Acta Technica *62* No. 2A/2017, 27–38

Research on intelligent home energy scheduling algorithm[1]

Chuanwei Qi[2]

Abstract. Aiming at the trade-off between energy utilization and user comfort in smart home, an intelligent home energy dispatching algorithm based on energy consumption prediction is proposed. Then, the concept of "dynamic comfort" is expounded, which describes the relationship between user comfort and energy savings in each time period. According to the prediction of the equipment operation and the energy information provided by outer family, the scheduling algorithm makes reasonable allocation and scheduling of energy and equipment. At the same time, aiming at the deviation between forecasting information and real-time information, the real-time correction scheduling algorithm is proposed. The prediction algorithm and the scheduling algorithm are corrected by collecting the feedback information of the user. The results show that the proposed algorithm can improve the energy utilization rate while protecting the user's comfort. It achieves a trade-off between user's comfort and energy savings.

Key words. Smart home, energy scheduling, energy utilization, users' comfort index.

1. Introduction

In recent years, with the development of science and technology, social life has become increasingly close ties with the information [1]. The standard of living is improved, and the living habits are changed. People are no longer satisfied with the most basic living environment. Therefore, smart home is very popular. Smart home will become a major change in people's way of life. In China, the irrational energy structure and environmental degradation have become the focus of current social concern [2]. Reasonable energy development strategy and smart grid construction have become very urgent. Smart grid is a new type of intelligent power network. By creating an open information platform, it promotes the linkage of power flow, information flow, and business flow [3]. The operation and management of the infrastructure and power supply of the power industry are optimized. Based on

[1]Funding program: 2017 Henan science and technology research plan 172102210433, the autonomous learning intelligent platform for Higher Vocational Education based on Bot Framework.

[2]The Mathematics and Information Engineering Department of Puyang Vocational and Technical College, Puyang, Henan, 457000, China

these advantages, many countries and regions around the world have taken the smart grid as an important development target for the future power grid [4]. Smart grid is widely researched and practiced in various fields. As a smart grid users, intelligent home integrated Internet of Things technology to build efficient residential facilities and family planning business management system [5]. It can enhance and protect the user's needs for the living environment, and realize the green living environment through energy management. At present, energy resources is becoming scarce, household electricity equipment is increasing, and users' demand for energy conservation is improving [6]. Therefore, intelligent home energy scheduling has become an important research direction. As an important part of smart grid, smart home has a good application prospect for smart grid technology [7].

In terms of energy, due to the deterioration of the environment and the increase in the greenhouse effect, energy conservation has become one of the development trends of all walks of life [8]. The popularity and development of energy-saving technologies in smart homes will play a key role in energy issues around the world. Through smart grid technology, users can reduce household energy costs by scheduling home appliances. It not only meets the interests of users, but also provides further theoretical support and technical support for energy conservation. Due to low energy consumption and the number of users, smart home can effectively achieve energy-saving and emission-reduction. Its size and efficiency are considerable. In this paper, an intelligent home energy scheduling algorithm based on the user's energy consumption prediction is used to schedule the energy use in smart home, which largely alleviates the energy pressure. In addition, this algorithm takes into account the user's comfort, and ensures the safety, convenience and comfort of the home. It helps to optimize people's way of life. Intelligent home control system has a very bright future, which is the significance of this research.

2. State of the art

With the development of electronic information technology, there has been an electronic home machine in the world since 1980 [9]. At this time, there is a residential electronic. Since 1985, residential electronics have been further developed [10]. The household appliances integrate the communication function, so as to realize the automation of the residence. Since 1988, with the further development of electronic information technology, all kinds of large companies began to develop residential automation system. The earlier commercial appliance automation system is the US Smart Home system. The system uses bus technology to achieve the electrical monitoring and management. It becomes the master and origin of the modern smart home system. Before the residential automation, the concept of smart home has emerged. However, after residential automation, smart home is gradually applied to the building. The earliest smart home is appeared in the United States Hartford City, known as City Place Building, that is, intelligent building. The building was built in 1984 by the United States of America Joint Technology Company [11]. The building opened the prelude of smart homes around the world. Smart home has become an integrated building system integrating information technology and home appliances.

