Application of Demand-side Technology in Power System Intelligent Regulation

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Abstract

To reduce peak demand for electricity, smooth load curve shape, improve power system safety and efficiency, this paper, by using intelligent home appliance user operation comfort model is set up to quantify the acceptance, this paper proposes a maximum minimum load management algorithm based on optimization strategy to change electric power use time and power consumption mode.The results show that the proposed model and algorithm can forecast and manage the power load well, and can reduce the peak to average ratio by 14.3% and the total expenditure by 15.3% while maintaining the operating comfort of power users to the maximum.The load management problem of multiple power users can reach Nash equilibrium in a finite number of iterations, and this Nash equilibrium point is also the global optimal point.

Keywords: Smart grid, demand response, load management.

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1 Introduction

The development of the electric power system has been more than a hundred years, and the rapid changes in the communication system, the electric power system is almost the same as a few decades ago. This does not mean that the existing power system is so perfect that it does not need to be improved, but because of the inherent conservatism of the power system itself, the application of high and new technologies in the power system is difficult and slow.

Since 2000, the Massachusetts Institute of Technology in the United States, the University of California, Berkeley, and McGill University in Canada have started the research of wireless sensors, which aims at protecting national security and preventing and controlling terrorist attacks. This is the first starting point of smart grid research in the world. In 2003, the "8.14" power outage in the United States and Canada exposed the deficiencies in the regulation and control of the traditional power system, and the safety and stability of the power grid attracted the close attention of various countries. The Electric Power Research Institute (EPRI) defined the future electric grid as "Intelligrid" in 2003, the same year the U.S. Department of Energy released its "GIRD2030" vision. In 2005, the SmartGrids European Technology Forum was formally established, which put forward the concept of SmartGrids and set up a corresponding strategic research agenda to promote the realization of SmartGrids. In China, State Grid Corporation of China started to implement "SG186" project in 2005. In 2007, East China Power Grid officially launched the Smart Grid Feasibility Study Project.

Smart power grid can be regarded as the synonym of the next generation power grid, which integrates advanced sensing technology, communication technology, computing and control mechanism, etc., aiming to provide power users with more reliable, safe, economic, effective and friendly power services, and improve the overall function of the entire power transmission system. In addition to environmental friendliness, the friendlier power grid also includes the characteristics of user friendliness, that is, it encourages and promotes the user to participate in the operation and management of the power system. The traditional research and application of user demand side management (DSM) takes the price of electricity as the only incentive factor to encourage users to adjust power consumption, ignoring the users' own feelings when they change the original power consumption mode.

In the traditional power grid, there are some problems such as low user participation, non-standard user management and interactive service standard system. Smart grid is characterized by friendly interaction. By adopting advanced measurement system, home domain network, two-way communication and remote control technology, intelligent management of power users' demand side is realized. Through two-way interaction, the user side is encouraged to actively participate in the safe and efficient operation of the power grid, so as to realize the optimal allocation of power generation and electricity resources.

In most of the researches on power demand side management, in order to change the load shape, the incentive provided is usually a single price incentive. The biggest characteristic of smart grid is centered on power users, who are the ultimate beneficiaries of load management. Therefore, in DSM, the acceptance of power users to changes in working hours or modes of electrical appliances must be taken into account.

Therefore, this paper introduces the concept of "user operating comfort" to quantitatively study the impact of changing power consumption plan on power users.

The power system intelligent control technology develops rapidly, and there are many researches at home and abroad. Chen et al. studied the application of intelligent technology in the automatic control of power system, and analyzed its application advantages from the aspects of power generation process, power consumption process and scheduling [1]. Fang et al. analyzed the application of intelligent technology in power system based on the status quo of intelligent application technology in power system [2]. Guo et al. studied the problems existing in the operation of the power system monitored by intelligent technology, so as to avoid affecting the normal operation of the system, save the cost for the power enterprises and guarantee the daily life needs of the people [3]. Yuan et al. improved the measurement technology of the temperature monitoring system for large transformers of 330MW units in China, replacing the mechanical contact temperature controller with a digital intelligent temperature controller. Resistance type temperature sensing element replaces thermal expansion and cold contraction type temperature sensing element, making the transformer temperature monitoring system more accurate, stable and reliable, and more suitable for the needs of safe production and long cycle production [4].

