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A Novel Approach of Demand Side Management Framework for Residential Consumers in Smart Grid

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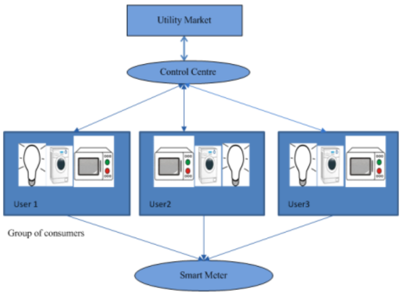
Graphical abstract



Abstract

In this paper, Demand Side Management scheme in a smart grid environment is proposed as a feature of reducing the peak demand for residential users and maximizing the profit for the utility. A smart grid scenario is considered for detailed analysis. Non-cooperative game theory approaches are generalized in this methodology for solving two dynamic conditions such as reducing peak demand and maximize the utility profit with respect to the users comfort. In this work a new strategy is developed among the various users for scheduling of appliances autonomously. Extensive simulations are carried out using actual load profiles and obtained results demonstrates reduction in Peak to average ratio. In addition the proposed system is analyzed by considering the changes in climatic conditions of summer and winter for a particular region.

Keywords: Demand Response, smart grid, PAR, peak demand

1.0 INTRODUCTION

Over the past 100 years, electrical engineering has been in the limelight in most of the possible areas i.e., from the invention of lighting in a room to the modern advancements in the field. The present grid is modernized in last few years after the involvement of effective communication and information technology with the by considering users participation in a more intelligent way. The need of modernization in the electric grid has become a necessity as the power industry is facing many convoluted issues with respect to environment, global warming and also the utility user management. The change in the electric grid has become a mandate to lead the future to a reliable and intelligent smart grid rectifying the disadvantages in the present grid system.

To understand the analysis of the smart grid venture, it is important to plan and monitor the utility activities to influence the use of electricity by the net user which is a more challenging issue in a residential environment. The important parameter of Demand Side Management (DSM) is Demand side program (DR) or shifting of loads and the energy efficiency presented by Palensky [1] and Strbac [2]. The DR exhibits the load management of the consumer loads depending on the situations of the supply from the utility provider. Thereby these techniques or programs are successfully incorporated to meet the situations of shifting the load from peak to non-peak hours and providing incentives to the users, with respect to the shifting programs.

An adequate use of energy is more critical than production in view of the smart meters, using of less cost sensors, usage of smart appliances like smart thermostat and interaction between customers and electricity provider. In this way, a standout amongst the most achievable solutions for every problem of these issues incorporates the DSM strategy. Existing DR schemes cutback the power consumption by mightily shutting down the user loads or changing the buyers with high usage costs amid peak hours without considering their solace level. It refers to consider load declinement during times of system need, for example at high market cost. As indicated in the literature there are numerous demand side management schemes which are particular and are not appropriate generally to practical systems that have independent devices discussed by Logenthiran [3]. Figure 1 depicts the load management system architecture in a smart grid environment. It performs the vital role of communication and control analysis between electricity provider and the user.

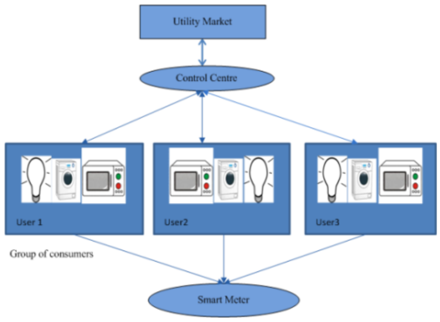


Figure 1 Block diagram of the processes of the system

The smart meter is a basic component in the system as the meter connects the interface with the consumers own power consumption plan. Thereby the arrangement of scheduling information by analysis of power consumption pattern of all appliances in the household for better home management system. The DR technique intends to balance between load and generation, through an advantageous shaping of energy utilization in some particular time periods; which are critical in regard to the point of preference to be with economic advantages. The utilization of energy is done in a effective way by considering time scheduling or load shedding. In paper [4] there is different techniques handled and to show the effectiveness of demand side management and construction of new power plants. Fundamentally discarding new plants removes anthropogenic green gases emission.

