

**GreenNet: Agent based Game-Theoretic Domestic Cost Optimization Techniques for Smart Grid**Ayesha Afzaal<sup>1</sup> and Mohsin Nazir<sup>2</sup><sup>1,2</sup>  
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**Abstract:** Due to continuous increase of population, this century the old system unfortunately suffers from many problems i-e limited production of electricity, while demand is going to be higher side on daily bases. To resolve this and similar other problems a quantum leap is required to connect communication via information technology. This dive towards a new efficient technology is called Smart Grid. The central vision of smart grid is the development of smart appliances that will allow autonomous software agents, working as consumers to optimize the use of smart devices while interacting with agents at grid. Overall electricity consumption increased, resulted to increase the amount of electricity bills. Then we need efficient electricity consumption management techniques having minimum user interaction. This paper will discuss different existing methodologies used for energy optimization in smart grid and also portrays how consumer agents can reduce their electricity bills by utilizing incentives from energy suppliers. Different load prediction and game theoretic methodologies for energy management system are also discussed; at the end a novel smart home framework is proposed, which can automate the smart home by considering the energy optimization techniques. The stated system will not only reduce the CO<sub>2</sub> emission, which is a main cause of global warming, but also reduced the cost of energy consumption for end users. [Ayesha Afzaal and Mohsin Nazir. **GreenNet: Agent based Game-Theoretic Domestic Cost Optimization Techniques for Smart Grid.** *Life Sci J* 2014;11(7s):61-67] (ISSN:1097-8135). <http://www.lifesciencesite.com>. 10

**Index Terms:** Demand response, Load prediction, Peak to average ratio, Multi agent system, Short-term load forecast.

## 1. Introduction

In past, energy flow was unidirectional with lot of problems like power comes from a centralized grid and distributed among different substations (like client server application fully dependent on server) but smart grid technology turned it into bi-directional power flow and also shifted it from top-down approach into distributed energy management system to maximize output. All these are possible by integrating information technology between point of generation and consumption of power (Robin Roche, 2010). It is possible only because of intelligent sensors (Phasor sensor system), data management system of smart grid (keeping record of energy generation and consumption), two-way communication between buyer and seller of electricity.

The proper management of all the components in smart grid is very important to get the full utilization of the system especially from the customer point of view; demand side management is an obligatory part of grid. The energy consumption model becomes smarter by advent of new smart devices; it also suffers from a more complex environment where heterogeneous devices work together to provide smart services; the need for efficient demand side management techniques with

minimum user interaction turn into reality same as human brain takes decision depends on situation; whatever he/she looks, hears and feels. By the increase of smart energy, the uses of smart appliances like smart TV, Robots doing home cleaning task etc. increased. According to market rule if the demand of any product is increased then the price of that product will also be increased, same situation existing with electricity unit price. As the flood of smart devices spread the usage of electricity is enhanced which ends up with the increase in electricity cost.

Smart grid plays a significant role in automation of power system and plenty of smart devices are introduced at domestic level to convert manual work towards computerization. With all these techniques the human exertion is reduced and less manpower is required to carry out even a massive chore but due to all this automation an enormous boost occur in electricity consumption pattern. Resulted, due to smart automation electricity demand almost increased by 70 percent if compared with last decade, while the energy resources are limited, neither momentous addition in energy resources has been seen in the past nor even in near future.

According to economic stipulation, electricity demand is much higher than supply resulted major

increase in electricity per unit cost. If the situation goes in the same way, it may be grounds to power outage or blackouts that are the worst scenario for the economy as a whole in any country. On the other hand energy production mechanism is the major cause of green house effect due to CO<sub>2</sub> emission that must be abridged. Escalating power prices plus the greenhouse consequence lead to more awareness of optimizing energy effectiveness of electricity provider. In past, many domestic energy management technologies have been proposed but all the proposed methodologies have their own distinguishing features.

The rest of the paper is organized as follows, section 2 is the state of the art of several publications in which multi-agent systems play a vital role in energy management system, section 3 profoundly explains the different domestic load prediction techniques, section 4 elucidates the role of game theory in energy management system, section 5 will discuss proposed system model in detail and we will conclude our work in section 6.

