A NOVEL POWER TARIFF MODEL FOR THE FUTURE SMART HOMES

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ABSTRACT

Considering the importance of energy pricing as an essential tool to develop efficient demand side management strategies, we propose a novel pricing model for the future smart homes. This model classed all the appliances we used into six groups and set different pricing to each group, in order to guide consumers saving energy as much as possible. Comparing with other tariff models, it has three advantages: compatibility, comprehensive guideline and durative. Finally, an experiment in a real residential house in Eastern Azarbaijan province of Iran is shown as the case study.

INTRODUCTION

There is no substitute for the status of electrical energy, which dramatically fuels both the development of economy and the improvement of people's living standard. Availability of affordable and sustainable electrical energy has been the key to prosperity and continued socioeconomic growth of nations and the world [1]. Two key characteristics of electrical energy are that it is easy to distribute but hard to store. More precisely, electrical energy can be transmitted to a faraway place with only a tiny loss, but unlike other common forms of energy such as chemical, electricity must be used as it is being generated. If storage is needed, it must typically be converted immediately into another form of energy such as potential, kinetic, or electrochemical.

Utility companies are interested in reducing the peak demand of energy consumers so that their cost can be reduced. However, the power demand depends on exogenous factors and varies dramatically as a function of time of day and seasonal factors.

Energy pricing is a useful method to provide an incentive for the costumers to shift their energy consumption from peak-energy-use hours to off-peak hours, thus save money on their monthly electrical bill. At the same time, by proper use of energy, utility companies save capital expenditure by not having to add new power plants to the grid in order to meet the customers' peak-hour demands. So energy pricing method can benefit both the consumer and the producer in an economical way.

Also energy pricing is the most popular demand-side management (DSM) method with excellent results. This paper proposed a new energy pricing model called necessity-time-of-day tariff. This model has three advantages: first, it is flexible in application, and is used in demand-side-control model, second, it will work at both load consumption decreasing and load shifting, third, it can be compatible with other tariffs. We need details of all appliances power consumption in this model and we can use non-intrusive load monitoring system (NILM) to extract and identify them [2]. We will describe NILM system which we propose will be used in future smart homes in Iran. Unfortunately we don't have NILM system or any smart meters now, so the energy audit is an appropriate and accurate approach to get details of appliances power consumption in the case study.

DESCRIPTION OF NILM SYSTEM

With the gradual depletion of resources, energy is the one of the most important issue for the world. Related research indicates that if the household is able to master appliances usage and energy consumption in the house that will achieve a warning effect and reduce the energy consumption about 5% to 15% [3]. However, normal resident does not have sufficient expertise and time to keep detailed records of all kinds of electrical parameters and status information. Load monitoring system identifies the object and its status by a various power parameters, which provides more detail electricity information as well as intelligent application.

In 1980s, NILM or non-intrusive appliance load monitoring was developed [4] as a low cost alternative to attaching individual monitors on each appliance. It can analyze what appliances are used in the house as well as their individual energy consumption. The block diagram of NILM is shown in Fig. 1.

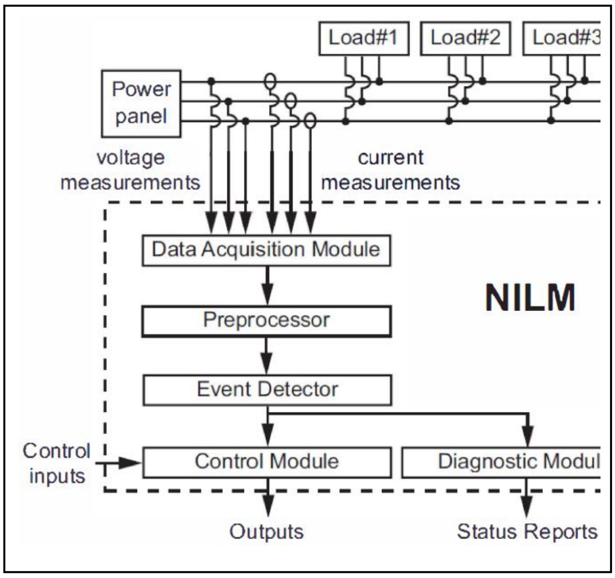

Fig. 1. NILM block diagram [5]

According to the frequency of the record, it can be divided into high-resolution and low-resolution. Generally speaking, the frequency of the electricity parameters is implemented at 120HZ or more in high-resolution. Because the high frequency sampling rate is high, it can reflect the electrical waveform of transient change with higher accuracy [6]. Because high frequency sensor is expensive and produce mass data records with more computing resource. Therefore, some researches support relatively small sampling time. Although slightly decrease in recognition accuracy, greatly reduces the cost for low-resolution identification method. Such as Mario [7] who made real power and reactive as parameters to identify appliance state with four different recognition algorithms, including KNN (K-Nearest Neighbor). Although the recognition accuracy is not quite perfect, but practical.

