirement of electrical energy by installing new plants in these countries. So we needamove towards the alternative means of efficient energy management and utilization. This emphasis the implementation of DSM techniques. The effective solution to the abovesaid problem is implemented using DSM techniques, which lowers the peak demand as well as the wastage of the electrical energy. DSM programs incorporates energy conservation and energy efficiency programs, fuel replacement programs, DSM programs and load management programs.Maximizing the end use efficiency to avoid or postpone the requirement of new generating capacity is the objective of the DSM strategies. These strategies decreases the power utilization in residential buildings, workplaces and industrial areas by persistently monitoring the consumption of energy consumption. DSM programs include DR strategies smart metering and green building with programmable appliances.DSM manipulates residential electricity usage to reduce cost by altering the system load shape. The utility estimates the electric demand and pricing by bidding . The customer can adopt their power consumption depending on the pricing strategy and maximum demand information obtained from the utility side.

Normal methods employed for shaping the load demanded on the system are peak trimming , filling valley and shifting of load as depicted in figure 1, 2, and 3.

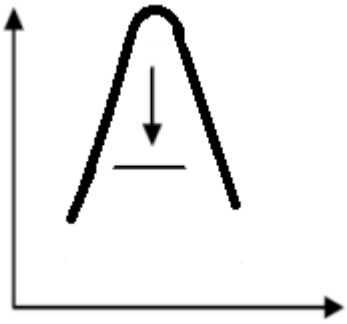

Figure 1: Peak Clipping

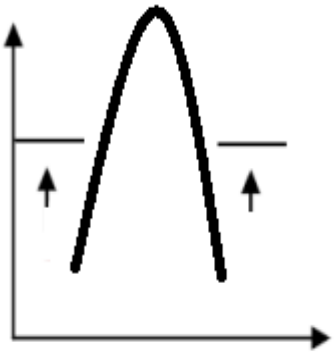

Figure 2: Valley Filling

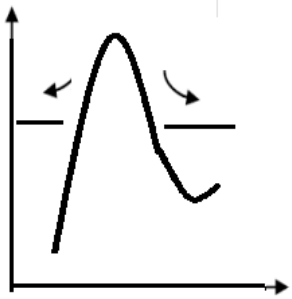

Figure3: Load Shifting

The usage of DSM algorithm accompanies the following outcome:

- Enhanes the system efficiency by improving efficiency of generation and load factor of the system.
- Reduced construction costs for new energy facilities by reducing the peak demand.
- Reduced CO_2 emissions throughtheefficient generation and minimizing thermal generation.
- Decrease the consumers electric consumption bill through the employment of load scheduling techniques.

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IV. SYSTEM MODEL

DSM emphasize on load scheduling and consumption of power for every user as an optimization problem,that targets on attaining a trade-off relating minimization of electricity bill payment and reducing the waiting time for the devices to be connected. The devices which are connected to the power supply operates in response to the signal sent from the utility end according to the pricing signals. This work considers DSM problem that includes transfer of shifting signals between utility and several users based on priority.After the estimation of price for consumption of electricity for the coming hours the utilityfix the price on hourly or timely basis. The pricing can made available at the user end by means of digital and communication network . Then, the user can decide the shifting of devices according to the strict, medium and no price reduction metods. The following are the pricing strategies considered in this work,TOUP strategy where the cost of electricity during peak hours is higher than that of during off-peak hours. DAP strategy is one where the generation company communicates the price of power consumption for the coming 24 hours in advance .This section, considers the demand scheduling problem as an minimization problem formulation. The main objective is to minimize the cost of electricity consumption oftheend-userand also the waiting time for the home appliance. The problem[15] is formulated as follows,

Minimise

$$\sum_{h=1}^{H} p^h \left(\sum_{a \in A} x_a^h \right) + \lambda_{wait} \frac{\sum_{h=1}^{H} \sum_{a \in A} (\delta_a)^{\beta_a - h} x_a^h}{E_a} \quad (1)$$

Subjected to,

$$\sum_{h=1}^{H} x_a^h \le L(t) \quad (2)$$

$$m_a = 24 - l_a \quad (3)$$

Where,

A = Set of appliances
H = Scheduling horizon
x_a^h = Hourly energy consumption of appliance a ϵ A
p^h= Pricing factor
λ_{wait} = Waiting cost factor
δ_a = Control parameter
E_a = Total energy needed for appliance a
$[\alpha_a,\beta_a]$= Scheduling period
L(t) = Maximum allowable power at the time "t".
m_a = Maximum admissible delay time ofthedevices
l_a = working duration of each device.

