Demand Response Scheme with Electricity Market Prices for Residential Sector using Stochastic Dynamic Optimization

S. Sofana Reka
School of Electrical Engineering,
VIT University
Vellore - 632014, India
chocos.sofana@gmail.com

V. Ramesh
School of Electrical Engineering
VIT University
Vellore - 632014, India
vramesh@vit.ac.in

***Abstract*—In the present smart grid framework, Demand side management (DSM) has been incorporated on the target of bridging the gap between the demand and the supply and gives a way for energy efficiency. The reduction of carbon emissions and conservation measures can be completely eradicated. Demand Response (DR) is indeed a valise of measures in order to improve the energy system at the consumer side and has gained importance in residential sector. In this paper a Demand Response algorithm considering the residential consumer is done with the consideration of electricity market prices and stochastic optimization is adapted for minimizing the peak demand in a day. The electricity market price framework is done with the residential consumers in India by optimizing the appliances which are categorized as deferrable and non deferrable loads. The DR algorithm is simulated for 10 different consumers considered using the pricing schemes like flat pricing. The numerical results using the optimization technique and the pricing scheme is discussed which underlines the need of dynamic pricing schemes in residential sector.**

Keywords—demand response; pricing scheme; residential appliances; stochastic optimization.

I. INTRODUCTION

Renewable Over the present day electrical era, the change of legacy power systems to modernizing electric power infrastructure needs the combination of many technological innovations. The Smart Grid plays a vital role for the change in the power grid with the combination of information and communication scenarios. Smart features like renewable integration, smart meters, automation protection and control are needed [1]-[2].Demand Side Management (DSM) refers to the schemes or programs which are implemented by the utility companies at the customer premises of the meter and attains an intelligent outlook [3].There is a interaction between directly in between the utility providers and with the consumers with a direct load control .On the way in a smart grid scenario, by having smart meters fixed at the consumer side and there is a two way communication between the power utility and user, demand response(DR) has a important characteristic feature with the approach of shaping the users pattern in a more convenient manner[4]-[6].

The main advantage is that it can intelligently control the users demand in accordance with the power generated, thereby reducing the peak demand load in a more dynamic way which in turn leads to a cost effective approach [6].DR is the major element in smart grid which have a direct help in electricity power markets to set much efficient energy prices, reduce the market power and overall improve efficiency and increase security issues [7]. The function of demand response includes peak clipping, valley filling, and load shifting [7].There are different ways the peak demand can be reduced with the interaction with the providers. A survey on Demand response potential in global energy market is presented in [8]

Demand Response programs are more performed in residential sectors compared to commercial and industrial district as the residential consumers are found to more susceptible to the price signal in accordance of shifting the appliances e.g. washing machine, PHEV, dryer , water pump. The Demand Response are been classified into two branches as incentive based and price based programs. The incentive based programs provides the users with the changes in the loads through incentives and there are many ways this can approached as direct load control [9], curtail able load, and demand bidding. The price based programs are non dispatch-able DR, which is an alternative form of flat electricity prices.

The consumers are inspired to change their energy consumption patterns depending upon the dynamic pricing schemes. These programs helps the users to reduce the peak load demand thereby reducing the costs and concurrently for the utility providers to reduce the Peak to average ratio. In reality issues, the incentive based approach is a rare approach in India where all the programs approached involves manual approaches. The potential vitality of DR programs can be enriched only by sufficient knowledge and adequate time for dynamic pricing schemes.

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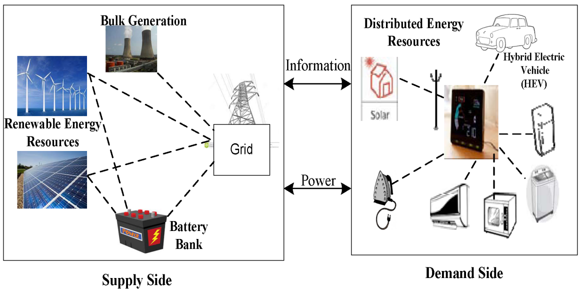

Fig. 1. Demand Response Architecture involving the interaction between supply and demand

The Fig.1 depicts the important characteristic of smart grid by installing smart meters at home for ability the shape the load pattern. An efficient DR algorithm inhibits reduced energy consumption scheduling patterns with the need of timely and appropriate decisions made based on the data for competent energy utilization.