The traditional power grid system generally adopts the one-way transmission mode from the power system to the power users. Smart power grid has the characteristics of two-way flow of power and information. By applying distributed computing and real-time communication technology, real-time supply and demand balance can be realized at the equipment level. In power demand side management (the operation of modern distribution network is also related to efforts and incentives that affect user behavior and load usage changes, known as demand side management (DSM)), with the development of wireless sensor network (WSN) and power line carrier (PLC) technology, it is possible for users to interact with each other in smart grid. From the perspective of smart grid, user demand can be seen as a manageable resource, which will help balance supply and demand and ensure the reliability and stability of the power system. From the perspective of power users, they can maximize their own interests by participating in the operation and management of the power system and optimizing the way of purchasing and using power. Users can adjust the mode of electricity consumption according to their own power demand and the ability of the power system to meet their demand, so that the power demand can be cut down from the peak load period of the power grid or transferred to the trough load period of the power grid, that is, load management can be realized. In China, the power demand side management in smart grid is still a relatively new topic, which has high theoretical research value. Especially, the power user demand-side management based on user comfort is rarely mentioned by scholars in the existing studies. Pathan et al. discussed the dominant position of remote power supply technology in the future sustainable development of energy through the application of remote power supply technology in the power demand side [5]. Wang et al. studied the development of energy storage technology under demand side response [6]. Liu et al. proposed a Network Physical System (CPS) based on Multi-Agent System (MAS) technology to realize intelligent demand side management system (DSM) [7]. Amato et al proposed a new demand-side management concept. It was implemented by a utility company focused on renewable energy. Through a specific billing mechanism, consumers are encouraged to balance the load and supply.A game theory approach models households as autonomous rational energy users who want to reduce personal electricity costs [8]. Pilz et al. proposed a fully distributed collaborative demand-side management framework based on adaptive diffusion strategy. In this method, each customer is autonomous and does not need any global information, thus minimizing the discomfort of customers [9].

The core idea of this paper is to take power users as the center of all demand-side management work. Therefore, through the method of quantifying the operating comfort of power users, the operating comfort of users is taken as the index to select the appropriate load change strategy. Striving to minimize the operating comfort of power users in the process of peak shifting and valley filling.

2 Research Methods

2.1 Single Intelligent Home Load Management Algorithm

The maximum and minimum algorithm was first used in artificial intelligence. This paper uses the basic idea of the maximum and minimum algorithm for reference and applies it in the process of load management. By embedding the designed maximum and minimum algorithm in the Energy Control System (ECS) of smart home to generate the optimal load strategy. The basic idea of the algorithm is to adjust the load in the hour when the load is maximum until all load values per unit time do not exceed the threshold value. Firstly, through short-term load prediction, find the hour with the highest load in the next 24 hours and judge whether the load value of this hour is greater than the set threshold value THR. If it is less than THR, the program will end; If it is greater than, find out the electrical appliance whose operating comfort of the user is minimized by changing its working time (for time-shifting electrical appliance) or working mode (for temperature-controlled electrical appliance) and move or reduce the load among all the electrical appliances working in this hour. Then recalculate the hourly load value and repeat the above steps until all the hourly load is no more than the threshold value, and the program ends.

2.2 Multiple Intelligent Home Load Management Algorithms

The load management problem of multiple smart homes is considered, and the idea of game theory is used to construct the power consumption game problem. When all power users reach the Nash equilibrium, the global optimum is reached.

The system model of this paper: A power market provides power services for I smart homes, and A smart appliance is included in one smart home. Through the two-way communication technology, power users can get the price information, power market can grasp the power users' load situation in real time.

