Application of Internet of Things into smart home scheduling

Abstract

The Internet of Things is widely used nowadays, which enabled real-time scheduling for electricity consumption task. It not only facilitates our daily life, but also provides us new thinking about how to respond to the call of “energy conservation and emission reduction” with information and high-tech. In this paper, we apply Internet of Things into the household electricity consumption task scheduling. According to the electricity usage of residents and peak-valley price, all the tasks are classified into different kinds. Based on these elements, a multi-objective optimization model is developed, with the objectives of cutting down daily electricity consumption and electricity cost, and the constraints of household electricity load and working period, to check whether “The Internet of Things” works well or not in the field of scheduling household electricity consumption task. The solution of the model shows that due to the application of The Internet of Things, we can schedule household electricity consumption task with the reduced electricity charge, and keep the satisfaction of users at a relatively high level at the same time.

Keywords: The Internet of Things, electricity consumption task scheduling, satisfaction level, peak-valley price.

I. Introduction

The application of the Internet of Things in smart homes is very common. The Internet of Things uses front-end hardware sensing devices such as temperature, humidity, light, gas and other sensors and cameras to collect product information of traditional home appliances, including location, working status, etc [1]. Through the network layer, such as Wi-Fi and Bluetooth, information is transmitted to the control terminal. Most smart homes use APP on personal handheld terminals or multi-screen controllers to achieve remote control. The mainstream smart home products that currently existed mainly include smart air conditioners, smart refrigerators, smart washing machines, smart speakers, smart curtains, smart lights, smart sockets, smart door locks, etc. In addition, although ordinary household products do not have functions such as network transmission of information, they can also be realized by using auxiliary media such as smart sockets, so that a simple smart home environment can be quickly established, which is conducive to future smart home scheduling [2,3].

It is found that there are few households research that combine the Internet and smart homes to optimize electricity charge and users’ satisfaction [4]. The in-depth research on the Internet and smart homes are limited, and thus, this paper tries to explore and supplement this deficiency in this area.

The rest of the paper is organized as follows. In Section 2, we propose the mathematic model. The feasibility of the model is tested through a case study in Section 3. Section 4 presents the conclusion.

II. Proposed model

Parameters and variables

X_i：index of non-deferrable appliance(i=1,2,3,4 correspond to air purification, water heater, dishwasher, air conditioner respectively)

Y_j：index of deferrable appliance (i=1,2 correspond to washing machine and charging equipment)

t：time periods for a whole day（t=1 indicates time period 0:00-1:00）

X^t_i：binary variable indicates the operation status of non-deferrable appliance i during period t.

Y^t_j：binary variable indicates the operation status of deferrable appliance j during period t.

M：the satisfaction level of the users about electricity consumption

N：the satisfaction level of the users about electricity charge

S：the overall satisfaction level, which is expressed as the weighted average of M and N.

E^t_B：the overall electricity load before scheduling

E^t_A：the overall electricity load after scheduling

C_x：the total working time for each non-deferrable appliance for a whole day

C_y：the total working time for each deferrable appliance for a whole day

F_i：the total working times for non-deferrable appliance in a whole day

R_t：the electricity charge for time period t

Objective function

Satisfaction level of the users

First of all, the satisfaction level of the users about electricity consumption is used as an indicator to measure the change of the users' electricity using habits. When they do not make any change, the satisfaction value is one. When they need to completely adjust the original electricity usage habits, which might greatly change the amount of electricity usage in each time period, the users' satisfaction with electricity consumption will infinitely approach zero. Therefore, the expression of satisfaction level about electricity consumption is:

$$\mathrm{M} = 1 - \frac{\sum_{t=1}^{T} |E_A^t - E_B^t|}{\sum_{t=1}^{T} E_B^t} \qquad (1)$$

Secondly, the satisfaction level about electricity charge is an indicator to measure the changes in the electricity expenses before and after the scheduling of appliance. If the user schedules and optimizes the daily electricity usage tasks, the daily electricity cost is lower than the optimized cost before the scheduling. Satisfaction level with electricity charge will be improved, the expression is:

$$\mathrm{N} = 1 - \frac{\sum_{t=1}^{T} (E_A^t \times R_t)}{\sum_{t=1}^{T} (E_B^t \times R_t)} \qquad (2)$$