In literature many DR programs have been proposed for effective energy efficiency dealing with better energy consumption patterns and they have mostly analyzed with the parameters of cost to be flat pricing where the cost is considered to be same throughout the day[10]-[13]. The proposed idea in this paper exhibits a DR algorithm which uses stochastic dynamic optimization for scheduling of appliances which uses dynamic pricing schemes directly obtained from the utility provider. The analysis and approach is done with energy consumption patterns to reduce the peak load considering actual market price data. The operation task of the scheduling appliances is classified as deferrable and non deferrable loads where the analysis is done. The contributions in this paper include the optimization of energy consumption pattern with actual market price data for different pricing schemes. Different tariff structures like flat tariff , time of use tariff , day ahead tariff are been analyzed with the data obtained from IEX (Indian Energy Exchange) in order to effect of the DR algorithm for dynamic pricing scheme according to Indian standards and the impact of this approach is done in a two level module in stochastic optimization.

The rest of the paper is organized as follows. Section II describes the analysis of this approach in a home management energy system. Section III depicts the system model and problem formulation. Some illustrative cases are analyzed in Section IV with simulation results and discussions. The paper is concluded in Section V

II. HOME ENERGY MANAGEMENT SYSTEM

Typically, Demand Response is executed in residential sector more easily than industry and commercial sector with the concern of sensitivity of electricity prices among the residential users as for appliance shift able can be done with the knowledge of DR programs with incentive and other basic concerns. On this concern to realize the dynamic of the proposed algorithm , DR system is needed with smart meters installed in residential homes with the Home energy management system(HEMS).The Fig. 2 depicts HEMS where the electricity price signal and the energy demand are exchanging with this aspect using smart meter and energy scheduler embedded within to automatically coordinate with all the appliances in order to satisfy user's comfort .The embedded controller in smart meter at each home is to control the operation and time of each appliance. The Demand Response algorithm runs inside the embedded controller generating load signals communication with the appliance resulting to optimal energy consumption schedule.

The need of proper communication interface between is very much required for the proposed approach in a smart grid environment. Communications are very much critical for the accuracy and optimal pattern of demand response and for the complete performance of the smart grid. Many cutting edge communication technologies have been used for the interface options between the utility and the user. Different technologies like Zigbee, wireless LAN, Lon works can be implemented on a real practice scheduling.

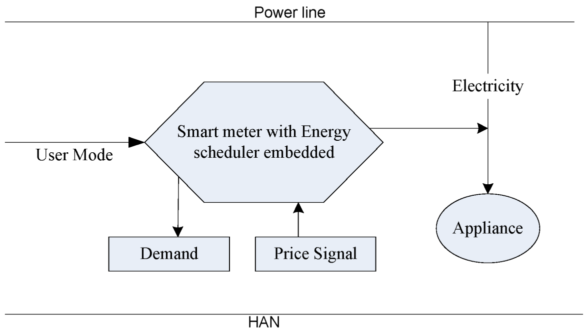

Fig. 2. Illustrative of Home energy Management System

As the smart meter works as a controller which coordinates with all the appliances depending on the user's comfort and need .Depending on the energy consumption schedule after the demand response the controller send necessary signals to the operating modes.

III. SYSTEM MODEL AND OPTIMIZATION

The demand response algorithm is formulated in regard with the interaction between the users and the utility where the behavior and decisions is mathematically model with an optimization problem. To minimize the cost is the objective function at the consumer side wherein maximizing the profit on the power utility side which exists two top down methodology. The constraint levels are decided based on realistic load models subject to operating pattern of different appliances with the users comfort, climatic conditions and energy usage needed for an optimal energy scheduling.