The emergence of the world's first smart home case caused the reform of home appliances in major countries, such as Europe and the United States. Various countries have introduced policies to promote the development of smart home. So far, in the United States and Japan and other developed countries, intelligent home has become an important part of people's daily lives. When the smart home is still a new concept, the prospects for its development have been widely endorsed by the world. With its market sensitivity, all large companies have launched smart home products. In the smart home industry, in order to occupy a place in the ranks of smart home development, these companies invest huge sums of money. Motorola, IBM, Panasonic and other home appliance giants have established branches for the smart home production [12]. These companies have launched a development and production of smart home systems and smart home mode. As a high-tech followers and creators, US Silicon Valley also carried out research and development of intelligent home [13]. It integrates information technology and intelligent home systems, and takes it as an important direction for the development of its home technology. In the smart home market, capital has become one of the most important factors limiting the development of the industry. However, it does not hinder the development of the industry because of the lack of capital. Various consortia and venture capital institutions have seen the future development of smart home, and invested in the industry. With venture capital, a variety of emerging small and medium enterprises also joined the smart home production and research and development. In the process of capital allocation, it not only reflects the support of small and medium-sized enterprises, but also reflects the combination of capital and large enterprises. Large household electrical appliance enterprises are working with the consortium and venture capital continue to improve the technology of smart home. They combine smart home with web browsers. Smart home network browsing allows it to carry out their own indicators of the collection and diagnosis, and can monitor their own performance. The strong research and development of these companies not only makes some intelligent products continue to emerge, but also makes the existing electronic products gradually intelligent and humane. TV, cameras and other home appliances can be remote control. People can choose a variety of functions. It shows more intelligent from the operation of electronic products to the use of home appliances.

At present, the development and application of intelligent home control system in our country are still in the initial stage. However, the smart home market has shown a prosperous development of the scene at this stage. "Twelfth Five-Year Plan" also made it clear that the smart home is taken as one of the directions of nurturing new industries. In the strong support of the Internet of Things, China's intelligent home control system will usher in a new period of prosperity. However, in the past decade, China's smart home market has encountered bottlenecks. In most homes, smart home systems are still a concept that does not form a consumer. China's smart home industry development status is not good, and it has a lot of problems. For example: China's smart home system technical standards are not uniform. Intelligent home system is poor operability and expensive. Over the past ten years, although the smart home system makes a lot of conceptual products become a reality, it cannot meet all the needs of people. The most important reason is that the stability of the smart home control system products is not strong, and the compatibility is still very immature. Therefore, the actual effect is very different, and it cannot achieve the desired effect.

At this stage, the development of China's real estate industry strongly supports the smart home industry, which has created a new direction and development goals for the development of the real estate industry. IT companies began to study the intelligent home control system from the practical point of view. Statistics show that 70 % of households in China have broadband networks [14]. In the process of urbanization, about 50 % of households achieve intelligent control. Although the smart home control system started late, some well-known traditional home appliance industry giants have entered the smart home industry, such as Haier, TCL and so on. These companies have invested a lot of money to study smart home technology. Basically, most home appliance companies are trying to launch their own flagship smart home products, such as Haier group launched the "U-home", and TCL launched the "mihome my intelligent housekeeper". Millet and developers cooperate to study the support of home appliances projects, which forms a smart home family experience closed-loop. It has been applied to a certain extent [15].

3. Methods

3.1. Overview of intelligent home energy scheduling algorithms

In the intelligent home energy dispatching algorithm, the user side of the renewable energy efficiency, low electricity costs, user comfort and the power grid side of the peak ratio and the avoidance of the rebound peak both are the main needs of intelligent home system development. It is also an important performance indicator for the merits of smart home systems. Their relationship is close and mutual influence. In the case of only considering the energy efficiency and electricity consumption, this may lead to a reduction in user comfort or the emergence of the peak of the grid side rebound. However, the optimization of user comfort will increase the peak to average ratio. Therefore, how to balance multiple objects of smart home energy scheduling algorithm is the current research hotspots. Based on the comprehensive consideration of multiple influencing factors, and from the general research methods that have been studied, this paper summarizes the technology and their characteristic related to the energy dispatching mechanism from different aspects, and analyzes its limitations and advantages. A reasonable method of energy dispatching algorithm is designed and applied.