The authors in [5] have presented an overview of applying game theory in three developing areas such as demand-side management, micro grid systems and communications, and also discussed on application of game theory in smart grid system. A structure of dynamic games used to model the demand side management and double layer optimization is developed by considering house hold appliances at lower level and at second level dynamic game is implemented in [6].

In [8], the authors proposed a linear model for optimizing the cost of system peak load reduction through direct load control. The authors in [10] implemented a simulation model that can generate load profiles under flat tariff. In [11], the authors presented a novel demand side management technique to reduce the peak load of the system by considering a smart power system. The potential for DSM to limit the requirement for curtailment and hence facilitate the integration of renewable energy has been presented in [12]. In [14] authors have worked on the impacts of TOU tariffs for residential users from the Province of Trento in Northern Italy in terms of changes in electricity demand. Even though the authors have worked on DSM with various approaches but they may failed by considering changes in climatic conditions.

By considering above facts in mind in this paper authors focused on a game theory algorithm as a new analysis in demand response modeling exhibiting two important issues such as reduction of Peak to average ratio and maximizing profit and it evaluated with climatic changes. The system implementation is done by using MATLAB software and the obtained results are presented. The validation is done by comparing the results in different climatic conditions considered on a particular region. Algorithm results elaborate the performance analysis made in three consumers in a locality interacting with their utility for reduction of the cost. The analysis develops a proper working assumption of load scheduling appliances in a residential environment. The proposed technique compares the result effectively with different case studies and proves the effectiveness of the proposed algorithm.

2.0 METHODOLOGY

In the proposed system model, a load management based algorithm is created based on game theories, which mainly focuses on energy consumption scheduling of devices in a decentralized system. To develop the model, a smart residential environment is created in which a generator is connected to the utility side and from there it is shared between many consumers in a certain locality. Regarding time constraints it is divided into equal time period for per day calculation for simple analysis.

Proposed system is modeled with the concept of game theory approach of dominant Tit for Tat game. By analyzing the model, the load profile with an intelligent module from the utility sends a signal to the user in regard to reduce considerably the user's demand. On receiving the signal from the utility provider, the customer moves on to a management policy which upholds a function benefits for some incentives for reduction and give a decision. A positive response exhibits to the present condition of the utility and vice versa, the model has to be activated again in regard to other consumer to give a request and Figure 2 represents a clear venture on DR module.

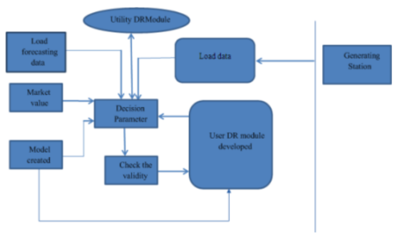


Figure 2 Demand Response Structure

The energy scheduling of appliances has been modeled in a game theory based decision making approach. Game theory is an approach of building in strategic decision making depending upon the circumstances handled. The strategy overruled here in this game is the Tit for Tat dominant Game. The players are the consumers in a smart grid framework where smart meters are developed in every consumer in the locality. The aim of this model is mainly to increase the profit of the utility provider by properly handling the energy consumption of the users and finally to reduce the cost with minimization of Peak to Average Ratio (PAR).

The proposed game shifts the loads from the users in accordance to the usage of their appliances. This develops a variety of energy consumption schedules, which normally comprises to the set of strategy handled by each player in scheduling their appliance in the household. Further the target of each consumer is to maximize their payoff. The modeling of payoff function in regard to the user pays for their energy consumed and also considering the comfort. As in this approach of game, the assumption of energy price primarily depends on two major binding factors: The energy cost adapted by the electricity provider and the number of appliances scheduled in a day using the total energy given in the particular time slot.