3 Result Discussion and Analysis

3.1 Single Intelligent Home Load Management Algorithm

The naming of specific parameters in the formula is shown in Table 1:

Table 1 Parameter named indexes

Index	
i	The i-th power user, i = 1,... I
a	The A smart appliance, a = 1,... A
h	Hour h, h = 1,... H
avg	The average of 1 time period
Parameter	
thr	Load threshold value, that is, the maximum hourly load in a day
l_a^h	The load value at hour h of intelligent electrical appliance A
Variable	
Δh	Change in working time of intelligent electrical appliances
Δl	Change in workload of intelligent electrical appliances
s	Intelligent electric start working time
d	Duration of intelligent electrical appliances
l	Intelligent electrical work load value
c	User operating comfort
p	Electricity prices
A collection of	
I	All power users set
A	All intelligent appliances set
H	H = 24

Firstly, the model of time – of – use electricity price is established. In this paper, the 24-hour load is divided into three periods of peak time, normal time and valley time. The conditions for the electricity price of these three periods are as follows:

$$P_f = P_p + \Lambda \quad (1)$$

$$P_g = P_p - \Lambda \quad (2)$$

P_f, P_p, P_g represents peak electricity price, normal electricity price and valley electricity price respectively, and is the pull off ratio.

The load management optimization problem established by drawing on the idea of the maximum and minimum algorithm used in the traditional communication field to allocate channel power is as follows:

$$\mathrm{Min}\sum_{a=1}^{A}\Delta C_a \tag{3}$$

$$\mathrm{Max}_{h\epsilon H} \le \mathrm{thr} \tag{4}$$

Where THR represents the threshold value of unit load, that is, after load adjustment, the load value of each hour is not higher than the set threshold value [10].

In the clear model, parameters, algorithm, now through an example to verify the effectiveness of the proposed algorithm.Combined with the optimal operation mode model of electrical appliances, the threshold value is set as 3600W, and then load management is carried out.

This paper compares the differences before and after DSM from the four indexes of threshold value, user comfort, peak to average ratio and electricity bill.

Threshold value: Threshold value is set in advance by power users according to their own power demand and electricity budget, which determines the load peak value in load management results. Through load demand side management, the peak load decreased from 6200 W to 3600 W, a decrease of 42%.

Operating comfort (OCL): The power user operating comfort is a key parameter in this paper, which represents the power user's acceptance of demand response.

After the load adjustment, the comfort decreased from 45 to 35. In this load management strategy, dishwashers and electric cars have been run for different hours, and the setting temperatures of air conditioners and water heaters have been changed.When the set threshold value is different or the user's operating comfort model is different, the user's operating comfort is also different. Power users can choose the most appropriate load management strategy according to their own needs.When the threshold value is set too low, the user's comfort level will decline sharply, which will directly affect the normal life of power users.When the threshold value is set at 3550, the user's comfort level is only 32. The low threshold value causes the load management system to be forced to change the set temperature of the refrigerator to achieve the algorithm goal.However, the adjustment of refrigerator temperature is difficult to accept for most power users, which directly affects the participation of power users in demand response projects.

Peak to Average Ration (PAR): Peak to Average Ration (PAR) is one of the important parameters to evaluate the effect of grain filling in the load management strategy, which is defined as:

$$\mathrm{PAR} = \frac{\mathrm{L_{peak}}}{\mathrm{L_{avg}}} = \frac{\mathrm{H l^{h}_{peak}}}{\sum_{\mathrm{h=1}}^{\mathrm{H}} \mathrm{l_h}} \tag{5}$$

Before demand-side management, the peak-to-average ratio was 2.62. After demand response, the peak-to-average ratio dropped to 2.45, which was about 6% lower than the original value. The reason why the peak-to-average ratio decline in this paper is not as significant as the result of demand-side management in some literatures is that most researches on load side management only consider time-shifting appliances, so the average load is a constant. In this paper, two kinds of intelligent electric appliances, time shift and temperature control, are considered. The controllable temperature electric appliance directly reduces the peak load and at the same time reduces the overall average load from 2367 W to 1467 W.