## 2. Literature Review:

Rehan Fazal in 2012 proposed the management of demand response by implementing multi-agent coordination. According to author agents are divided into grid agents, control agents and residential agents located at grid generation, power control center and residential area respectively. Agents will also accommodate micro side generation at consumption level to control demand of electricity. The proposed system will switch the load of residential agents to off peak time with the help of control agents, to overcome the overall cost of residential electricity consumption. The system will also control the load of plug-in hybrid electrical vehicles (PHEV); it will allow users to charge their PHEVs according to their battery status. It is clear from the results that by implementing the proposed system the overall load to the main grid are reduced (R.Fazal, J.Solanki, & S.Sarika, 2012). There are different types of communication protocols used by agents in smart grid (Afzaal, A, Nazir, M, 2012).

In 2011 Sarvapali, Perukrishnen et al presents the idea of decentralized demand side management controlled by agents. The loads can be divided into multiple types like wet, cold, water heating and space heating. The wet loads for example dish washer or washing machine loads can be shifted easily that's why they are called static shift-able loads (Logenthiran, Srinivasan, & Wong, 2008). The cost of shift-able loads is calculated depending on the unit price, time slot, power rating and marginal comfort cost relating to deferring the device. Second category of loads related to coldness, water heating and environment heating fall in the category of thermal loads. These loads are dependent on the environment temperature so the author calculates the cost to

maintain the temperature of the house as to make these loads stable (Ramchurn, Vytelingum, Rogers, & Jennings, 2011).

Yonghua cheng presents the philosophy of distributed power generation management. The wholesale market architecture of smart grid based on agents is proposed. There are two types of controls in smart grid based on agents and events. In agent based control market every agent will send the price vs. quantity signal to access responsible party (ARP), this pair of each agent represent the capability of electricity production and consumption at any specified time period. In this way server will get all the information related to each agents production with specified price and consumption (Phillips, Link, Smith, & Weiland, 2009). Now ARP is responsible for auction based market because of agreement between agents paired price and quantity. ARP will also deal with renewable resources but the production of renewable sources is not conformed so a tariff-based market is also required to accommodate the difference between prediction and actual generation. It is not necessary that all the loads will send quantity vs. price signal to ARP because some loads are event based for examples some load depends on the occurrence of particular event like variation in electricity price and frequency etc. (Cheng, 2012).

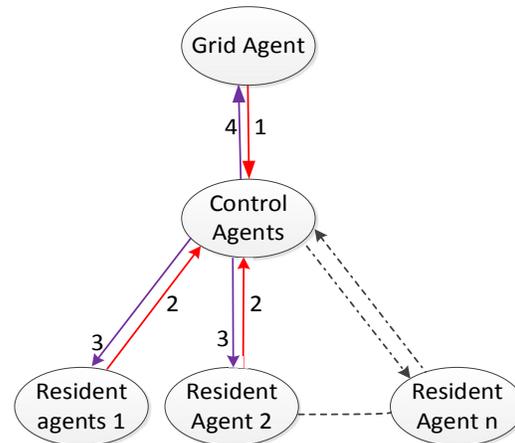


Figure 1: Different type of agents

## 3. Load Prediction in Smart Grid:

To optimize the efficiency of smart grid at domestic level Albert Molderink, Vincent Bakker et al. proposed methods for both local and global scale optimization. Local and global scale optimization deals with single and multiple homes respectively. In their proposed model every house has distributed generation (DG), distributed heat and electricity storage and distributed demand side load management controller. Distributed electricity storage will store

electricity when production of renewable resource is greater than consumption for example at night electricity generation is greater than power consumption. Load demands are of two types flexible and non-flexible and a significant benefit can be obtained by shifting only flexible demands to off peak time also explains the concept of peak shaving and virtual power plants. According to others proposed method a small-scale reduction in comfort can provide large benefits in term of reduction in electricity bills. The result shows that after implementing the proposed algorithm the heat and electricity cost of a single house is reduced (Molderink, Bakker, Bosman, Hurink,&Smit, 2009).

