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A Compilation of various Home Energy Management Systems in Smart Grid Networks

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ABSTRACT:In recent years Home Energy Management (HEM) system, a Smart Grid (SG) technology has been widely used to reduce electric power consumption in home appliances. A significant amount of research has been conducted in order to make home energy consumption more efficient to control the power demand and supply. In this paper we present an organized review of various HEM schemes. The prime objective of HEM system includes energy saving, reduce Peak to Average Ratio (PAR), electricity consumption cost, peak demand and energy wastage. In this paper we discuss about, a.) Various pricing technique such as Real time Pricing (RTP), Time of Use (ToU), Critical Peak Pricing (CPP), b.) Various HEM schemes for Energy Management. The SG applications such as HEM, DES etc. leads toward efficient energy consumption. The results of these HEM program show how domestic electricity consumption became more efficient, reliable and smarter. This work presents the effect of smart grid development on social, economical and power sector. This paper reviews different research works on a wide range of energy management techniques for smart home aimed at reducing energy consumption and minimizing energy wastage.

KEYWORDS: Smart Grid(SG), Home Energy Management (HEM), Distributed Energy Sources(DES), Green House Gas(GHG), optimization, Information and Communication Technology(ICT), on-peak , off-peak hour.

I.INTRODUCTION

Electrical power system is the combination of power generation, transmission, distribution, monitoring and control. World‘s population and energy demand increases exponentially. To meet the increasing power demand we need to switch on a new kind of electric grid that can automate and manage the increasing complexity and needs of electricity in an automated fashion. The requirement for more electricity is unquestioned, but the current power system is not suitable for continued power expansion. Aggregated Technical & Commercial (AT&C) losses, GHG emission, increasing fuel cost etc. are some of the issues which make the power producers to lean toward cheap, environmental friendly power source. The emerging technologies and combination of ICT makes the power system digitally enhance, robust, more accurate, fast, automated, reliable, safe, efficient and increase level of consumer‘s comfort. The Smart Grid provides a two way dialogue where electricity and information can be exchange between the utility and its customer, which increase the customer‘s participation in the power system. Thebidirectional communication system connects all the nodes with each other to exchange the information. Erol-Kantarci *et-al*(2011)[1], describes the various smart grid technologies such as Home Area Network(HAN), home automation, Advance Metering Infrastructure(AMI), smart meter. The SG opened a new way for demand response program by using low cost sensors, smart meter, and combination of ICT with conventional electrical system [1]. The smart grid has the unique feature to help the consumers to save money by giving choice to each and every consumer for deciding them to manage their electricity use and choose the best time to purchase electricity. In [2], various initiatives has been taken by Government of India (GoI) to improve energy scenario in India. Electricity act 2003 in India initiate a positive change in the Indian power industry. It also aimed to reforming electricity laws, bring back FDI and guide the manufacturer to label the appliance with energy efficiency label. It includes renovation of existing power system, reduction in AT&C losses, improvement in power quality, rationalization of electricity tariff and most important to improve customer satisfaction. Recently GoI has formed ―Smart Grid Forum‖ and ―Smart Grid Task Force‖ for the implementation of smart grid technology on the Indian power system. P.Acharjee [3], provide the power loss percentages in India. India is the sixth largest country on the basis of energy consumption. Nearly 62% of total power generation is from coal and for thermal generation approximately 70% of total coal is used. Among the total power generation in India 54% and 34% comes from coal and oil respectively and the remaining amount comes from renewable source, natural gas and nuclear [4-5]. India‘s transmission and distribution losses are highest in the world; averaging 30% of its total production, with some

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states as high as 50%. Non-technical losses mainly energy theft is nearly 40% of total production [2]. India's electric grid is the weakest in the world. It reaches only 80% of its population [6].

From the bottom up, the renovation of power system is required because of the availability of low cost, highly reliable and more efficient SG technologies. The energy is the prime ingrediance for the economic and social growth of society. In near future power generation crucially depend on environmental regulation availability of low cost fuel on long term basis with good efficiency [7-8]. The developed as well as the developing countries like India are now focusing on the green power generation by implementing SG technology [6].Anas, M *et-al*[9], describe the technique to minimize the electricity thefting. The home appliances are equipped with AMI and sensors for load prediction. The employment of HEM system reduces the energy consumption and energy bills. In[10], a quality of power is monitor by using sensors in smart grid network. Home appliances equipped with sensors along with AMI makes the real time energy monitoring possible which help in reducing carbon footprint, and smoothen the load curve of grid [11].

