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Designing Decision Maker in a Smart Home for Energy Consumption Optimization Using Fuzzy Modeling

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Abstract

existed electricity grids deliver produced power to the consumer passing through transmission and distribution grids. According to high losses of these grids in transmission level and inexistence of bilateral interaction for simultaneous information exchange, a concept of smart grids were made by capabilities such as consciously participation of consumers in the smart electricity grids, an amount of energy saving, monitoring and automation of electricity grids. These grids give necessary information about the cost of power consumption to the users and it is possible that subscribers change their consumption power amount based on a balance between requested power and electricity grid. Since smart home in a form of environment where all control systems were designed in a pre-defined logical framework, so it can be introduced as a solution to reduce energy consumption through controlling equipment based on function schedule charts. In this paper, an approach has been presented to optimize energy consumption which decision maker model is designed in order to reduce cost and to increase user utility. Indeed designed home energy management system select optimum duration about how to use the equipment by using fuzzy modelling.

Keywords: home energy management system, fuzzy modeling, smart grid, smart home

1. Introduction

With development of new technologies in last years, energy consumption is considerably increasing; therefore, it is necessary to design smart systems for management of energy consumption.

Smart grid has the ability to reduce the amount of power consumption by coordinating load amount in system, leveraging demand-response mechanisms with time-based pricing notification oriented towards residents [1].

Management of load demand mechanisms play an important role in designing smart grids to reduce consuming in the peak time. Smart grids make possibility for their users to have great effect on energy saving through management of using household devices toward reducing energy consumption and losses [2].

Nowadays due to shortage of energy sources in the world, the importance of optimal energy consumption has been considered more than before. So, utilizing energy management systems in smart homes to integrate control and making maximum coordination for increasing productivity and reducing undesirable consumptions has taken place by automatically monitoring and controlling home devices and equipment.

In recent years with the appearance of artificial intelligence, some researches have appeared in the field of designing smart homes as an environment with management ability on energy consumption for decreasing user expenses [3]. Smart control systems have high flexibility that could be easily matched with human needs. Smart spaces could be effectively designed considering consumer tastes and uncertainty of input parameters.

Smart home provides a context for making an environment safer, more comfortable, and low cast by assimilating information, communication, and electronic technologies [3]. The most researches based on smart homes focus on each physical, communication, information, and decision making layers [4]. Smart home technology was developed in 1975 with the appearance of X10 [5]. Internet as another communication solution in smart home makes it possible for its user to control electrical equipment online wherever in home [6]. Furthermore, in many studies, various approaches were presented about designing smart homes including fuzzy logic and multi-criteria decision making [7].Home energy management system has a great effect on energy controlling and optimization as an essential interface between smart grid and smart home toward reducing energy consumption and losses [8]. One of the most important effects is a possibility to reduce energy consumption by smart controlling home devices and equipment. There are many techniques for reducing energy consumption. For example, this capability in smart buildings exists that empty spaces could be determined with utilization of motion sensors and existence load in them could be interrupted for reducing energy consumption. On the other hand, the users can automatically turn off home devices and equipment in the peak time of energy consumption [9].

By using latest technologies, management system of smart home tries to make ideal condition along with optimizing energy consumption in buildings. In the most studies based on management system of energy consumption, designing household automation grid has introduced as one of a solution to reduce energy consumption toward controlling the equipment. Home energy management systems have both optimization and anticipating capabilities. These systems make it possible for the users to adjust the amount of energy consumption according to diversity of energy cost.

Home energy management system toward optimal power consumption must able to show consumption amount of home equipment, analysis data of power consumption, decide to turning on or off any equipment based on control rules and have the ability to deliver power consumption reports for selected period of time [10]. A sample of management system of energy consumption was designed through smartly control equipment with selecting some multi-criteria decision making approaches toward monitoring users over the amount of energy consumption of home equipment [11]. One decision making model to determine performance time of devices and equipment in a smart home was designed utilizing linear programming method to obtain minimum of costs and maximum desirability level [12]. Since electrical devices and equipment have a large proportion of energy consumption in home grid, so smart control these devices is of particular significance. Therefore, our focus in this paper is on developing smart system for efficient management of energy consumption.