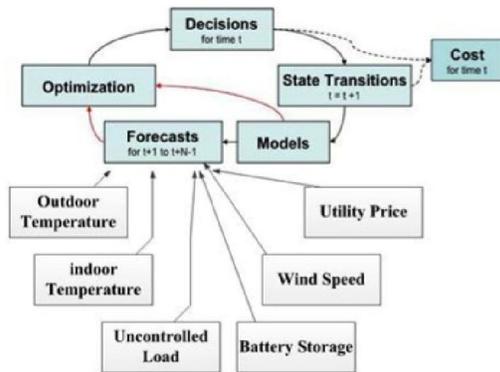


Figure 2: Load forecasting model

Micro-grids are becoming an important part of macro-grid due to their most efficient individuality like reliability, cost reduction and low carbon emission etc. Although micro-grids can disconnect themselves from the macro-grid (main grid) in case of any emergency condition and can work in island mode (Mcarthur & Funabashi, 2007). By adding another feature of storage management into a micro-grid make it more realistic. The prediction of expected load for both macro and micro-grid are very important to get maximum benefits from this infrastructure (Amjady, Keynia, & Zareipour, 2010). As the size of the micro-grid is very small as compare to main grid that's why a little bit difference in load make the instable. A case study is discussed comparing the volatility in term of time and frequency of micro-grid and two other macro-grids and it is clear from the table that micro-grids are more volatile.

The smart grid management system has two ways to control the cost of electricity for end user i.e. load shedding and load scheduling, an example of load shedding is to term off the electrical appliance if the load on the grid is monitored and load scheduling is to shift the load for other off peak time (Kantarci & Hussein, 2010). Nathan Kowahl also discussed the forecast models for optimizing the energy (Figure. 2).

According to system model there are several factors, which should be forecasts for decision-making about optimization, which includes indoor temperature, time, wind power, uncontrolled load, battery level and outdoor temperature etc.

#### 4. Game Theoretic Techniques and Smart Grid:

Real time evaluation and operation of the smart grid using game theory is precise imperative, according to present approach; utility will fix the problem when it occurs like reactive approach but the system will be more efficient when it follows proactive approach (make the solution before so that the problem will not occur). Engineering and analysis (EA) software is a powerful tool for evaluating and planning of the smart grid. EA software uses SCADA and line identifiers. Power grid is divided into segments and every segment in the power grid has a condition in the form of equipment and a state to represent corresponding values. The set containing the information of each segment of power grid in the form of matrix is called critical information set. The purpose of applying game theory is to eliminate the factor of uncertainty in the grid reliability. The proposed system uses the conditions and the corresponding state of each segment to develop decision tree that would return the power tree to equilibrium. The prisoner's dilemma can also be used with respect to condition and state players (Michael Swearingen, 2011).

Auctioning game based demand response scheduling is explained by Ding Li, Sudharman K. et al. with block processing model to minimize the utilities generation cost and delay operation cost. The centralized and static generation pattern is inefficient and costly operation for example US load pattern is almost 55 percent of which 25 percent are used less than 350 hours per year means only 4 percent of the total time. There is a need to improve the generation pattern for huge saving. According to the author the customer load demand can be decoupled as (Li, Jayaweera, & Naseri, 2011).

1. Non-Flexible: The non-flexible load demands reflects the basic energy requirements of customers, it represents the amount of electrical energy needed during each time interval of a time block.
2. Flexible: Flexible load demands can be postponed or adjusted according to supply condition.

Walid saad and Zhu han propose the idea of micro-grid management to reduce the amount of power losses during electricity transfer from macro to micro grid. According to the author any house hold or any consumer can get the electricity from multiple sources for example they can get electricity from main/ macro grid or they can get it from its own micro grid but any consumers electricity requirement is not fulfilled by its own micro grid then they can get

electricity from neighborhood micro-grid to reduce power losses during transfer of electricity as compare to macro grid (Saad, Han, Poor, & Bacsar, 2012). Power loss is a function of several factors like distance between micro-grid and substation, power transfer voltage, amount of power that is being transferred and losses during transfer from substation. Suppose for any substation  $i \in N$  is a set of micro-grids.  $P_{i,loss}$  is the power losses during power exchange between the micro-grid and substation. The total utility function of micro-grid  $i$  can be expressed as the function of power losses during power transfer.

$$U(i) = -H_i P_i^{loss} \dots\dots(1)$$

Here  $H$  is the price paid by micro-grid  $i$  per unit of

function can be expressed as

$$U(S, II) = -\{ \sum_{i \in S_s, j \in S_b} (h_i p_{ij}^{loss}) + \sum_{i \in S_s} (h_i p_i^{loss}) + \sum_{j \in S_b} (h_j p_j^{loss}) \} \dots (2)$$