The model is adapted with the game concept denoting a set of players N = {1, 2, 3…n} in which N is the total number of players denoting the set of consumers in a locality with a utility provider. Each player in this game exhibits their own strategy S in order to adapt the best consumption of energy by scheduling the appliances in order to manage the loads from peak hours to non-peak hours probably in the morning hours and developing a steady model. It also maximizes their payoff from the schedules adapted. Peak to average ratio (PAR) is reduced with which the ratio of the maximum and average power consumption should be calculated for every user at a particular time. The objective function is given as:

Minimize Cost function $C_a^T L(X_{ah})$

Subject to $$\sum_{h=1}^{24} X_{a,h} = Load$$

$$\sum_{a \in A} X_{a,h} = L_{Hourly} < u_{Hourly}$$

where C_a= cost vector, L= Hourly load for 24 hours

$$Minimize\ PAR = \frac{\sum_{n=1}^{N} \max(X_{loadprofile-eachuser})}{\sum_{n=1}^{N} (X_{loadprofile-eachuser})1/T} \quad (1)$$

Further to develop the game model, an energy consumption scheduling vector is assigned as

$b^i = [b_1^i, b_2^i \ldots .b_h^i]$ where $b_h^i = \begin{Bmatrix} 1, timeslot \\ 0, otherwise \end{Bmatrix}$

= Total energy consumed by each user with the appliance scheduling in the time slot as it is separated for a day schedule.

s_i = {1,2,3….s} where S_i individual actions. The generalized tit for tat dominant game is involved in this framework in a repeated manner at a stage time *t*, where the player *'i'* adapts particular energy consumption schedule represented as S_t^i. The utility pay off function for the user is denoted as $U_t^i = u_i(strategy)$ Reaching the Nash equilibrium stage is obtaining the state when all the players participate in the Demand Response Strategy game and receiving the payoff function after scheduling their appliances to reduce the cost, maximize the profit of the utility. The equilibrium stage is a solution of any non cooperative game knowing the equilibrium strategies of each player with different strategy in hold with them and any of the players have anything to obtain by changing their own strategy. In the proposed game, the strategy handled by them is a scheduling of appliances in a day from changing the peak hours to non-peak hours to reduce the DR.

The final equilibrium stage is obtained with the below given payoff function

$$u_i(s_i^*, \vec{s}_{-i}^{\,*}) > u_i(s_i, \vec{s}_{-i}^{\,*}), \forall s_i \in S_i \quad (2)$$

The main advantage of this game is that each consumer in the smart grid framework has to observe their actions of scheduling and reduction of cost by the concept of dominant one and winning strategy. The strategies involved by other players are kept unknown to others and never exchanged with other schemes. As a result, privacy of players is ensured. The algorithm model is explained in section III and results obtained with different case studies are discussed in section IV.

3.0 ALGORITHM MODEL

Consider the case of three users and the algorithm can be extended to 100 users in a locality and scheduling of 15 appliances in residential consumers where the smart meters are installed and interaction between the utility provider and user is done. The implementation of algorithm is explained in the following steps.

- Let the maximum demand of three users considered as demand of three users. C_a is the maximum demand of three users in the proposed case
- For the whole day consumption, for each user PAR is obtained at each hour.
- Energy consumption scheduling vector is defined as $x_{n,a} = [x_{n,a}^1, \ldots .x_{n,a}^H]$
- Load of each user = $\sum_{a \in A} x_{n,a}^h$ where h=24 hours
- Minimum load usage hours of each house is calculated
- For each particular hour, total demand 'L' calculated by adding three customers value

for that house so total demand found for first case for three users split for first four hours in a day