The paper is organized in the following way: Section-II elaborates the brief introduction of different pricing technique used in smart grid and in Section-III we explain the different energy management schemes. Section-IV concludes the paper.

II.HEM BY USING DIFFERENT PRICING TECHNIQUE

There are different optimization techniques, schemes, algorithms have been proposed for efficient coordination of home appliances and DES to reduce peak load and electricity bill. In paper [14], two type of HEM schemes are discussed, one is communication based other is optimization based. For example in [15], a day ahead pricing has been used in a HEM scheme to minimize the electricity charges of a consumer. The process of observing, controlling and conserving electricity usage is termed as HEM [16]. According to paper [17], more than 40% of global energy consumption is done by residential building and homes. A HEM program is presented in paper [1] with local generation facility and gives its comparative study with other schemes. It shows the cost saving behavior of proposed work. The distribution companies follow or use different pricing schemes for consumer's billing purpose. There are so many pricing schemes has been proposed so far for HEM, out of those mainly are RTP, ToU, CPP etc.

A. Real Time Pricing(RTP):

In RTP technique, consumer is informed hourly about the electricity prices as the rate changes hourly. In paper [18], an algorithm is proposed which use RTP to reduce the energy consumption cost. This algorithm subset into three stages, namely Real Time Monitoring(RTM), Stochastic Scheduling(STS) and Real Time Control(RTC). In RTM stage, HEMS gets the current information about RTP data from utility and the working status of each appliance. Attributes of smart appliances are observed and all the data stored in HEMS.

Similarly in STS stage, HEMS figure out an ideal policy by using Stochastic Dynamic Programming (SDP) to choose a set of appliances to be controlled with an objective of minimum energy consumption cost. It use Markov Decision Process(MDP) to predict the appliances schedule to minimize the electricity bill. Now selected appliances are controlled in RTC stage. In this stage the number of control signals are reduces because of categorization of appliances in STS stage.

B. Time of Use(ToU):

In this pricing technique a day is divided into mainly three time of use pricing periods i.e. the off-peak, on-peak and mid- peak hour. Off-peak hour: when electricity price is least, mid- peak: when electricity price is moderate and on-peak: the busiest time of a day when electricity price is highest [12].

Reason behind higher and lower prices are like cell phones tariff, which are cheapest when demand is lowest mainly during late nights and highest at the day time. The use of electricity is also depends on season as demonstrate in figure 1(a) & (b). In summer, per unit price of electricity is highest at the afternoon time, when air conditioners running on high.Similarly, in winter on-peak hour is at the morning and at late nights, when the environmental temperature is too low. In [1], the author bifurcate the generation plants in base plant and peaker plant. The base plant which works on renewable energy sources such as hydro, solar etc. and peaker plants which work on non-renewable energy sources or fossil fuel such as petrol, coal, diesel etc. During the on-peak hour when the consumer's demand climbs rapidly we need to maintain the balance between demand and load, the utilities switches to their peaker plants. The peaker plants help to maintain the balance but there maintenance cost is too high with the additional cost of large GHG emission.

This results in increase the consumers electricity bills and also pollutes the environment. The aim of averting the services of peaker plants can be achieved by scheduling the domestic appliances as mention in [11]. To manage the HEM system various innovative technologies and routing protocols for Wireless Sensor Networks (WSN‘s) has been discuss in [11,17,18].

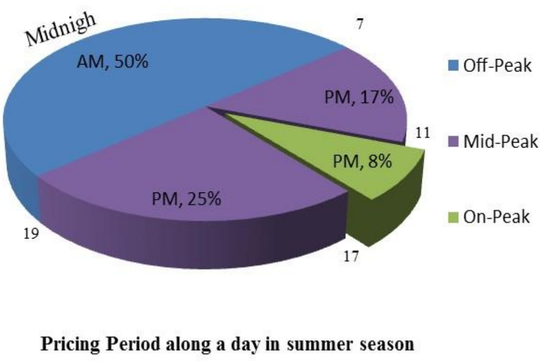

Figure1.(a)

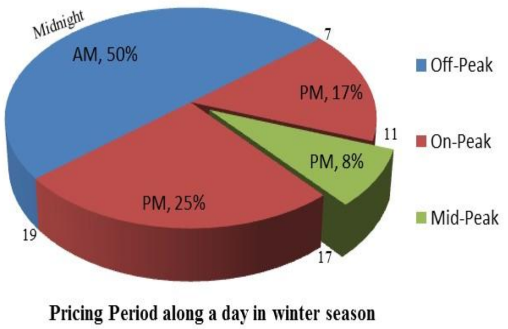

Figure1.(b)

The chart above in figure1 (a) & (b) shows the price a consumer pays daily for electricity consumption at different times of the day.