DR algorithm proposed in this work implements the use of time differentiated prices with the emphasis of optimal schedule of loads in accordance to market price data. The algorithm is structured depending upon the appliance scheduling of loads with a strategy. The classification of loads is done based on controllable loads and critical loads. As the critical loads, when controlled like refrigerators, freezers may affect the consumer's life pattern, whereas controllable loads like HVAC, water heaters, Washing machines can be controlled according to the consumers need. These loads can be shifted according to user's need, if the user adapts according to the lifestyle the washing machine loads can be shifted to non peak hours from 2-3pm. Similarly the other loads can be shifted from peak hours to non peak hours. Similarly the appliances like refrigerators which are critical loads cannot be controlled as the operation periods are fixed over time. Sometime shiftable appliances like water pumps, water heaters can be used any time of the day depending upon the need of the consumers. This paper holds the optimization of all the appliances for scheduling considering actual market data.

The tasks of the appliances are indeed classified into interruptible and non interruptible tasks, where the tasks performed by the appliances are done by stochastic programming technique with actual market price data collected from IEX. Table 1 shows appliances schedule.

TABLE I. APPLIANCES SCHEDULING

Shiftable Appliances	Non Shiftable Appliances
HVAC, PHEV	Refrigerators
Water heaters, Water Pumps	Freezers
Cloth dryers	Lighting loads
Vaccum Cleaner, Washing Machine	Other Plug in Loads

A. Problem formulation

The operation of the household appliances has to be managed so that the total cost is reduced as smart meters fixed at each home. The proposed approach is done using stochastic approach where there is tradeoff between the utility and the user. Let us consider residential users with set of appliances and the time slot is divided for a day scale. Each appliance which is shiftable like water heaters have a particular pattern for energy consumption pattern for minimizes the cost.

This algorithm is operated in a two stage stochastic process with the target of maximizing the profit and minimizing the cost. Fig. 3 depicts the scheduling process in two stage scenario

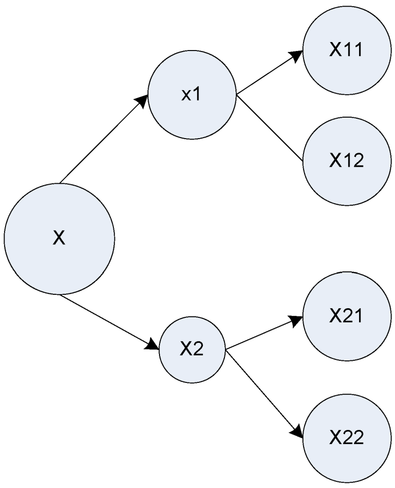

Fig. 3. Scheduling Process in two stage

The objective function is to schedule the appliances for reducing the peak demand to customers depending on demand. The two stage process is done with first time slot of the appliance scheduling and takes a particular pattern which rolls down in the second stage. There is a probability density function which exists with all the consumers following their energy consumption pattern of the appliances under the utility market provider. The function is denoted as $\sum_{k=1} \mu^k = 1$. The Fig. 4 shows the two task types involved for the optimization where the appliances taken for consideration is 15 appliances and they are separated according to deferrable and non deferrable tasks. The Non deferrable means that the operation task cannot be stopped until it is finished and they should be started at a fixed time slot.

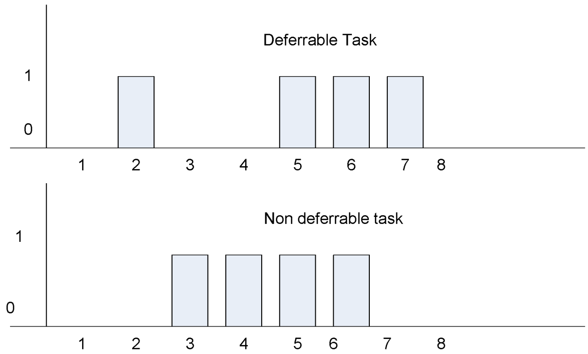

Fig. 4. Residential Appliances – Tasks Scheduling Pattern

The objective function of minimizing the cost with the scheduling vector and the corresponding load is calculated for 24 hours. Constraints and the proposed optimization problem for actual market price data. The decision of choosing the desired pattern is done in 2 steps as time slots with the dependency of earlier decision coordinate value with the target of optimal schedule for each consumers.