$P_i^{loss}$  and  $P_j^{loss}$  are the power losses between buyer and seller of  $S$  and substation while  $P_{ij}^{loss}$  are the power losses between seller  $i$  and buyer  $j$ .  $H$  is the pricing factor, association between buyer and seller can be achieved with two techniques i.e. matching game and auction theory (Saad et al., 2012). Customer can order electricity in advance via Internet to tell the required amount of electricity as well as the time of consumption prior to consumption hour explained by

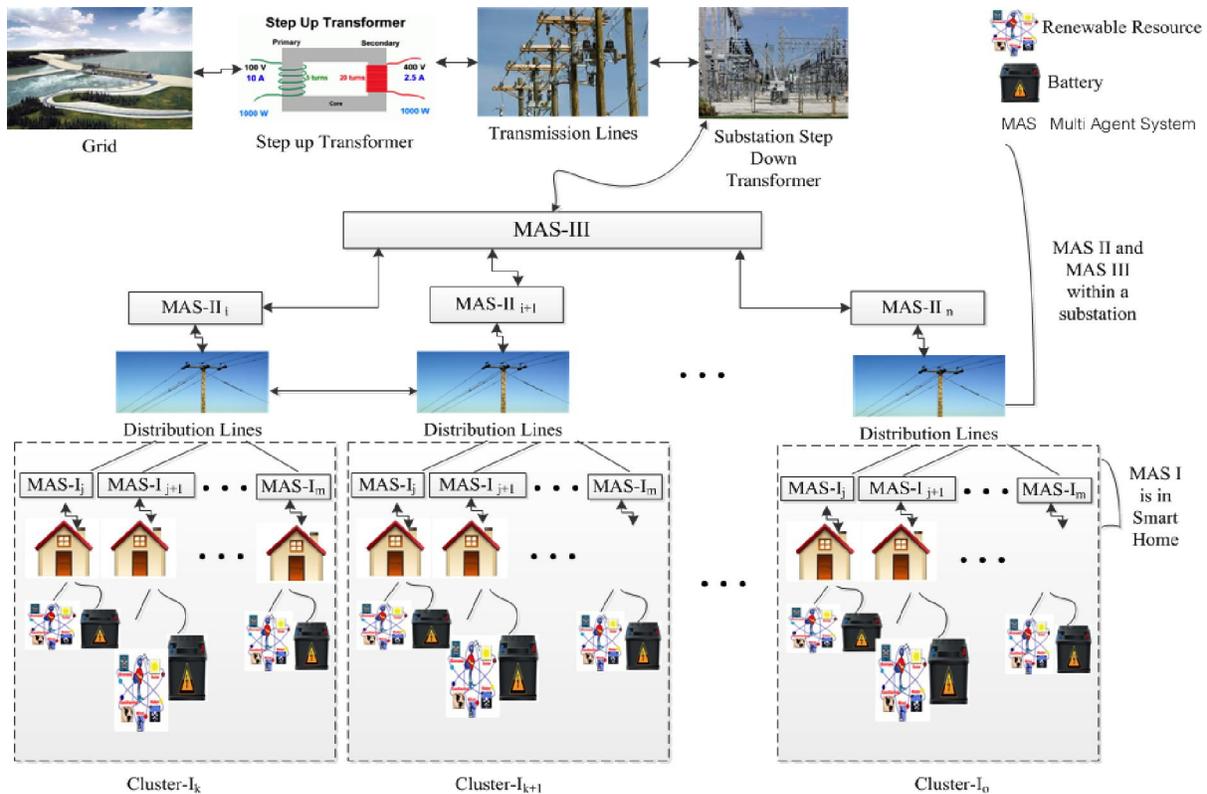


Figure 3: Proposed System Model

power loss and negative sign indicate that the utility function's objective is to minimize losses, to overcome this issue micro-grids can be divided into group of coalition micro-grids  $S$  which consist of two types of groups, buyers and seller  $S_b, S_s$  micro-grids respectively. In this situation a association between buyer and seller is required called II, now the utility function can be derived by considering other micro-grids for power source as compare to substation because the cost of energy losses is reduced when the power is obtained from the nearest resource so the

tongdan (Jin, 2010). Power generator calculates the average demand of all users to predict the load of upcoming hour in advance.