- L_{max} is found as maximum demand value and arrangement of load in ascending order with respect to demand hours
- *The load* profile is created as adding load of 3 consumers and obtaining PAR, sampling up to 10 houses. Determine the time for which the value of the load profile which gives minimum power usage.
- Rescheduling the appliance vector in a matrix array for 3 houses and with time slot.
- Based on the appliances , determine the total number of appliances where the load is shifted from the peak hours and it can be divided among the three houses
- The developed array gives the random shifting of load for first 8 hours in a day as a random way is generated with ones and zeroes , where the once denotes the shifted hour so as such for each customer the array is produced
- Updating the appliance array based on the minimum hours array created and the obtained vector determines the users strategy and further the new appliance array is obtained by shift able hours to minimum array found in limited demand hours
- Obtain the total tariff for each consumer and deciding the winning strategy for each user as in the game played by the user. The strategy among all the users are obtained and the winning strategy is obtained by comparing the vector with presented in [1] utility function to reach final Nash equilibrium stage
- Arranging the demand hours in ascending order for each users and updating array based on minimum hour's array is obtained. The winning strategy is obtained as the final dominant vector and every iteration the new winning strategy is established with the obtained vector if the latter dominates and the process continues.
- At the end of the consumer iteration of the algorithm, individual tariff for each consumer is evaluated creating a dominant game.

4.0 RESULTS AND DISCUSSIONS

The different case studies is been analyzed considering a normal day schedule where the algorithm works in a smart grid environment. The dual understanding of the utility and the user with the game strategy process is made vital by the results obtained.

Case 1: In this case study the results obtained in Figure 3 represents the energy consumed by each user for a day, where the peak hours are to be shifted to non-peak hours depending on PAR value by developing the individual tariff.

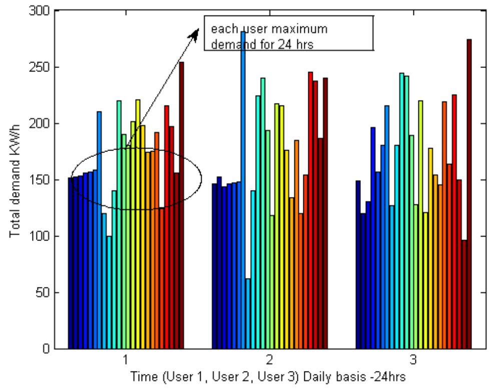


Figure 3 Energy consumed by 3 users for per day analysis

Henceforth shifting the loads happens to the non-peak hours leads to congestion. This develops DR programs in perplex situation. The algorithm rectifies and upholds by considering this situation, where the concept of winning strategy exhibits and they stay in the first position and hence take up the first order, where the non-peak hours are relaxed. The Figure 4 presents the expected results among three users and the winning user occupies the first position in ascending order and develops individual tariff. This shows there is change in the demand and reduction in cost. This idea can be done for multiuser commodity.

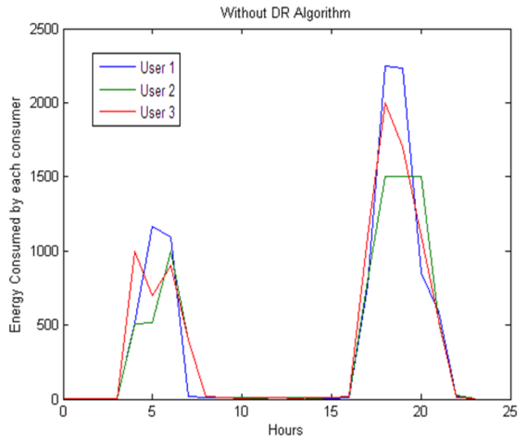


Figure 4 Energy consumed by three users in a locality without the game strategy

The shifting of load in a day is calculated by each user depending on balancing the load with shift able and nonshiftable loads. Each user follows a strategy to manage the load schedule accordingly. For example depending on a middle class working family, usage of a washing machine can be done in late evening hours. Time-shift able appliances exhibits fixed power consumption pattern which is ineffective. At instance consider a water pump which needs to be run in a day for every twelve hours. The actions here ensure that the total power consumed by the appliance is needed for requirement. The scheduling can change for every one hour from 1.5 kW, 2.5 kW for next hour and rest for other duration in a day. As such depending upon their needs, the consumers schedule the device. Some of the appliances used for the scheduling considered are elaborated. Table 1 shows the power consumption in hourly basis. Ratings of the appliances considered in Table 1 are given below.