Optimization process in designing decision maker model is introduced considering both cost and user utility criteria as a multi-criteria decision making problem. Cost-benefit analysis is used as a helpful instrument to solve these types of problems. Thus, presented approach in this paper is formed based on this method. In first step, expected cost of any equipment is determined according to anticipated cost curves based on time and amount of equipment consumption. Finally, decision maker model will determine the most appropriate attitude with having energy cost for any equipment and modeling user utility in form fuzzy number by using a multi-criteria decision making method.

2. Proposed Algorithm

Proposed algorithm in this paper is based for designing decision maker model toward reducing consumption cost and increasing user utility level based on artificial intelligence techniques in a fuzzy modelling form. Designing decision maker model according to the effects of different parameters on electric cost included which could be pointed to weather situation, working and non-working days, seasons and etc. encounters to the uncertainty of electricity prices. Electricity price signal is obtained from combining the anticipated electricity cost curves based on time which are estimated in a given intervals (for example, every half hour). Energy cost form each equipment based on resulted electricity price estimation and according to the amount of energy consumption of related equipment that were defined by manufacturer is consider as one of the inputs of decision maker model. Then, user request of how to use equipment will model by fuzzy method which fuzzy numbers, according to high dimension of search space, is used as appropriate tools to reduce a volume of this space for modelling user utility. Finally, it is determined the most appropriate time to turn on related equipment using cost-benefit technique.

As shown in Fig.1, decision maker model is designed by using two criteria such as estimated power price and user utility level.

2.1. To calculate electricity cost function observing uncertainty of electricity cost

Predicted curves of electricity cost based on time which are estimated in given intervals (for example every half hour) were combined together applying a probabilistic method as formula (1) to make a signal of electricity price for the model.

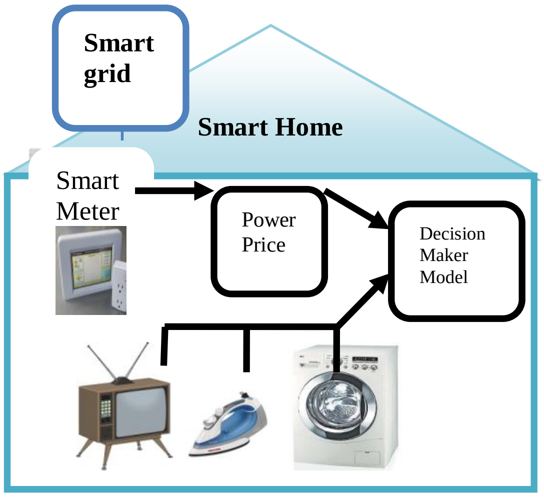

Fig.1. Suggested Algorithm

$$E(\text{Price}) = \sum_{i=1}^{k} P_i \times \text{Price}_i$$

$$\sum_{i=1}^{k} P_i = 1 \qquad (1)$$

Price_i refers to the signals of electricity cost. P_i refers to coefficients of utilization each signals of electricity cost.

2.2. To calculate energy cost for any equipment

A cost of any equipment is determined according to equation (2) considering consumption amount of related device (CU_i) which is defined by manufacturer.

$$C_i = \left[\text{Price}^{Rial/Kwh} \times m^h \times Cu_i^{Kw}\right] \qquad (2)$$

m refers to time intervals on which the curves of electricity price are predicted.

2.3. To calculate energy cost for any equipment

A search space of the most appropriate operating interval of devices and equipments is reached according to equation (3) based on the number of equipment used in designing decision model.

$$N = \left[(24/m)^n\right] \qquad (3)$$

As you see, search space for *n* equipment is of very high volume that selecting appropriate interval in this space has high calculation load. On the other hand, using electrical equipment usually takes place in a certain interval. Thus, fuzzy numbers reduce the volume of search space as a useful solution and membership degree for each time shows utility level of user utility to use related equipment. In proposed model, it is used triangular fuzzy numbers according to equation (4) where A_1 , A_3 are beginning and end of consumption interval, respectively, and A_2 is maximum utility level.

$$B_i = [A_1, A_2, A_3] \qquad (4)$$

2.4. Optimization process by analyzing cost-utility

Since, optimization process of energy consumption could be considered a multi-criteria decision making problem according to two objective parameters of cost and utility level thus analysing cost-benefit is applied and effective tool for selecting optimal operation interval toward reducing cost and increasing user utility level.

$$D_i = (C_i / B_i) \qquad (5)$$

Regarding equation (5), if user does not need to use some equipment in a given times, the utility will be considered zero and consequently D tends to infinity thus it could be remove these situation form this space to reduce calculation load. So, D is the best option to obtain minimum cost and maximum utility.