Total electricity cost: In this paper, it is assumed that the electricity price in normal period is 0.25 cent/kWh. Through calculation, it can be seen that the total electricity cost in 24 hours decreases from \$9.18 to \$4.46, a decrease of 51.4%. The details are shown in Figure 1.

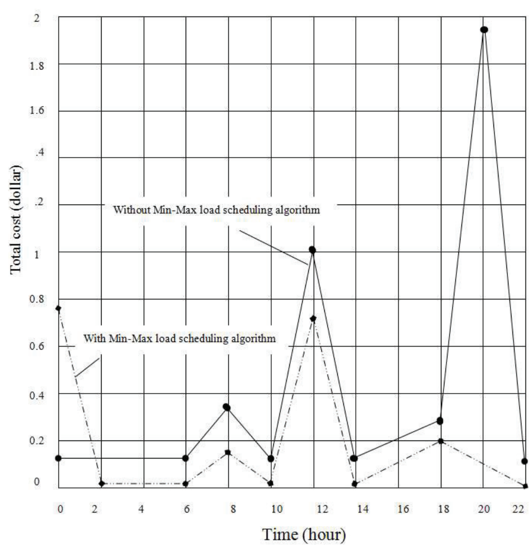

Figure 1 Comparison of energy costs before and after load management.

3.2 Multiple Smart Home Load Management Algorithms

The optimization problem of load management is divided into two parts: minimization of user operating comfort and minimization of electricity cost.

Minimization of user's operating comfort can be expressed as:

$$\mathrm{Min}\sum_{i\in I}\sum_{a\in A}\Delta C_{i,a} \tag{6}$$

Electricity minimization can be expressed as:

$$\mathrm{Min}\sum_{h=1}^{H}P_h\left(\sum_{i\in I}\sum_{a\in A}l_{i,a}^{h}\right) \tag{7}$$

The electricity price is still in the form of time-of-use electricity price, and the electricity price function is an increasing strictly convex function, namely:

$$p^h(\widetilde{l^h}) < p^h(\widehat{l^h}),\ \forall\widetilde{l^h} < \widehat{l^h} \tag{8}$$

$$p^h(\theta\widetilde{l^h} + (1-\theta)\widehat{l^h}) < \theta p^h(\widetilde{l^h}) + (1-\theta)p^h(\widehat{l^h}) \tag{9}$$

Based on the above formulas, the objective function of this problem is:

$$\mathrm{Min}\left(\alpha\sum_{i\in I}\sum_{a\in A}\Delta C_{i,a} + \beta\sum_{h=1}^{H}P_h\left(\sum_{i\in I}\sum_{a\in A}l_{i,a}^{h}\right)\right) \tag{10}$$

Where α and β are normalized coefficients. This function can be evaluated by Interior Point Method (IPM).

The game problem of load management depends on the strategy taken by a single user after the actions of other users. The three elements are:

Players: A collection I of all power users involved in load management.

Strategies: Each user chooses the most suitable electric energy use vector $x_i \triangleq [a, s, d, l, c]$

Payoffs: After choosing the optimal strategy, it achieves the minimum reduction of comfort level and the minimum electricity cost. The formula is expressed as:

$$P_i\,(x_i\colon x_{-i}) = -\left(\alpha\sum_{i\in I}\sum_{a\in A}\Delta C_{i,a} + \beta\sum_{h=1}^{H}P_h\left(\sum_{i\in I}\sum_{a\in A}l_{i,a}^{h}\right)\right) \tag{11}$$

$x_{-i} \triangleq [x_1, \ldots x_{i-1}, x_{i+1}, \ldots x_I, \ldots]$ represents the power usage policies of all power users except the i-th power user.

If and only if all power users are optimal, the optimal strategy is expressed as * IX, the whole game problem reaches the Nash equilibrium point, and each power user no longer adjusts his or her power consumption strategy. Since the objective function of the optimal problem is an increasing strictly convex function, the found optimal advantage is the global optimal advantage.

$$P_i(x_i^*:x_{-i}^*) \geq P_i(x_i:x_{-i}^*), \forall i \in I \tag{12}$$

In order to verify the effectiveness of the designed algorithm, the simulation experiment of load management based on game theory is carried out. Assume that there are 10 smart homes under a power user interface, i.e. $I = 10$. There are about 10 smart appliances in each smart home, and the simulation results are shown in Figure 2.