In the scheduling area, there are multi-user energy scheduling algorithm and single-user energy scheduling algorithm. The energy scheduling algorithm focuses on how to coordinate the behavior of multi-user electricity to protect the stability of the power grid. User privacy issues are an urgent need to address the problem, and it lacks user comfort considerations. The indoor energy dispatching algorithm focuses on how to coordinate the operation of home appliances in the home to reduce the cost of the family and how to ensure comfort. However, it will affect the stability of the grid in the actual grid environment. Therefore, in the scope of scheduling, we need to achieve the combination of indoor scheduling. On the basis of ensuring the user comfort and optimizing the electric charge, we should take into account the stability of the grid. This will be the main direction of the future research.

In the aspect of data information providing technology, the basic information of scheduling algorithm is mainly provided by real-time information acquisition technology and prediction algorithm. Among them, the energy scheduling algorithm based on real-time information is more flexible and real-time, but it has a great influence on the stability of grid side. By using the prediction algorithm, the energy dispatching algorithm obtains the basic information needed for scheduling, so as to realize the large-scale pre-scheduling of the home equipment. According to the different forecast data, it is divided into electricity price prediction and energy consumption prediction. The energy dispatching algorithm based on electricity price forecast has some effect on reducing the peak-to-peak ratio of the grid and preventing the rebound peak. The energy dispatching algorithm based on energy consumption forecast has some effect on the comfort of the user and the stability of the grid side grid. Because of the inevitability of the difference between the predicted information and the real-time information and the unavoidability of the occurrence of an unexpected event (artificially open the equipment without the task of the task) during the scheduling process, there is a disadvantage of the predictive energy scheduling algorithm, that is, the processing capacity of real-time information. Therefore, on the basis of the forecast, it realizes the pre-scheduling repair through real-time scheduling, thus combining the advantages of the two scheduling. This is the only way to the development of smart home energy management strategy.

In the aspect of user participation, the existing intelligent home system embedded in the energy dispatching algorithm mainly includes simple functions such as setting the parameters of the scheduling range and the user's sudden intervention operation. Most of the energy scheduling algorithms have less consideration for user interaction. Under the premise of simple operation, the effective use of user interaction technology can enhance the observation and protection of user comfort. At the same time, after the user feedback information is dataized, it is applied to the feedback of the intelligent algorithm. According to the user feedback information, the algorithm can be adjusted in time, so that the algorithm is more close to the actual needs of the user, to achieve intelligent user feedback information processing unit. These are not only an important part of user interaction, but also an integral part of the future smart home system.

Therefore, the multi-objective trade-offs and the effective combination of multiple technologies will further develop the energy dispatching algorithm. Intelligent and humanized design is the key to solve the demand of energy scheduling algorithm.

3.2. The concept of dynamic comfort

In order to achieve a dynamic balance between energy efficiency and user comfort, this paper puts forward the concept of dynamic comfort. This concept refers to the dynamic relationship between energy efficiency and user comfort within 24 hours. Through the analysis of the household energy consumption data in the REDD database, we can get the operation time of the equipment within 24 hours and the frequency of use is different in the working day and the non-working day. Therefore, we set the dynamic comfort in 24 hours on weekdays and non-working days respectively. As shown in Table 1, on weekdays, in these two time periods of 09:00–18:00 and 00:00–06:00, the user's comfort requirements are relatively low, and the energy utilization rate is relatively high, so it can be set to low comfort and high energy saving state. Because in the time period of 09:00–18:00, the user is usually at work or in school, the family is less or not, so the requirements of the home environment are not very high. In the time period of 00:00–06:00, the user is in a state of sleep, and they do not have too much activity, so there is not much demand for the operation of most equipment. In other time periods, the users have higher requirements for the comfort of the home environment, and the promotion of energy efficiency is carried out under the premise of satisfying the user's comfort. Therefore, in this period of time, the dynamic comfort is high comfort and low energy state. In this period of time, the user is more active in the use of equipment, and the requirements for the home environment are high. In non-working days, in the time period of 06:00–24:00, the users have higher requirements for the comfort of the home environment, and the promotion of energy efficiency is carried out under the premise of satisfying the user's comfort. Therefore, in this period of time, the dynamic comfort is high comfort and low energy state. In the non-working days, in this period of time, the user's activities are more frequently, and the use of equipment is higher.