C. Critical PeakPricing(CPP):

CPP is the electricity consumption per unit rate that applies to those customers whose electricity demand lies under a threshold value decided by the utility and whose smart electric meter records usage data in regular interval. The period of high energy use is called peak event. The unit price is higher during peak events and lower prices during all other times. The CPP scheme provides accurate information about energy consumption so a user can better decide how and when to use electricity. It gives more flexibility to reduce monthly energy cost [13].

III.ENERGY MANAGEMENT SCHEME

In this section, few energy management schemes are presented. The main objective of these schemes is to reduce peak load demand, electricity consumption charge and emission of GHG.

A. Optimization Based Residential EnergyManagement (OREM):

Erol-Kantarci et-al [1], present a Linear Programming (LP) based model to minimize the electricity bill at domestic level. In this scheme, a day is divided into time slots of equal lengths with different rate of electricity per unit. It is very much similar to ToU scheme. In LP model the home appliances are schedule in an appropriate time slots to reduce the electricity bill. The consumer may enter the schedule detail in the LP model and the model gives the most efficient and optimal scheduling output. The objective function proposed is defined as in equation-1.

$$\sum_{a=1}^{A}\sum_{d=1}^{D}\sum_{t=1}^{T}\sum_{r=1}^{R} E_a L_a U_t S_t^{a,d,r} \qquad \ldots\ldots(1)$$

Here,

a= number of appliances.

d= number of days.

t= number of time slot.

E_a = energy consumption of appliance _a.

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L_a = length of cycle of appliance _a.

U_t = unit price for time slot _t.

$S_t^{a,d,r}$ = ratio of time that an appliance _a takes in time slot _t to the total time taken by appliance _a.

To achieve the minimal electricity unit price the LP model always try to schedule the appliance in the minimum rate time slot. This process bring a non-acceptable amount of delay to the appliance cycle and create a chaos at the low price time slot. To avoid this problem a maximum delay is defines for each appliance. The value of delay is defined as-

$$D_{\max} \leq 2D_i \qquad \ldots\ldots(2)$$

Where,

$D_{\max}$ = maximum allowed delay in scheduling.

D_i = length of each time slot.

B. In-Home EnergyManagement(i-HEM):

Reference [1], demonstrate a unique in home management algorithm which is based on coordination and communication between smart appliances, central EMU and WSHAN‘s. The communication system is based on Zigbee protocol for wireless communication. Dissimilar to OREM, the i-HEM work on real time pricing [19]. The consumer may switch on any appliance to any moment of time irrespective of the peak hour concern and the i-HEM algorithm suggest an appropriate time to the consumer to start the appliance.

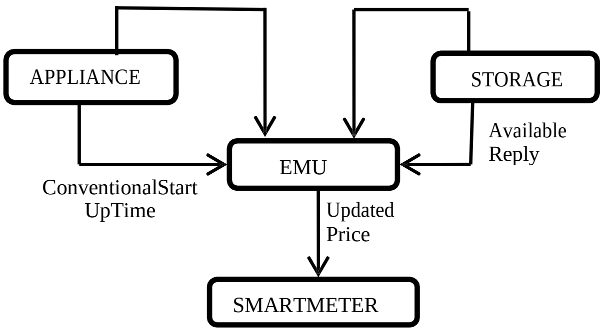

Figure 2. The message flow of i-HEM system.

Now it depend on the consumer to accept the suggested schedule or to override it. Here in [1], 30% of the load takes place during on-peak hour in the absence of HEM programand after implementation of HEM program the load reduce upto 5%. This finally result in reduce bills, GHG emission, energy consumption etc.