The overall satisfaction level S is expressed as the weighted average of the satisfaction level about electricity consumption and the satisfaction level about electricity charge [4].

$$\mathrm{S} = \alpha \mathrm{M} + \beta \mathrm{N} \qquad (3)$$

$$\alpha + \beta = 1 \qquad (4)$$

Thus, the first objective function is:

$$\mathrm{Max\ S} \qquad (5)$$

Electricity load

Besides considering the users' satisfaction level about electricity consumption, to implement peak and valley electricity prices, we need to minimize the daily electricity consumption peak and the difference between daily electricity consumption peak and valley, the second and third objective functions are:

$$\mathrm{Min}(\mathrm{Max}\ E_A^t) \qquad (6)$$

$$\mathrm{Min}(\mathrm{Max}\ E_A^t - \mathrm{Min}\ E_A^t) \qquad (7)$$

Weighted objective function

Considering the above objective functions, we can obtain the following objective function by weighting method:

$$\mathrm{Min}(\gamma_1 \frac{\mathrm{Max}\ E_A^t}{\mathrm{Max}\ E_B^t} + \gamma_2 \frac{\mathrm{Max}\ E_A^t - \mathrm{Min}\ E_A^t}{\mathrm{Max}\ E_B^t - \mathrm{Min}\ E_B^t} - \gamma_3 \mathrm{S}) \qquad (8)$$

$$\gamma_1 + \gamma_2 + \gamma_3 = 1 \qquad (9)$$

Among them, $\frac{\mathrm{Max}\ E_A^t}{\mathrm{Max}\ E_B^t}$ and $\frac{\mathrm{Max}\ E_A^t - \mathrm{Min}\ E_A^t}{\mathrm{Max}\ E_B^t - \mathrm{Min}\ E_B^t}$ are designed to set the target value at around 1, which facilitates comparison with users' satisfaction level at the close range, and thus, reduces the impact of the large numerical gap.

Constraints

First of all, because the optimization is affected by the users' satisfaction level, if the daily electricity consumption after the scheduling and the user's original consumption are quite different, it will significantly change real life of the users, which is impractical. Therefore, the following constraint ensures that the user's total daily electricity consumption remains the same after re-scheduling:

$$\sum_{t=1}^{T} E_A^t = \sum_{t=1}^{T} E_B^t \qquad (10)$$

Second, since electricity billing is one of the most important factors, it is necessary to ensure that the user's electricity charge is lower than the original charge after scheduling:

$$\sum_{t=1}^{T} (\mathrm{E}_A^t \times R_t) \leq \sum_{t=1}^{T} (\mathrm{E}_B^t \times R_t) \qquad (11)$$

In addition, taking into account the threshold of the household users' electricity load, if the power consumption is too large in a short period of time, it will lead to overload protection of the electric gate, causing tripping phenomenon. Thus, after scheduling optimization, the electricity consumption at various times of the day should also be lower than the electricity gate overload protection. In this paper, the maximum carrying load of 8.8kw (=40A x 220V) of the general household electricity meter with specification 5 (40)A is used to calculate the upper limit of each household's electricity load.

Since this research excludes the scheduling of basic electricity tasks, including: refrigerator, lighting equipment, rice cooker, induction cooker, television set, vacuum cleaner. The corresponding power rates are: 0.04kw/h, 0.2kw/h, 0.5kw/h, 2kw/h, 0.1kw/h, 1.4kw/h. Therefore, after excluding the basic power tasks electricity load, the maximum load can be set at 5.5kw for each time period.

$$\forall E_A^t \leq 5.5 \qquad (12)$$

III. Case study

Due to the different living habits of each family, there are some differences in the using time periods of the appliance. For example, the fifth household chooses air conditioner running time in the evening peak period of electricity consumption, and the sixth household has no special requirements on the running time of the air conditioner. The following table records the electricity consumption habits of the ten households for six appliance.

Table 1. Electricity consumption habits of ten households (hr.)