There are two kinds of identification methods, transient and steady-state identification. Transient identification method is used when the electricity signal become changing, it has to detect the event that occur load differences. That way the system must to monitor the situation of the circuit in time. And load monitor system will compare signal with one in database which is learned [8]. But if it exists unstable appliances or noise, the method may lose its accuracy [9]. Steady state identification method collects data in fixed- interval, so the size of the sampling is particular important.

No matter what it uses, it has some drawback. It must to execute learning process a period of time, not completely non-invasive. Thus, NILM reveal several degrees of Non-Intrusive, they can be classified in two classes [10]: MS-NILM (Manual Step) and AS-NILM (Automatic Step). MS-NILM is more precise than AS-NILM, but is not easy to step meter for a large scale.

We propose AS-NILM be used in the future smart homes in Iran because it is non-intrusive in every processes and its sampling instrument is a multi-function meter which ensures being financially viable and easily applicable.

ENERGY AUDIT

This approach requires the registration of all parameters affecting energy consumption (e.g. size, users, activity, number and type of energy consuming devices, etc.). This is achieved by means of an audit of the equipment being installed (kw) along with an estimation of how long they will be running. When an energy audit is carried out, all the energy devices/systems in place as well as their nominal figures [power: p_n, w] should be identified. The wattage labeled is the power drawn by the appliance. Since many appliances have a range of settings (for example, the volume on radio), the actual amount of power consumed depends on the setting used, at any particular time. Devices such as speakers rarely work on their full power. Therefore, the auditor should make a relatively accurate approximation of the actual power as a percentage of the respective nominal one. The energy audit approach, closely reflects the actual energy infrastructure in place [11]. Thus, through energy auditing of a residential house in Maragheh city, this facility was considered for its energy consumption and the power consumption data for each appliance extracted in a sample month.

TARIFF MODEL

Time-of-Day-Tariff

This tariff model is used in many countries and areas. The basic idea is dividing a day's 24 hours into peak, valley and plane sections, and set different prices to each time section, in order to encourage the consumers to make reasonable arrangements of power consumption, which can achieve peak load shifting, and improve efficiency in the use of power.

This tariff is based on the two conditions of power system: first storage of power is not easily applicable and the excess energy will be wasted; second, the demand of the consumers must be fulfilled as possible. These two assumptions decided that the average use of load can improve the efficiency of power. This tariff uses principles of economics, sets power as products in the market, and leave the adjusting to different pricing and consumers. This tariff is aimed at shifting peak load and peak shaving.

The advantage of this tariff and the peak load shifting attendant can be brought to all participants, the consumers, the operating companies, power generation enterprise and society. So the propulsion is strong enough to support the implementation and the most successful pricing model. But it still has limitations:

first, the peak load shifting can not restrain the increase of load and appliance which is the most basic problem of energy crisis; second, the details of tariff may need to be changed for better guideline, so a real-time pricing model is proposed, but the float information of the tariff bored many consumers which reduced the effect.

Both of the limitations above are hard to eliminate for the foundation of the tariff, so the other tariff models are proposed to remedy the power market guideline, such as progressive tariff and so on.

Progressive Tariff

This tariff model has been proposed before the establishment of power system market. It was used to prevent wasting. The basic idea is setting pricing punishment rules to the resource wasting actions, if the consumer uses resource more than the normal situation, he will pay higher price for it. Table I shows a progressive tariff model used in Iran.

The advantage of this model can be easily calculated without further information of consumer or power system. We only use the total power consumption.

The disadvantage also comes from the simple model, due to the one-house-one-meter in the power measuring system. It is not fair when the number of people living in the house and the kind of appliances are not the same. Of course, more people need more energy, and a huge poor family will pay at high prices.