Table 1. The distribution of the dynamic comfort

	Time	Comfort requirements	Energy-saving requirements
Working day	06:00-09:00	high	low
	18:00-00:00	high	low
	00:00-06:00	low	high
Non-working day	09:00-18:00	low	high
	06:00-00:00	high	low
	00:00-06:00	low	high

3.3. The users' feedback

In high-level entity management system (HEMS), the equipment operation display module provides a platform for users to evaluate the performance of the equipment. According to their own habits, users can evaluate the operation of today's equipment. They can point out that they are not satisfied with the equipment, and the satisfaction of the equipment running status, including the best opening time, run time and open point range. According to the difference between the feedback information and the actual operation information, the prediction algorithm and the scheduling algorithm are used to correct the algorithm. If the proposed opening range does not include the predicted optimal opening point, the feedback information is fed back to the prediction algorithm to retrain the network in the prediction algorithm. If the proposed opening range includes the predicted optimal opening point, the feedback information is fed back to the scheduling algorithm to modify the corresponding information.

4. Simulation results analysis

In this paper, we use MATLAB simulation software. The household energy data in the REDD database, the renewable energy data in IRENA-Global-Atlas, and the real-time electricity price in the Com Ed's RRTP program are used to simulate the proposed algorithm. Then, its feasibility is verified. In the case of using the scheduling algorithm and without the use of scheduling algorithm, we can verify the effectiveness of the proposed scheduling algorithm in improving the energy efficiency by comparing the daily electricity expenditure for one week, the total energy consumption of the day, and the power consumption of the grid of the day. By calculating the average offset of the device's turn-on time deviation from the user's satisfaction time, we validate the effectiveness of the proposed algorithm in improving user comfort. Through a comprehensive comparison, we verify that the proposed algorithm can achieve a good tradeoff between energy efficiency and user comfort.

In the case of using the scheduling algorithm and without the use of scheduling algorithm, the daily cost of the week is compared. The results are shown in Fig. 1.

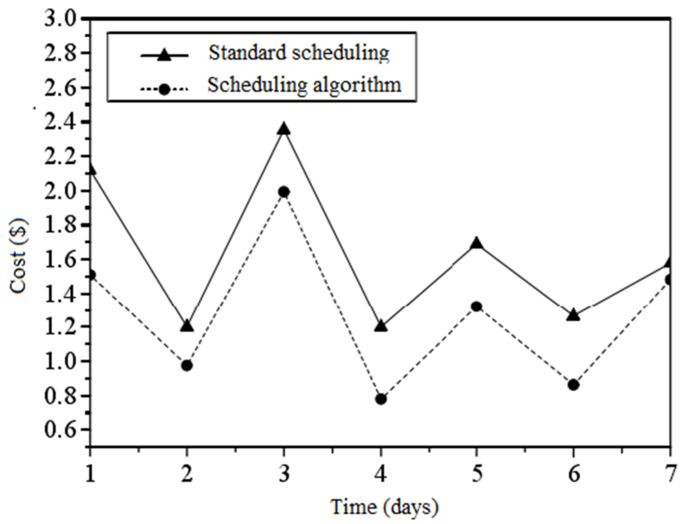

Fig. 1. The daily cost in a week

From Figure 1, it can be seen that the daily electricity bill is less when using the scheduling algorithm. The daily electricity bill is great when not using the scheduling algorithm. Through the calculation, we can conclude that the average daily 22 % of electricity bills are saved. It meets the requirements of users to reduce electricity costs. As a result, it verifies the effectiveness and feasibility of the algorithm in reducing the electricity consumption of users.

On weekdays, the energy consumption is compared for each time period by using the scheduling algorithm and not using the scheduling algorithm. The results are shown in Fig. 2. On non-working days, the energy consumption is compared for each time period by using the scheduling algorithm and not using the scheduling algorithm. The results are shown in Fig. 3.