The first term in the equation (1) denotes the total electricity cost of each appliance. It is calculated by multiplying each appliances energy consumption and cost of electricity. The main aim is to reduce this cost of energy consumption. Because it helps both utility company and end users. Since more users are attracted towards the electricity because of its low price. More usage of electricity makesaprofit for utility companies in today's scenario. The cost reduction is obtained by shifting the non-essential loads to low price hours while meeting the hourly demand. While shifting of loads may result uncomfortable for users. Because they need to wait for a long time to perform the particular operation. This waiting can be reduced by including a factor called waiting time cost to the objective function and minimize it. So the second term in the equation (2) denotes cost due to waiting time.

Waiting time is the time of delay allowed from the normal start of the particular device.Inoder to satisy the user the delay time of the device should be kept minimum. The cost of waiting increases as more energy consumption is scheduled at later hours. The waiting time (in percentage) for each appliance a ∈ A is given by the equation 4

$$\text{Waiting Time} = \frac{\mu_a - \alpha_a}{\beta_a - \alpha_a} * 100 \quad (4)$$

Where $\mu_a \ge \alpha_a$denotes the finishing time, i.e., the smallest hour h such that $x_a^h = 0$.

The total aggregate load at every hour h ϵ H can be calculated as,

$$X_h = \sum x_a^h \quad (5)$$

The peak and average loads are calculated as,

$$X_{peak} = \max X_h \quad (6)$$

and

$$X_{avg} = \frac{1}{H} \sum_{h \in H} X_h \quad (7)$$

The PARfactor is calculated as,

$$PARfactor = \frac{H_{\max}}{\sum_{h \in H} X_h} X_h \quad (8)$$

The algorithm for load scheduling is as follows,

Step 1: Input the consumer number and their load details, here we are considering three usersand eleven home appliances.

Step 2: Categorise the appliance as fixed and elastic devices where fixed appliance meanstheir operation can't be shifted and elastic appliance means their operation can beshifted.

Step 3: Specify the maximum limit for the energy i.e. L(t), and price details.

Step 4: Calculate the total load at each time slot and differentiate the peak and off-peak hours.

Step 5: For each time slot shift the elastic load in peak load hour to base load hours satisfying the condition waiting time for each appliance is less than 3 hours.

Step 6: Check whether the demand in each interval is less than the maximum power limit for that particular interval.

Step 7: Do steps 5 and 6 for each appliance for 24 hours.

Step 8: Calculate the electricity cost before and after the load scheduling, PAR and compare theresult.

Step 9: Stop.

V. RESULTS AND DISCUSSIONS

Three residential users and eleven home appliances are considered in this paper and the data is given in Table 1.The input data were obtained by [9,10] as a reference by consideringadifferent class of consumer as shown in [11].

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Out of this eleven appliances play station, Microwave Oven, Coffee Maker, Washing Machine, Hair Dryer and Dish Washer are considered as the shiftable devices and remaining as fixed devices. Three pricing strategies are discussed here, they are TOUP based on Inclined Block Rate andDAP. In TOUP peak hour is charged by Rs. 2.7kW/hr and off-peak hour byRs. 1.5 kW/hr. DAP values are given in Table 2.

Table 1: The Power demand of appliances

Appliances	Power Rating(W)		
	User 1	User 2	User 3
Refrigerator	150	225	400
TV	100	150	150
Computer	100	450	450
Air Conditioner	1000	4000	6500
Lighting	60	100	100
Play Station	90	250	250
Microwave Oven	1600	1700	2150
Coffee Maker	800	1000	1400
Washing Machine	255	500	500
Hair Dryer	710	2500	2500
Dish Washer	1200	1500	1500

The load curve with and without load scheduling is given in figure 4.