Household / Appliance	1	2	3	4	5	6	7	8	9	10
Air purification	6	5	6	6	6	4	4	5	5	6
Water heater	3	2	3	3	3.5	2.5	2.5	3	2.5	3
Dishwasher	3	3	3	3	3.5	3.5	2.5	3	3	2
Washing machine	2.5	2	1.5	2.5	3	1.5	1.5	2.5	2.5	2
Air conditioner	8	7	9	8.5	4	7.5	8	8.5	8	8
Charging equipment	4.5	5	3.5	3.5	4	3.5	3.5	4	3.5	4.5

After scheduling, take first household as an example, the optimal running time for the appliance is listed as follows:

Table 2. Running time for household 1 after scheduling

Appliance	Running time after scheduling	Total running hours (hr.)
Air purification	8:00-14:00	6
Water heater	11:00-14:00	3
Dishwasher	9:00-12:00	3
Washing machine	9:00-11:30	2.5
Air conditioner	0:00-8:00	8
Charging equipment	1:00-3:00,4:00-5:00, 6:00-6:30,8:00-9:00	4.5

The following figure shows the electricity consumption before and after scheduling.

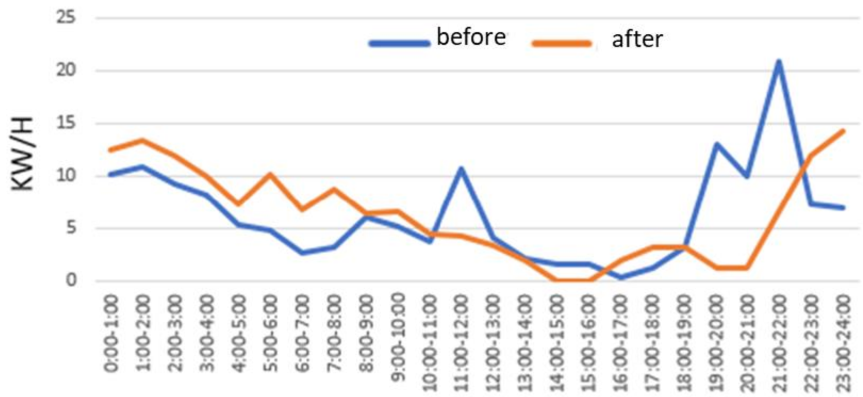

Fig. 1. Electricity consumption before and after scheduling

Through the comparison between before and after the rescheduling of daily electricity consumption of the ten households, it can be observed that the distribution of daily electricity consumption of residents has changed significantly, and the trend of electricity consumption throughout the day has fluctuated and decreased from 0:00 onwards, and goes up slightly in the evening. For example, during the original period of 19:00-23:00, when residents used flexible power tasks, and under the effect of scheduling optimization, the power consumption of that period was significantly reduced and the peak was reduced; Electricity consumption remains low from 00-17:00, while new peaks are delayed to 0:00-1:00 a.m., and electricity consumption during peak is lower than the original one. Because the start-up modes of appliance are changed from the original manual mode to the remote control, many power tasks can be scheduled during the time that the residents are not at home. Thus, the fluctuations in daily electricity consumption can also be reduced. It is explained that after optimizing the electricity task scheduling model based on the satisfaction of the user's electricity price, the difference between the peak and valley of the daily electricity consumption of these ten households has indeed been reduced.

IV. Conclusion

In this paper, we apply Internet of Things into smart home electricity consumption scheduling. This paper simultaneously takes residents' original electricity consumption habits and reducing electricity charge into consideration, combined with the current peak-to-valley electricity price policies, to provide household electricity consumption scheduling. The specific scheduling scheme was studied and the following conclusions were obtained:

After optimizing the scheduling and optimization of the collected electricity consumption of ten households, the residents' daily electricity consumption has been reduced, and the optimization effect of the situation is obvious. Residents use electricity to cut peaks and fill valleys to a certain extent;

Since the scheduling is based on the actual electricity consumption habits of residents, the optimization results firstly consider the users' experience of household users. Meanwhile, the electricity charge of each household after optimization has been reduced by 20%-30%. That is to say, under the current peak and valley electricity price policy, the Internet of Things technology can effectively solve the problem of power dispatch, while ensuring a high level of residential power satisfaction, and helping users develop an orderly and reasonable electricity consumption habit.

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Reference

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