- Washing machine: 600W/h (shiftable load, duration 1 hour)
- Microwave Oven: 1000 W/h (shiftable load, duration 1 hour)
- Air Conditioner: 1500 W/h (shiftable load, using duration 1 hour)
- Electric Car: 20 kWh (shiftable load, maximum power 4kW, using duration 5 hours)
- Nonshiftable loads (television, lights, computer, etc.): 6 kWh

Table 1 Power consumption by hourly basis

Appliance	Per hour consumption of appliance considered (kW)		
	1st hr	2nd hr	3rd hr
Washing Machine	0.5	0.6	
Microwave Oven	1.5	1.8	
Iron	1.0	-	-
Fan	0.25	0.25	0.25
Coffeemaker	0.8	-	-
Dishwasher	0.9	-	-
Dryer	1.5	-	-

In the Table 2, considers the case of normal working day in a locality of residential consumers with scheduling of 15 appliances and there is a cost reduction and the PAR value is minimized considerably. As such to show the vitality of the new algorithm proposed of the winning dominant game, different case studies have analyzed in a seasonal basis to minimize cost among them. Figure 5 presents the change in shifting of load using the algorithm implementation. Further in the analysis of normal case study, at the peak time considerable amount of load is shifted in user 1 and they are equally balanced throughout the day, so that the tariff is reduced without affecting the comfort level of the users.

Table 2 Benefits obtained for utility and user

Implementation type	Peak load		PAR	Cost(Rs)
	10pm-2pm	6pm-9pm		
Without DR algorithm	11.5kw	18.3kw	1.5	250
With DR algorithm	8.5kw	13.5kw	0.95	225

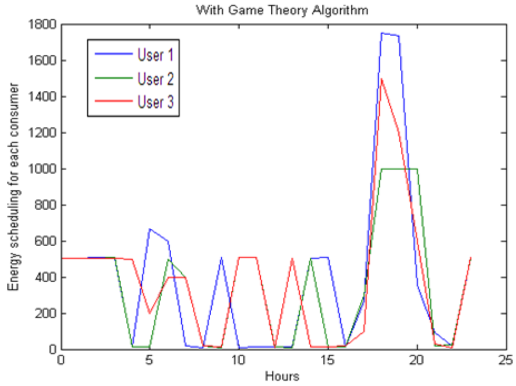


Figure 5 Three users profile with the Game theory Strategy

Case 2: The graph below illustrates the load seasonal data on a typical summer and winter day in India, and the data is exhibited from the survey analysis made in Gujarat load survey paper [7]. The case considered depending on climatic conditions in India, where the scheduling of appliances have been developed as the energy consumed by the end users. Figure 6 represents the model case of load profile on summer and winter in India for the working of the algorithm.

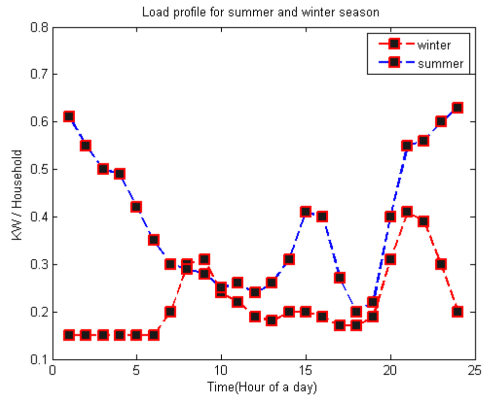


Figure 6 Load Profile –seasonal data in a household

Figure 7 and Figure 8 pictorially exhibits, according to the given load profile, the individual loads are calculated and tariff is generated.