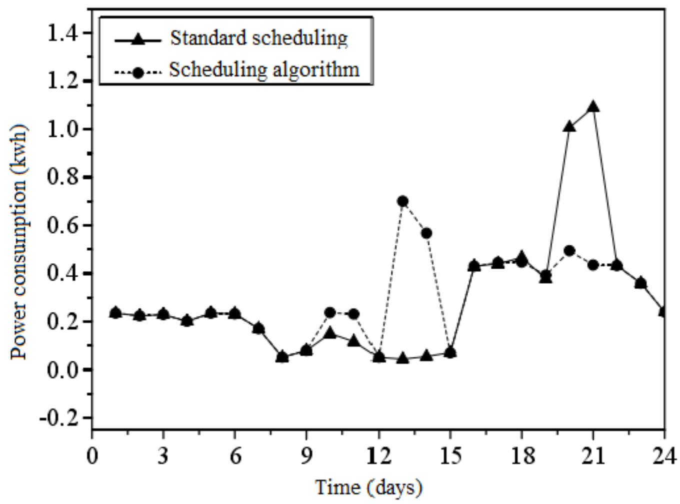

Fig. 2. The hourly electricity consumption in a workday

From Figs. 2 and 3, it can be seen that the total energy consumption is not reduced every day, but the peak of electricity has changed. The concentration of electricity in the family effectively avoids the peak price or uses renewable energy to reduce the amount of electricity consumed during peak hours, which reduces carbon emissions and household expenses.

Figure 4 shows the use of grid power under the condition of using the scheduling algorithm and not using the scheduling algorithm on weekdays.

Figure 5 shows the use of grid power under the condition of using the scheduling algorithm and not using the scheduling algorithm on non-working days.

From Figs. 4 and 5, it can be seen that the use of the scheduling algorithm for grid energy usage is significantly less than that without the use of scheduling algorithms. Among them, in the working day, an average of 38 % of the grid power usage is reduced. In non-working days, an average of 44 % of grid power usage is reduced. Combined with Figures 4 and Figure 5, it is verified that the scheduling algorithm can help users to reduce the cost of energy utilization during periods of low comfort and high energy efficiency requirements.

Figure 6 shows the average offset per hour for the turn-on time of the device after the dispatching algorithm deviates from the user's happy opening time in the