Present Tariff Model in Iran

Present tariff model used in Iran is a combination of time-of-day tariff model and progressive tariff model. Equation (1) and table I illustrate this model. E1 is the energy cost in a month calculated in this model [12].

E1=X(0-100)+1.166X(101-200)+2.5X(201-300)+4.5X(301-400)+5.66X(401-500)+6.5X(501-600)+7.166X(amount more than 600)+X(peak time consumption(kwh))-0.5X(valley time consumption(kwh)) (1)

TABLE I.

Progressive section		
Steps(kwh)	***Price(Rials)***	***Price***
0-100	300	X
101-200	350	1.166X
201-300	750	2.5X
301-400	1350	4.5X
401-500	1550	5.66X
501-600	1950	6.5X
More than 600	2150	7.166X

Necessity-Time-of-Day Tariff Model

This tariff is a new model proposed in this paper and is based on DSM and peak load shift. It is a combination of necessity tariff and time-of-day tariff model. The basic idea is to set pricing principles by the necessity of power consumption. The use of some necessity appliances for life is low price; the energy price of normal appliance stays still; the use of some luxury appliances are changed in a high price, such as high power air conditioners (AC).

The foundation of this tariff model is that the power consumption of each appliance can be counted in an automatic way. All the appliances can be classed into six groups by electric company, like table II. The appliance in the table is just an example for the taxonomy of the appliances, and the complete classification needs more research and experiments. The Cn are symbols for corresponding appliance class in this paper.

The classification is carried out from two aspects: the purpose and using degree. From the purpose of energy consumption, it can be classed into for living and entertainment. For using degrees, it can be classed into basic use, normal use and luxury use. Basic use stands for appliances that people can not leave or social unrest may rise without these appliances. Normal use stands for appliances which people use them for convenience. Luxury use stands for appliances which people use them for enjoyment.

Equation (2) and table II illustrate this model. Pn is the price of Cn class appliances consumption. E2 is the energy cost in a month calculated in this model.

E2=

$$\sum_{n=1}^{n=6} \mathrm{Pn} \times \left(\text{total consumption of Cn class aplliances}\right) +$$

+X(peak time consumption (kwh))-0.5X(valley time consumption (kwh))

TABLE II.

Classification of Appliances		
	Living	***Entertainment***
Basic	C1	C2
Normal	C3	C4
Luxury	C5	C6

CASE STUDY

The case study involves a residential house with four residents, in Maragheh city, Iran. The electricity power consumption of this house in a sample month in the summer is shown in table III. The power consumption of each appliance is shown in table IV, which is obtained from energy audit study of this house [13]. In this case study, the result E1 is 505.16X by (1), and in new necessity-time-of-day tariff model assuming the pricing rules is as table V, the result E2 is 501.97X by (2). So the new tariff model is not the high charge model, and it will not increase the burden of normal resident. But if the luxury power consumption is too much, the charge will rise quickly which is the main guideline of this tariff.

TABLE III.

A Sample Month Consumption Based on Bill	
Time of day	***Consumption(kwh)***
peak	69.11
valley	87.9
plane	145.8
total	303.13

TABLE IV.

Consumption Details of Appliance		
Appliance	***Classification***	***Consumption(kwh)***
Lighting	C1	13.95
Refrigerator	C1	19.33
Freezer	C1	37.5
Iron	C3	1.35
Vacuum	C3	1.05
Hair dryer	C3	2.5
PC	C4	35
TV	C4	52
Tea maker	C5	7.6
Dishwasher	C5	11.5
Microwave oven	C5	6
Air conditioner	C5	110
Game console	C6	5.35

TABLE V.

Pricing Rules	
Appliance Classification	***Price***
C1	0.5X
C2	0.8X
C3	X
C4	1.2X
C5	2.3X
C6	4X

CONCLUSION

A new pricing model is proposed in this paper. This model classed all the appliances we used into six groups, and set different pricing to each group, in order to guide consumers saving energy as much as possible. Also this model encourages consumers to shift the energy consumption schedule of their high-load household appliances to off-peak hours. It has three advantages: comprehensive guideline, compatibility and durative. This model was studied in a real residential house and the data extracted by energy audit. We will need a load monitoring system like NILM to extract details of appliances consumption data in practice. In the future researches the classification of appliances should be improved for fair rules of pricing model and for different weather conditions.

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