$$P_g(t) = \sum_{i=1}^n d_i(t) \dots\dots (3)$$

Where  $d_i(t)$  is the demand of customer  $i$  at time  $t$  and  $p_g(t)$  is the total required generation for  $n$  customers. Customer use On-line Purchase Electricity Now (OPEN) system for on-line purchasing of power similarly purchasing of any other on line item like e-shopping. User can demand electricity by estimating upper and lower bound of demanded electricity for any

specified time period. The two bounds are provided to power generator or any energy management system to prepare for the upcoming demand; virtual power plants can be used to full fill the demand of customer. The upper and lower bounds of upcoming demand can be calculated as

$$P_{gL}(t) = \sum_{i=1}^n d_{li}(t) \dots (4)$$

$$P_{gu}(t) = \sum_{i=1}^n d_{ui}(t) \dots (5)$$

$P_{gL}(t)$ ,  $P_{gu}(t)$  is the lower and upper estimated power generation based on  $d_{li}(t)$ ,  $d_{ui}(t)$  lower and upper bounds of estimated demand for hour  $t$ . In the same way generator of electricity also calculate the

based game by using proposed strategies, to maximize the benefits for actively participating users.

**5.1. System Model:**

The framework is divided into three layers MAS (Multi-Agent System)-I, II, and III respectively as explained in Figure. 3. MAS-I will be in smart home it can be embedded into smart meter and MAS-II and MAS-III will reside on substation. MAS at layer II will deals multiple homes called clusters but MAS at layer III will utterly control all the operations between the macro, micro grid (consist of clusters) and

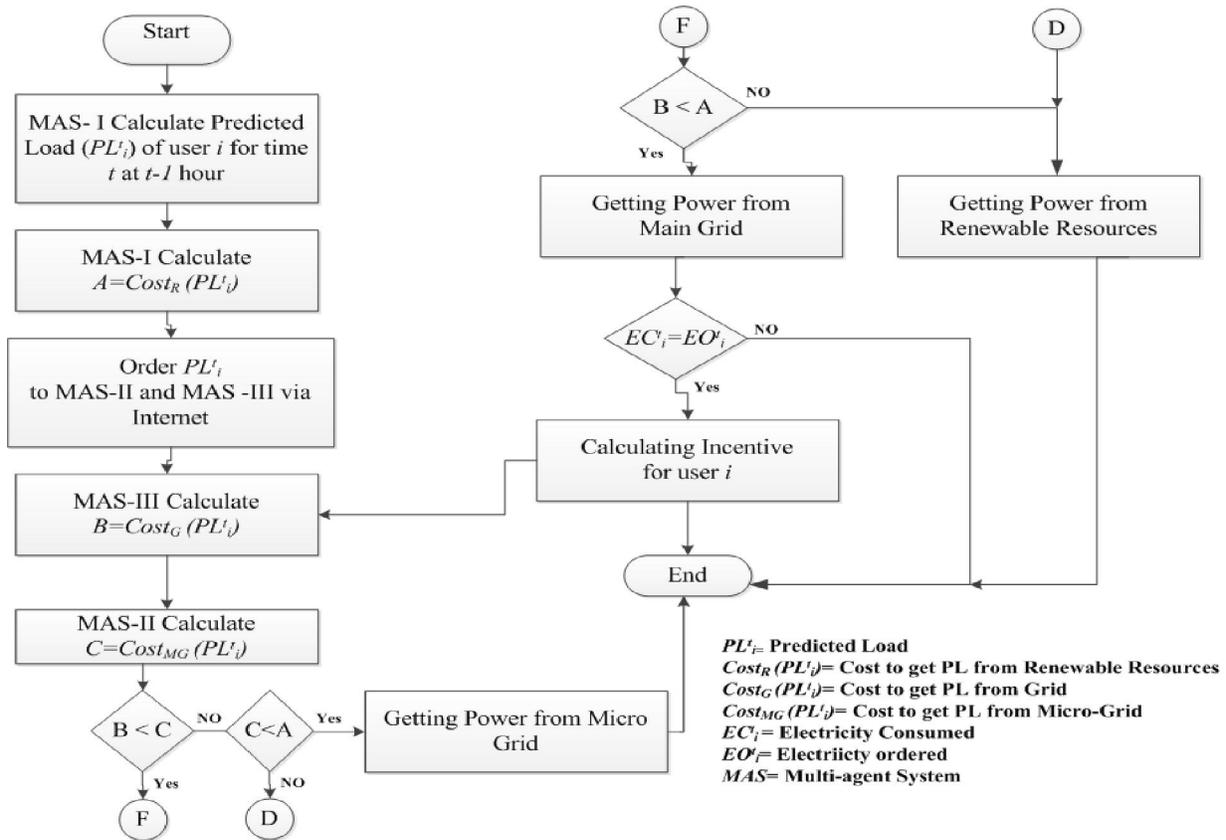


Figure 4: Flow chart of proposed model

maximum and minimum generation capacity so that they can evaluate that whether they can full fill the demand or not or they have to hire some other resource of power etc. User can also use other appropriate approaches to put order like in tabular explicitly explaining the quantity, time etc.