2.5. To select decision variable considering total cost

In the case of using in equipment during the day, decision variable is determined utility due to the signal of electricity cost for all home devices and equipment (estimated demand) through counting one by one situations of the most appropriate time for equipment operation based on minimizing equation (6) to have minimum cost and maximum utility.

$$D_T = \sum_{i=1}^{n} (D_i) \qquad (6)$$

Finally, objective function is obtained as equation (7).

$$F = \min_{i=n}(D_1, D_2, ..., D_i) \qquad (7)$$

To investigate optimizing rate for presented model, it could introduce two parameters called optimum factor and final factor for any equipment.

Optimum factor ($D_{optimum}$) refers to parameter that model output reaches at maximum utility.

In fact, model output occurs when user tends to use equipment with maximum membership degree.

Final factor (D_{Final}) refers to parameter in which model output occurs.

Range of optimization rate could be introduced based on mentioned parameters according to equation (8).

$$Optimization\% = \left[D_{Optimum} - D_{Final} \right] / D_{Optimum} \times 100 \quad (8)$$

3. A sample of designed model

3.1. To calculate electricity cost function observing uncertainty of electricity price

Electricity cost curves are shown in Fig.2 based on time in half hour period.

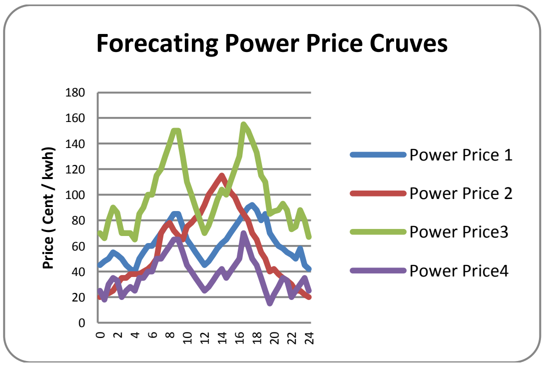

Fig.2. Sample of Forecasting Power Price

Signal of electricity cost which is obtained by combination of offered curves in Fig.2 according to applied coefficients in Table.1 is shown in Fig.3.

Table.1.
Applied coefficients for electricity cost functions

Electricity Price 1	Electricity Price 2	Electricity Price 3	Electricity Price 4	Cost function
0.2	0.3	0.4	0.1	coefficients

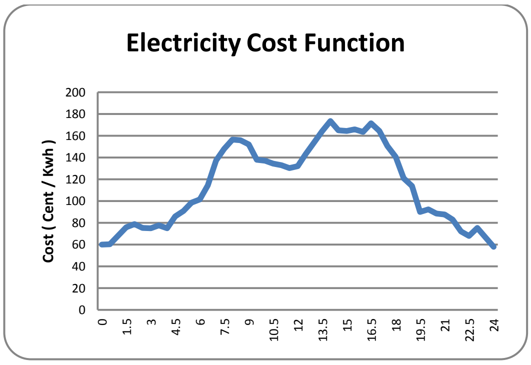

Fig.3. electricity cost function

3.2. To calculate energy expense for any equipment

Applying consumption amount of each equipment according to Table.2, it is observed in Fig.4 energy cost for each equipment according to equation (2).

Table.2.
Consumption range for each equipment

Vacuum cleaner	Dishwasher	Microwave	Washing machine	Decision factor
0.5^{Kw}	1.2^{Kw}	0.7^{Kw}	1.6^{Kw}	Consumption range

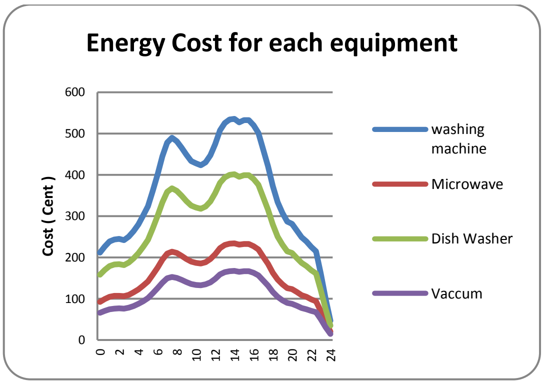

Fig.4. Energy cost for each equipment

3.3. To present user utility by fuzzy modelling

Fuzzy numbers are used as useful solution in utility modelling to reduce calculation load. A sample of user utility level for using related equipment has presented in Table.3.