$$\min \; C^T L + \int a(r) b(r) c(r) d(r) \tag{1}$$

x(T+1)= f(x,u,w), where the function denotes consumers x with the utility function u and w denotes the scheduling pattern

a(r), b(r), c(r), d(r) where r denotes the random event of scheduling appliances depending upon the consumer and a(r)gives their probability function with successive stages are b(r) for scheduling the pattern.

Subject to AX=B

$$\begin{gathered} T(\mathrm{r})\,\mathrm{L} + \mathrm{W(r)\,c(w) = H(w)} \\ x \geq 0, y \geq 0 \end{gathered} \tag{2}$$

Where w denotes the finite number of discrete values by the users $w_i = \{w_i^1 \ldots . w_i^n\}$. Using Bellman function the scheduling is calculated where each appliances is scheduled giving each vector to reduce the pattern .The time constraint are given as the goal to find the best optimized energy schedule for performing their tasks in two different stages. Probability of the appliances is the possibilities which are done with Bellman function.

$$S_i(\mathrm{L}_i) = \min \sum_{k=1}^{r} P_i^k [L_i(x_i, u_i, w_i) + \mathrm{L}_{i+1}(f_i(x_i, u_i, \mathrm{w}_i))] \quad (3)$$

The above stated optimization problem uses the optimization task in which the scheduling vectors of the time shiftable appliances are been done and the process is done in Mat lab and Java programming for better results.

IV. RESULTS AND DISCUSSION

The simulations are carried out in JAVA programming and MATLAB to bring in the effect of the proposed idea mainly involving dynamic pricing schemes. The final target is to flatten the load profile and improve them for the residential consumer. The set of appliances of scheduled task and non-scheduled task are been separated and the optimization is carried. The time slot is divided for a day period; hence the slot is the given process of scheduling time of each appliance with a start and end time. In the case of non interruptible and deferrable tasks like washing machine and dish washer , as these are loads since the tasks period can be changed from high prices time to low price time.

The constraint concerned here is that as this task starts, the scheduling is carried out without any interruptions. The task with the air conditioner follows the function of possibilities from Bellman function as such the consumer's comfortableness is considered. The task carries the fact when the indoor temperature reaches the maximum value, the AC should be operated and the cooling zone is operated unless it reaches the specified one.

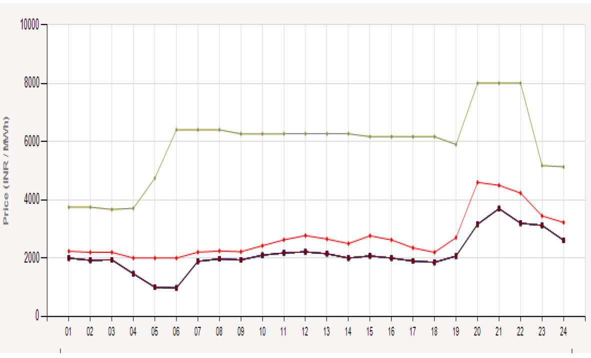

Fig. 5. Market Price data [15]

The tasks are given as discrete values from eqn (1) as the w sets the each users schedule procedure and the task is involved with the successive stages of them to reach the optimal value. For the cost vector C, pricing schemes like flat pricing, TOU pricing are considered according to the actual market price. The price trend is obtained from IEX given in Fig. 5 used for the mathematical optimization.

The results have been obtained using the pricing schemes using dynamic programming and scheduling vectors of the entire appliance are obtained. As for washing machine, the user preference starts with a time slot for first hour of operation it takes 1 kW and for second hour goes to 0.5kW as in a day schedule. Similarly the operating pattern of appliances is considered.