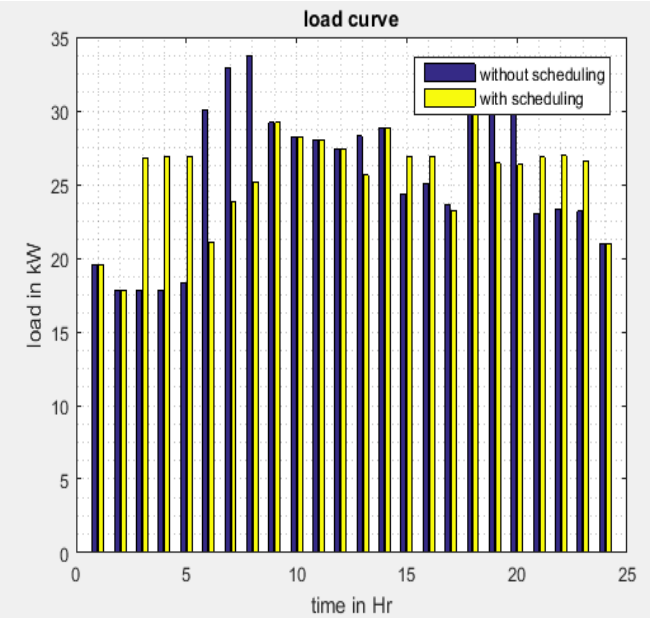

Figure 4: Total Load Curve

Scheduled appliances load curve is also shown in figure 5, 6, 7 and 8 respectively.