**5. Proposed Conceptual Model for Energy Cost Optimization:**

In the following, first of all a framework for energy cost optimization along with agent’s strategies is proposed. We then explain our envisioned incentive

even individual home. According to the flow chart shown in Figure. 4 first of all MAS-I of every individual smart home will calculate the predicted load (PL) of each smart home in a cluster  $c$  where  $c \in Z$ .  $Z$  is a set of all the clusters in any area  $A$  belongs to substation  $S$ . There are multiple load prediction methodologies, which can be used, and a new smart load prediction methodology can be used based on expert agent’s advice using weighted average prediction. In second step MAS-I will calculate the cost to produce electricity equal to  $PL'_i$  of user  $i$  for time  $t$  in  $(t - I)$  hour from renewable resources

(located in user  $i$  dwelling) means load is predicted one hour before use.

### 5.2 Flow Chart of System Model

After calculating the predicted load (PL) and the cost to produce predicted load  $C(PL_i^t)$  of user  $i$  for time interval  $t$  will be calculated. System will send the  $PL_i^t$  to MAS-II and MAS-III via Internet to order electricity in advance (to get incentive or system reliability). Multi-agent system at layer II and III will calculate the cost to get electricity from micro and macro grid respectively, while calculating the cost to produce  $PL_i^t$  from macro grid the macro grid will also consider the previous incentives of a particular user  $i$  if any. Now the system will compare all the three costs and decide the optimal source to full fill  $PL_i^t$ , in this process if the user get  $PL_i^t$  from macro grid and its ordered electricity is exactly equal to the consumed electricity then incentive will be given to that specific user  $i$  in term of cost reduction for next ordered amount of electricity. As well as the MAS-I will also consider when to store electricity from macro or micro grid to maximize their user payoff as the players at MAS-I are rational and try to maximize their own profit.

In our proposed system agents are used instead of consumers to reduce human system interaction that's why agents behave like players. There are three levels of game and in every level agents compete with each other to maximize the profit of home to which they belong, at level I of game the objective of agents is to reduce the electricity bill of individual home to which they belong regardless with cost of electricity of other neighboring home, In this way competition lies between every home agent, every agent wants to win the game by reducing the electricity consumption cost of smart home, level II of game again deal with different type of agents but here the objective function of agents is not only to reduce the electricity consumption cost of individual home instead a whole cluster behave like a single home and objective of players/ agents at this level is to collectively overcome the cost of their cluster as compare to others. Game at level III will deal with agents at different substation level and objective of every player is to reduce overall cost of substation as compare to other nearest substations.

Every smart home behave like a micro-grid (MG) controlled by micro-grid controller (MGC), each home has its own MGC and a group of agents that perform multiple task. A whole cluster acts like a bidding bot (BB), because the objective of all agents in a cluster is to maximize their profit by bidding with other cluster's agents, it is monitored by control agents (CA). Agents are divided into different types according to their functionality, all the agents are controlled by leader agent, neighboring agent is

responsible for all type of communication between neighboring homes, similarly grid agent will calculate the cost to get predicted load from main grid as well as communicate with incentive agent for inducement information of any particular user.

### 6. Conclusion:

The proper management of resources in smart grid is very important to achieve the full utilization of the system. Different load prediction techniques for smart grid are discussed. Game theory plays a vital role in smart grid energy management system; it is also useful to reduce power losses during power transfer from one resource to another.

Existing cost optimization techniques are not sufficient. New agent based energy cost optimization techniques are proposed which will not only reduce human system interaction but also develop consumer's interest in energy management system by providing them incentives.

The objective of the proposed system is to overcome the demand of electricity from main grid during peak hours by implementing agent based computational algorithms that will reduce the cost of electricity especially for those consumers who can compromise with their comfort.

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