C. Home Appliance Coordination Scheme ForEnergyManagement(HACS4EM):

A.Mahamood *et-al* [11], demonstrates a home energy management scheme based upon coordination and communication among appliances through a WSHAN to reduce the peak to average ratio, increase saving, better peak load management. Sensors are deployed in smart home for monitoring attributes of domestic appliances. Home appliances equipped with sensors along with AMI makes the real time energy monitoring possible. This scheme use ToU pricing scheme. HACS4EM also address the role of standby appliances. Standby power is the power consumed by the appliance when it is not functioning or when switched off[20]. According to paper[11], standby appliances consume 10% of electricity. A new energy consumption scheduling scheme to motivate the Consumer for participation in energy

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management is proposed in [21]. The simulation result shows that reduction in energy cost, energy consumption and peak load are 21%, 24%, 24% respectively [21]. The objective of ApplianceCoordination (ACORD) algorithm is to shift the appliance from on-peak hour to off-peak hour. The consumerspenetration in the energy management system increases the efficiency of the system. As the number of consumers request increase it significantly reduce the electricity bills [22].

D. Decision Support Tool(DST):

The prime objective of DST is to enhance the consumer‘s comfort by making intelligent decision during appliance coordination. The output of HEMS increases if the DES simultaneously coordinates with the appliances. The work done in [23] used an enhanced Particle Swarm Optimization (PSO) solver. Coordination scaling has been done in two cases when DES is scheduled independently and when DES is cooperates with each other. DST is the combination of DES scheduling and appliances coordination to maximize the system output. The net result of this algorithm is reduction of electricity bill by 16-25%.

E. Optimum Load Management(OLM) Strategy:

In [24], an objective function is defined by the user by forecasting and scheduling the activities of appliances. Various options is to be consider before fore casting such as solar, wind energy, per unit price of electricity at different time slot of a day.

Following objective function is proposed in [24]-

$$y=\sum_{i=1}^{24}\left[\begin{array}{l}\left(\sum_{n=1}^{N}UA_n(i)PDA_n(a_n,i)+\sum_{k=1}^{K}UEV_k(i)PDEV_k(B_k,i)\right)\\ -EP(i)(\sum_{n=1}^{N}PDA_n(a_n,i)+\\ \sum_{k=1}^{K}PDEV_k(B_k,i))+EP(i)(WP(i)+PVP(i))\end{array}\right] \qquad \ldots\ldots(3)$$

Where,

y is the difference function between the amount the user have paid and the cost of obtaining the required energy from grid.

$UA_n(i)$ - unit price of user _n in ith hour.

$PDA_n(a_n,i)$ - power demand of user _n in ith hour.

$UEV_k(i)$ - unit price of electric vehicle _k for ith hour.

$PDEV_k(B_k,i)$ - power demand of electric vehicle _k‘ in ith hour.

$EP(i)$ - Forecasted prices for i^{th} hour.
$WP(i)$ - Forecasted wind power for i^{th} hour.
$PVP(i)$ - forecasted photovoltaic power for ith hour.

The authors proposed a novel optimization technique to solve the optimization problem due to nonlinear nature of function. The simulation results show reduction in electricity bill by 8-22% [24].

IV.CONCLUSION

In this paper we summarized the study of various pricing technique and HEM schemes to achieve an intelligent, economical, efficient and sustainable use of electricity. This paper is a compilation of numerous energy management research works in order to obtain efficient solution to the energy management issues. It eventually benefits the consumer by reducing the cost, improved services, and increase convenience. Results show the minimization of peak loads, reduction in both electricity bill and emission of GHG. This paper focused on several HEM schemes along with different pricing schemes, schemes summarized in table-1. The smartappliances present in the smart home are work in anautomated fashion that provides customer with higher comfortlevel. Both communication and optimization based HEMschemes are discussed in this paper. In future smart gridnetwork can be extended for development of more reliable,efficient and user friendly HEM system. In future scope, the methods to minimize both energy wastage and electricity billcan be further improved and simplified by applying efficient optimization techniques.

Table 1: Comparative study of different HEM schemes

Name ofHE M	Pricing Technique used	Objective	Methodology	Areaof Coverage	PeakLoad Reduction	Bill Reduc tion
OREM	ToU	Reductionin electricity consumptionbill	Linear ProgramingBased Optimization	HAN	N/A	35%
HACS4EM	ToU	Reduction in Peak to average ratio,better peak loadmanagement	Scheduling ofHome appliance	HAN	21%	24%
RLC	RTP	PAR and costminimiz	Linear ProgramingBased Optimization	HAN	22%	16-25%
OLM	RTP	Decrease inelectricity bill andconsumption.	Heuristicoptimization technique	HAN	N/A	8-22%
DST	ToU	SchedulingDES	Particle SwarmOptimization (PSO)	HAN	N/A	16-25%
i-HEM	ToU	CostMinimization	InteractiveLoad Shifting(ILS)	HAN	40%	30%

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