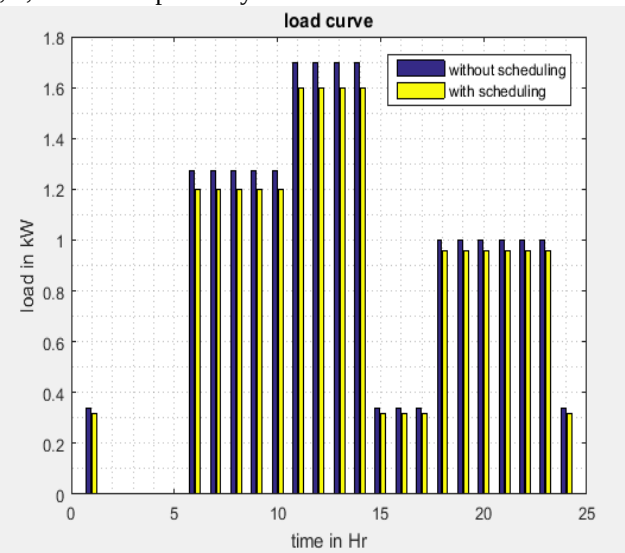

Figure 5: Oven Load Curve

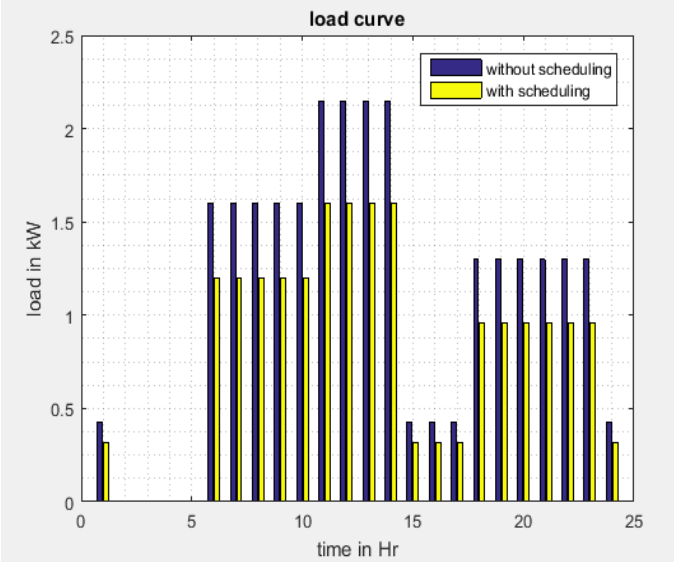

Figure 6: Washing Machine Load Curve

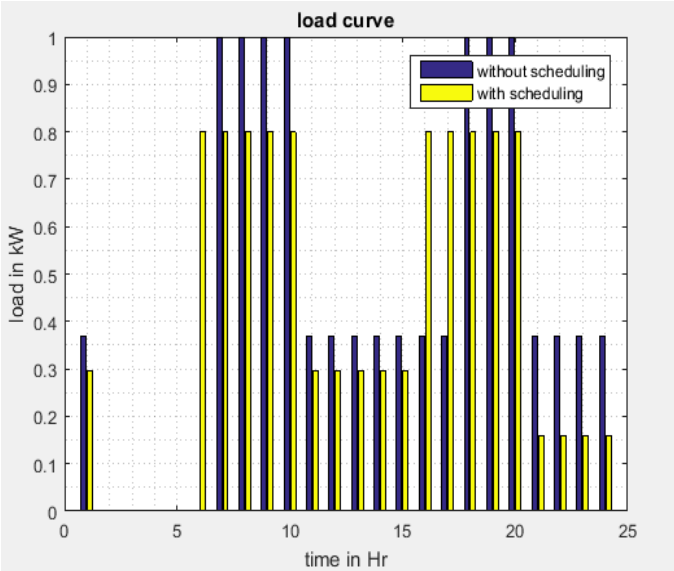

Figure 7: Dish Washer Load Curve

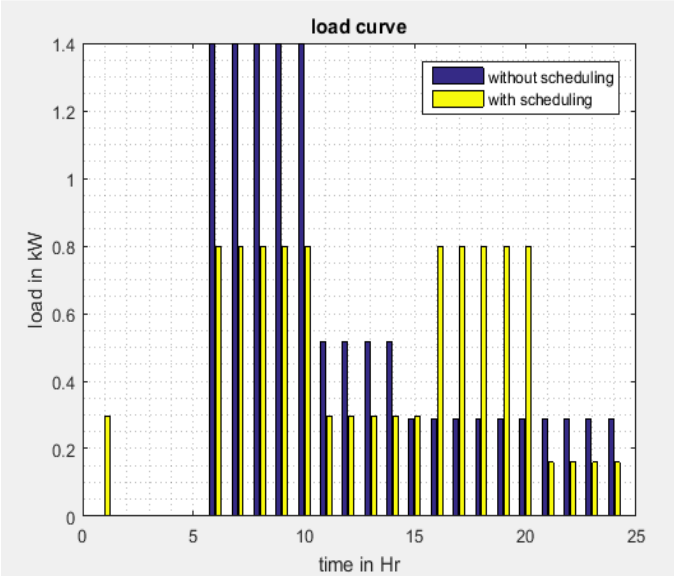

Figure 8: Coffee Maker Load Curve

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Table 2: Electricity Cost

Pricing Strategies	Cost in Rs.	
	Without Scheduling	With Scheduling
Time-Of-Use Pricing	1418	1401
Day-Ahead-Pricing	1181	1173

Table 3: Load Values

Peak Load	29.751 kW
Average Load	25.6757 kW
PAR	1.1587

It is clear from the graph that the load during the peak hours is reduced by the load scheduling algorithm. Thereby the electricity cost and PAR value of the load is also reduced. Thus it benefits both utility as well as the consumers.The cost of electricity under different pricing strategies is depicted in Table 2. Table 3 gives the value of peak load, average load and PAR ratio. Among the three pricing strategies Day-Ahead Pricing and TOU is profitable over inclined block rates because electricity cost is different in each hour.

VI. CONCLUSION

Demand Side Management techniques is an attractive tool in load management programs. Load scheduling techniques and different pricing strategies optimizethe demand response of the residential users. Based on the pricing information the consumers allocates the loads in order to minimizethe electricity cost. This will also reduce the burden of generating stations during peak hours. The results shown depicts that the user can adopt the reschedule of the operating devices and reduce the cost of electric bill on priority basis. Also while shifting the discomfort level of the user is reduced by having a minimum waiting time for each appliance.Thus a cost effective energy management can be obtained by using different demand response strategies, which leads to reduction in stress on utility during peak hours.

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