Table.3.
How to use each equipment in a form of fuzzy modeling

Vacuum cleaner	Dishwasher	Microwave	Washing machine	Decision factor
[20,22,24]	[19,21,22]	[18,20,22]	[14,16,18]	Utility 1
[8,10,12]	-	[10,12,14]	-	Utility 2

3.4. Optimization process by analyzing cost-Benefit

Since it must be counted one by one situation for doing optimization process to have minimum energy cost and maximum user utility level according to equation (5) thus search space of this model due to equation (3) is 48^4 or 5308416 situation which calculation is of high load. So, this space is highly reduced with applying user utility regarding Table.3. Search space to have minimum cost and maximum utility was shown in Fig.5.

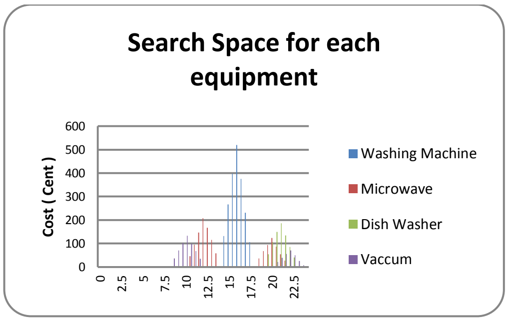

Fig.5. Search spaces for each equipment

3.5. To select decision variable considering total cost

Decision variable regarding to signal of total electricity cost from all equipment offer model output as Fig.6. For example, when we use 2 or more equipment, decision variable determines model output based on total cost from all equipment.

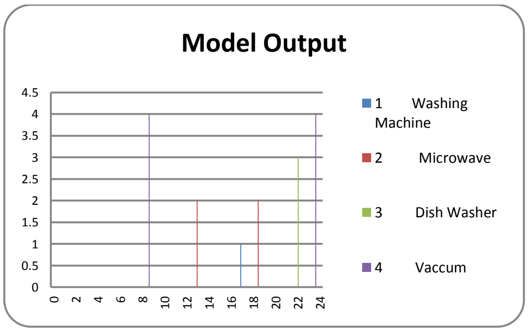

Fig.6. Model output

Optimal and final factors for sample model are summarized in Table.4 which optimization rate for each equipment was calculated according to formula (8).

Table.4.
Range of optimization rate

Vacuum cleaner	Dishwasher	Microwave	Washing machine	Decision factor
622.201	741.145	547.27	519.5	Optimal factor (Rial)
341.69	193.063	304.95	209.05	Final factor (Rial)
%45	%74	%44	%60	Optimization rate

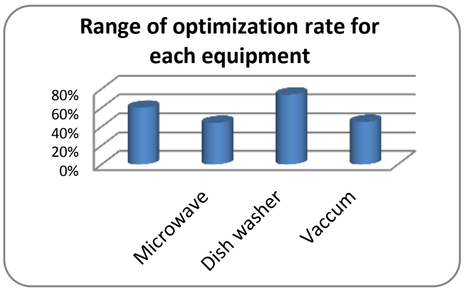

Fig.7. Range of optimization rate based on optimal and final factor

4. Conclusion

With increasingly growth of energy consumption in recent years, management of energy consumption in residual environments is of particular importance. Management system of energy consumption steps toward reducing costs and increasing user utility level. Managing on energy consumption in residual spaces plays an important role in reducing user costs such that users could manage their energy consumption by smart control on devices and equipment and costs reduce considerably.

In this paper, a decision maker model was designed for smart control devices and equipment toward providing optimization goals. Designed model select the best option to turn on and off related equipment according to predicted electricity price and how to use equipment in a form of fuzzy modelling. Since in this algorithm due to counting one by one situation, it has high calculation load according to the number of equipment thus it is reduced calculation complexity using fuzzy technique

For investigating a correctness of proposed algorithm, a model was presented for four washing machine, microwave, dishwashing, and vacuum cleaner equipment. A range of optimization rate is calculated based on optimum and final factors for each equipment.

An average of optimization rate 56% shows appropriate level of designed optimization model which indicates favourable optimization in the cost field for the model.

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