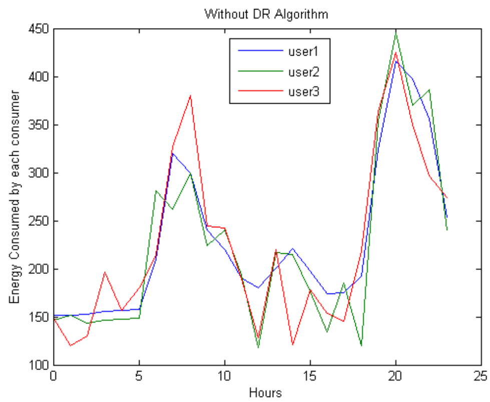


Figure 7 Seasonal analysis of the load profile – Without DR algorithm

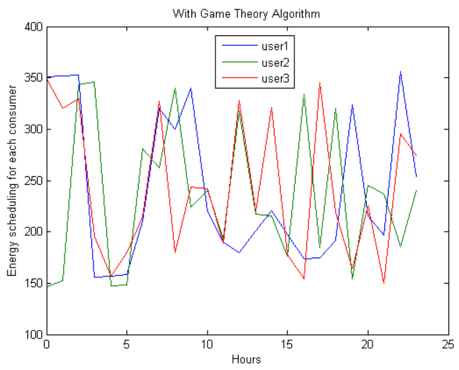


Figure 8 Seasonal analysis of the load profile for three users – Without DR algorithm

The results exhibits how the change of load happens in these conditions also improving the vulnerability of the algorithm in different case studies made. Thereby this algorithm tends to help the users to play in a safe environment without the concept of cheating another one. Since the energy consumed in the results obtained, vividly explains that the shifting of the loads is done depending upon the winning strategy played and also the congestion problem is addressed. The algorithm fits in for all situations and improves the cost. The load profiles obtained from the seasonal data exhibits the peak load period as the rating comes down considerably and it is insignificant in the beginning hours of the day when the net load demand is very low. There is considerable reduction in PAR as shifting the loads and net saving per month in a household is obtained. For the second consumer also the major demand occurring in the night period the peak load is shifted and reduced. Further in the analysis, the normal case study at the peak time, considerable amount of load is shifted in user 1 and they are equally balanced throughout the day, so that the tariff is reduced without affecting the comfort level of the users.

The simulation result in the two cases observes that the demand side management is an advantage to both consumers and utility. In the case studies made, the users have arrived at cost savings to 10% and the utility also have a good saving. The studies are some isolated examples considering the load profile in a winter season usage of certain devices like air conditioner are never used rather at upper class family room heaters are used and the situations are changed. They handle the cases of different strategy applied for smart grid operation. The further analysis of the problem is the controlling of the load, their pattern, with power consumption at each time slot. The computation time is less considered in all cases which is carried out in 24 hour duration. The algorithm of dominant game strategy provides good results with real time load profile data considered in a region.

The proposed strategy obtains good results, with the consideration of day ahead demand side management strategy of load shifting, load curtailment depending upon the climatic conditions and the user daily profile. The nature of DSM problem develops on a distributed area in which intelligence is built in the algorithm by interacting with the user and the utility. The number of units of scheduling the load is needed on the effect of local peak reduction reaching the final equilibrium. The users can sell the energy back to the electrical grid at the peak time in a day. The analysis is carried out on residential load management, similar models can be moved on to an aggregate load profile by creating aggregators in an industrial region. Extending the analysis of the algorithm to bigger group of residential consumers will lead to more successful results of flattening the overall load profile with reduction of the cost without the comfort of the users are not affected.

5.0 CONCLUSION

This paper presented a demand side management strategy exhibiting a new algorithm of game theory as dominant game based energy scheduler to achieve reduction in peak demand and maximize the profit. In addition to that home appliance of each user is scheduled with Nash equilibrium strategy with the help of simulations considering different cases of climatic conditions in a region as a real time data. The simulation demonstrated that the proposed algorithm achieves good savings for the user by reducing the peak load demand.

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