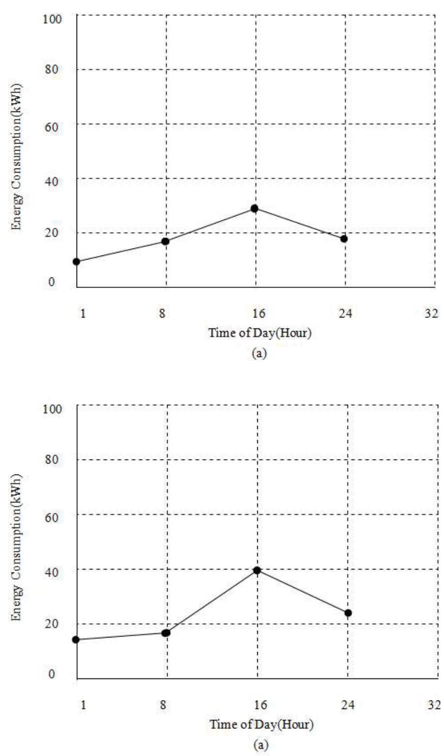

Figure 2 Continued

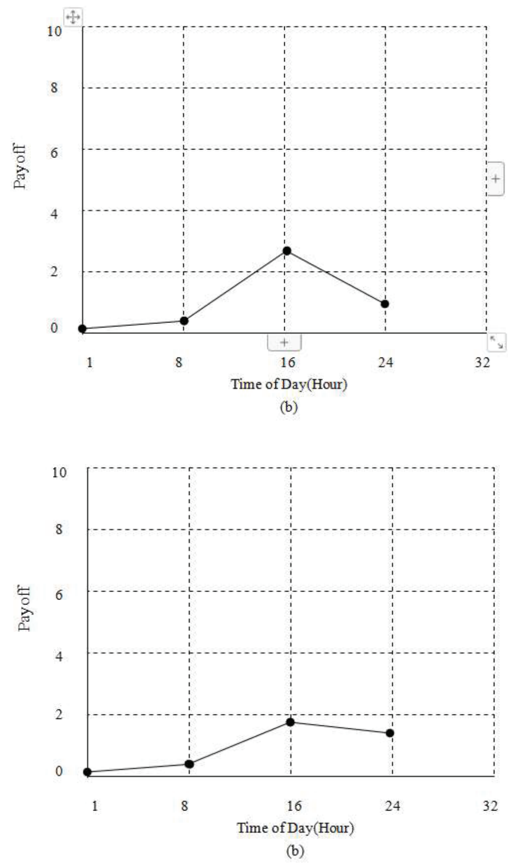

Figure 2 Comparison of power consumption and revenue before and after load management.

Before DSM, the peak-to-average ratio is 2.1, and the total expenditure (including comfort reduction and electricity expenditure) is 44.77. After load optimization adjustment, the peak to average ratio was reduced to 1.8, a 14.3% decrease, and the total expenditure was 37.90, a 15.3% decrease.

4 Conclusions

This paper proposes the power demand side load management algorithm: (1) For a single power user, the maximum and minimum algorithm is used to make the optimal load management decision. The simulation results show that the algorithm has good performance, which can well reduce the power consumption, peak-to-average ratio of load and electricity expenditure, while keeping the maximum operating comfort of power users, and ensuring the enthusiasm of power users to participate in the demand response. (2) For multiple power users, a game model is established to solve the problem of load optimization management, in which the players of the game are power users, the strategy is the operation mode of intelligent electric appliances, and the revenue is the negative of user comfort and electricity cost. The experimental results show that the load management problem of multiple power users can reach Nash equilibrium in a finite number of iterations, and this Nash equilibrium point is also the global optimal point.

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Biographies

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