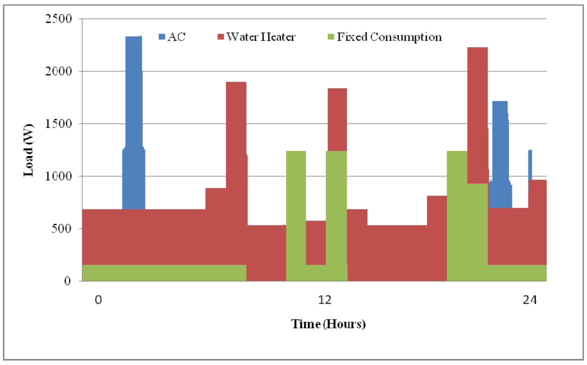

Fig. 6. Appliance load profile for different pricing scheme

Each combined profiles for each customer considered is done in analysis for both the pricing scheme. When considered the load profile the shifting is done from the peak time between 11pm - 2pm, the load sheds from 2kW to 1.5 kW. Thereby using dynamic pricing schemes the cost for each consumer is subsequent decreasing from 5% in hourly pricing with TOU pricing. The Fig. 6 depict the scheduling of appliances output based on flat pricing .It is understood from the graph that there can been continuous consumptions on the entire day. In regard to the pricing scheme there is difference among the consumers in scheduling starting from deferrable and non deferrable tasks. Fig. 7. Exhibits the load profile consumption with TOU pricing schemes.

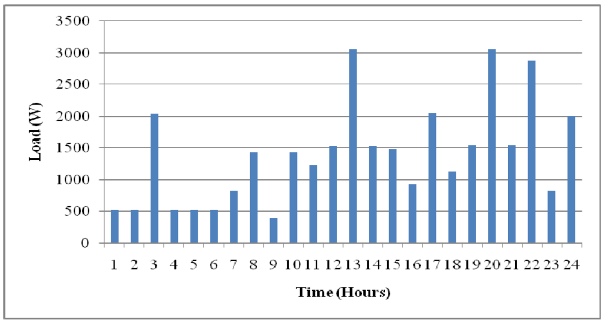

Fig. 7. Load profile consumption with TOU pricing scheme

Considering the first consumer the major demand obtained can be from the morning period, so the proposed optimization is involved so that the peak demand comes down around 3kW as shown in Fig. 8. Thus the stochastic aspects are introduced in programming to model a DR structure which involves uncertainty as probability function. There are integer variables considered for scheduling the appliances with S_i (t) as time varying parameters in DR.

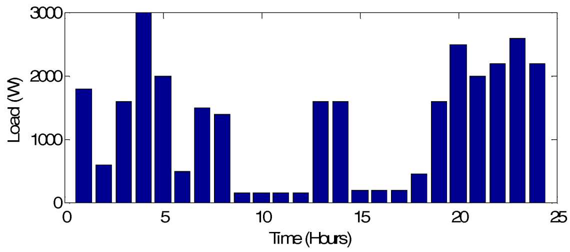

Fig. 8. Load Profile with normal consumption pattern

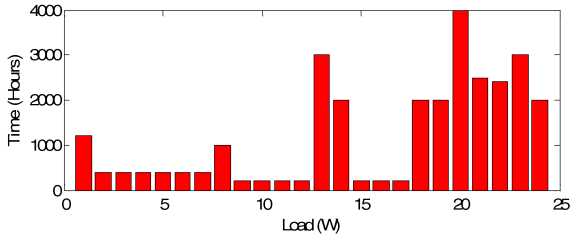

Fig. 9. Load Profile after DR

The results obtained from Fig. 8, Fig 9 exhibits the load profiles of the consumers analyzed in a middle class family and the operation characteristic. In Fig. 10 shows the combined load profiles of the user with and without DR. The algorithm with the pricing schemes is evaluated randomly for 10 houses with constraints of 143 appliances and all appliances are the same in all family. The comparison of the user profile is demonstrated in Fig.10. As dynamic pricing scheme is involved, there can be found from the results the peak demand is reduced. Consequently the cost is reduced during this period. Further from the utility provider side, maximization of profit is important, so the peak to average ratio have to be decreased in 0.5%. operation data for various appliances were given in Table 2.