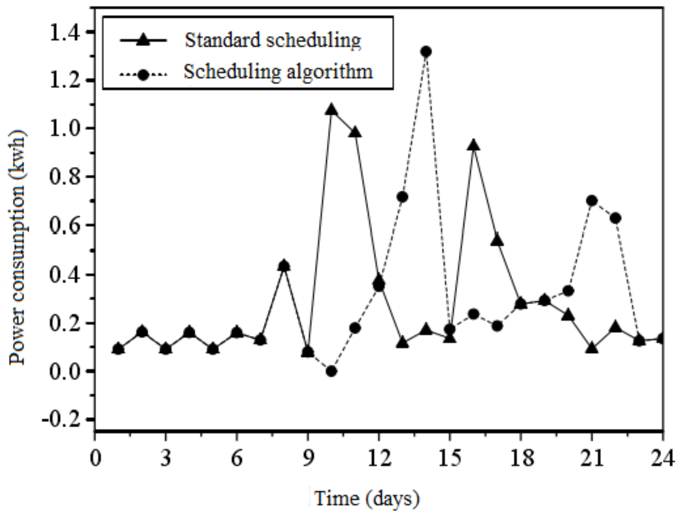

Fig. 3. The hourly electricity consumption in a weekend

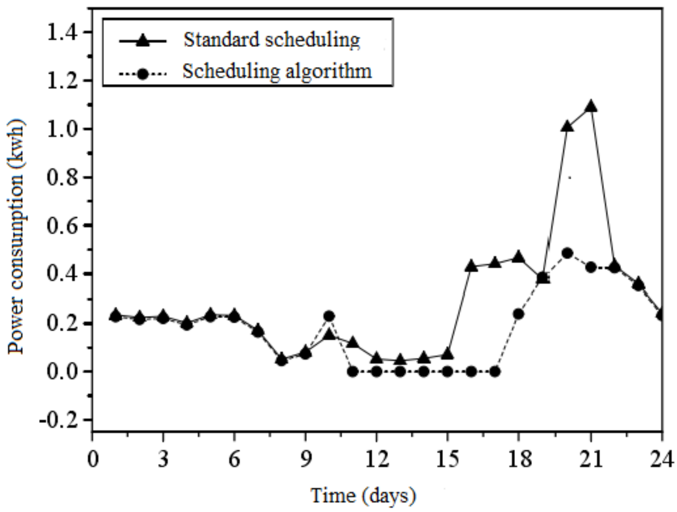

Fig. 4. The hourly grid's electricity consumption in a workday

working and non-working days. The average offset represents the average opening time of the device and the average time that the user is most satisfied with the opening time or the delay.

As can be seen from Figure 6, the offset of the device opening time is small in the period of high comfort requirement. This ensures the comfort of the user. It proves that the scheduling algorithm can effectively guarantee the user's requirements for the operation of the equipment while saving energy.

To sum up, the proposed algorithm meets the requirements of users to reduce the household power expenditure. In the period of low comfort requirements, it

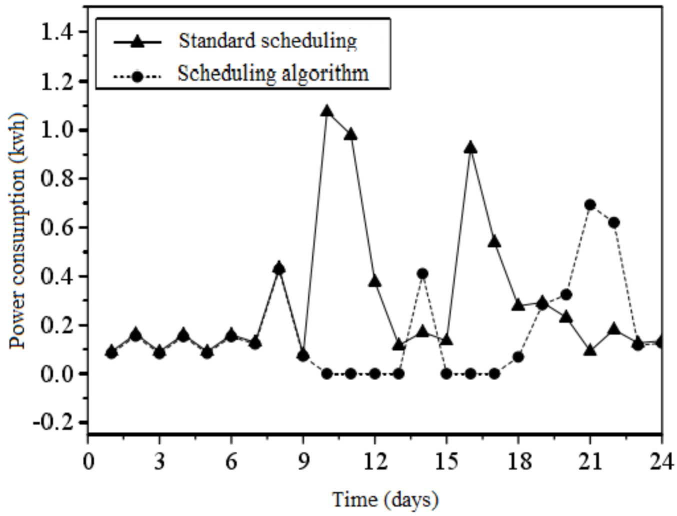

Fig. 5. The hourly grid's electricity consumption in a weekend

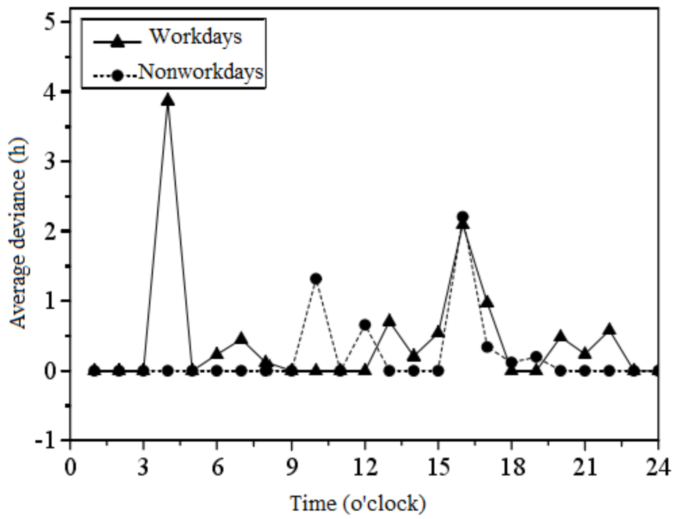

Fig. 6. The average offset of the opening time of the appliances

improves the energy efficiency. In the period of high comfort requirements, it ensures and improves user comfort. The scheduling algorithm achieves a trade-off between energy utilization and user comfort.

5. Conclusion

The scheduling algorithm distributed energy and equipment reasonably according to forecast and real-time information. The user feedback link provided the user with feedback information for the prediction algorithm and the scheduling algorithm, which can be used to correct the algorithm. The results show that the scheduling algorithm achieves a trade-off between energy utilization and user comfort. When the demand of comfort is high, it improves energy efficiency while protecting the user's comfort. When the demand of energy-saving is high, it ensures the user's comfort while improving energy efficiency.

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Received July 12, 2017