TABLE II. OPERATION DATA OF HOME APPLIANCES

	Microwave oven	Dishwasher	Water heater
Minimum energy usage (kWh)	3.8	0.6/1.28	3.0
Running slot (2-stage)	12	3/12	4.0
Power level	0.8	0.59/0.75	4.5 - 6.2

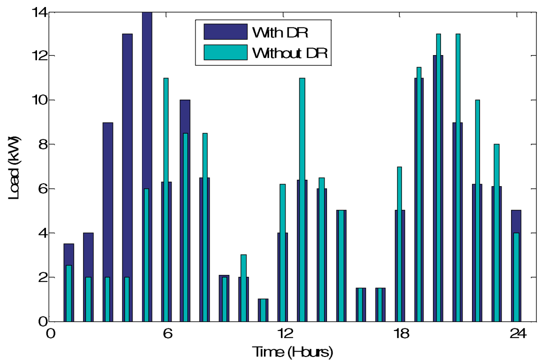

Fig. 10. Combination of Load Profiles

In Fig.11 the comparison of average load for the different pricing schemes like flat pricing, hourly pricing and TOU pricing with the respect of appliance scheduling done with respect to the dynamic programming. Here as per the Table 3, the operation task of the appliances and the running slot which is done from running time to ending time is scheduled. To an average basis the loads are been shifted in the evening with high prices and less prices at night time. The Load patterns changes from the appliances scheduling in to different task pattern as integer variables. There is reduction of load pattern with demand response algorithm which gives a varied cost difference of the user 3 savings are the maximum. Ten users are considered for simulation and checked for the algorithm, the first three users where better results are been tabulated.

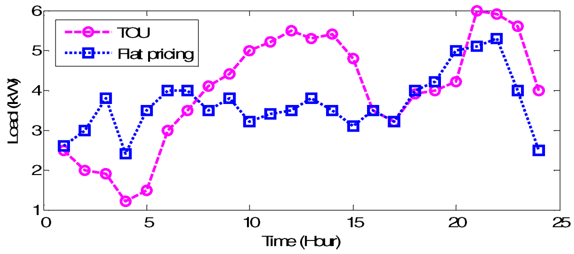

Fig. 11. Comparison of average load for the different pricing scheme with respect to appliances

TABLE III. RESULT OUTCOME FOR THE CONSIDERED USER AS EXAMPLE

Scheme	User 1	User 2	User3
TOU Pricing	75.6	67.5	81.2
Hourly Pricing	68.5	75.2	80.9
Savings calculated	124	113	224

The benefits of utility with this approach are analyzed where the case is analyzed in two level approaches for the utility and the user. The user top module is to reduce the cost by changing the scheduling pattern developing a proper route of exhibiting a probability density function for the schedule. The utility maximizes the profit by reducing the peak to average ratio with the comparison of the pricing scheme. The PAR ratio is reduced at 0.5% level and the peak load reduction from 6-9pm is reduced to about 11.4kW form 12.8kW as there is considerable saving. The analysis can be moved on to set of users or can be extended to depending on the class of family to flatten the overall load profile.

V. CONCLUSION

In order to match the potential benefits and bring the demand side consumers to actively participate in DR schemes is needed in a smart grid paradigm. This paper focus on demand response algorithm with mathematical programming in Java and MATLAB for scheduling of appliances in house hold sector depending on Indian market prices. Seven domestic appliances are studied as they are evaluated based on stochastic characteristic in two stage process. Results shows that the minimization of cost is done among the set of consumers showing dynamic pricing schemes which helps to develop a flatten load profile. The user priorities are considered in this case to show the approach can reduce higher computational burden and allow the users to develop their own consumption patterns. Future work can be carried out using different dynamic optimization approaches to reduce the cost.

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