A simple polymerization control method for the air conditioning cluster

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Abstract: Taking the air conditioner cluster as the object, under the condition of individual perception and controllable state of the air conditioner, the cluster state is given a considerable and controllable function. In the analysis of the load model of a single air conditioner, considering the comfort of indoor temperature, the characteristics of on and off are given, that is, the cycle of on time and off time; on this basis, the air conditioning clusters are divided according to the same or similar switching cycles, thereby forming a switching strategy of series and parallel groups to achieve load balance. In the on state, if the adjustment of the power of the air conditioner itself is not considered, a simple aggregation control method is given. The analysis of numerical examples shows that this method is simple and reliable.

1. Introduction

With the rapid development of the national economy and the continuous improvement of people's living standards, the power consumption of the power system keeps rising, and the phenomenon of power shortage is becoming more and more serious[1]. Due to the adjustment of China's industrial structure, the proportion of electricity consumption and electricity consumption in the tertiary industry is increasing year by year, and the air-conditioning load in the power terminal equipment accounts for a large proportion[2]. This kind of load is characterized by large quantity and large total capacity, which generally constitutes peak load[3] and leads to the further widening of peak-valley difference.

In modern society, air conditioning is a major category of electricity load, which has become an important reason for power shortage of power grid electricity load in hot summer and cold winter[4]. Blindly being passive to meet this demand, is bound to need a large number of low utilization of power supply, because of large investment, high cost and cause huge economic losses. At the same time, when large-scale air-conditioning load is put into use, because its own start-stop conditions are affected by environmental changes, it will produce great volatility and time-variability[5], which will bring huge burden to the safe and stable operation of the power grid, and even destroy the stability of the power grid operation. Due to its thermal storage capacity, the air conditioner has good demand response potential [6]. However, the number of air-conditioning loads is huge and the distribution area is wide. For the power system, to control this kind of load, the first step is to establish an accurate aggregation model. In recent years, relevant researches have been carried out on air conditioning aggregation model at home and abroad, mainly considering the division of state space and reasonable grouping of air conditioning load group. The equivalent thermal parameter model and state queue model that can simulate the heat exchange process of air conditioning are adopted in literature [7]. It is assumed that the running state of air conditioning is uniformly distributed and the aggregation state of
air conditioning group can be represented by some continuous state queues, and then the aggregation model of air conditioning group is presented. Literature [8] describes the variation of air conditioning operating state based on the state queueing model, and studies the performance of polymerization air conditioning load at different electricity price levels. In the literature [9], the state space is divided according to temperature, and the operating state of air conditioning is divided into some state units, and the aggregation model of temperature state space is established. The time-varying characteristics of the aggregation model can be realized through the state transition matrix. Literature [10] proposed an air conditioning load control strategy based on improved state space model, which expanded the length of state space and established a more accurate improved state space model. Load regulation of air conditioning groups was realized through temperature control, but there were too many state divisions and no specific control strategy of air conditioning load was given. Literature [11-12] proposed the clustering grouping method and the dynamic optimization method of the group rotation control for a large number of distributed air-conditioning loads, and used the improved temperature regulation method to control the distributed polymerization air-conditioning.

But with the maturity of real-time measurement, state perception and Internet technology, every air conditioner is installed with intelligent controller, all state information of air conditioning load can be obtained, and the start and stop states of air conditioning are controllable. On this basis, there is no need for cluster analysis and state analysis of the air-conditioning system, only need to arrange the reasonable start and stop sequence, to achieve large-scale aggregation regulation of the air-conditioning system. In view of the above considerations, this paper takes air conditioning load as the main control object, and on the basis of considering user comfort, takes a certain number of air conditioning load as a control unit through successive delayed start and stop, regarding large-scale air conditioning load as the superposition of many control units to build an aggregation model of air conditioning load.

2. Materials and Methods

2.1 Air conditioning individual switching characteristics

2.1.1 Thermodynamic model of air conditioning unit

In order to simulate the operation process of air conditioning load, equivalent thermodynamics (EquivalentThermal Parameters, ETP) model is widely used at present[13]. In actual modeling, if the room wall temperature is assumed to be equal to the air temperature in the room, the first-order equivalent thermal parameter model of electricity load regulation of air conditioning can be obtained, as shown in Fig. 1, which can be expressed as formula(1):

$$\frac{dT_i}{dt} = \frac{1}{R_iC_a}(T_o - T_i) - \frac{Q}{C_a}$$  \hspace{1cm} (1)

In formula (1), $R_i$ is equivalent thermal resistance; $C_a$ is the equivalent specific heat capacity; $T_o$ is the external environment temperature; $T_i$ is indoor gas temperature; $Q$ is heat produced.

Fig. 1. First-order equivalent thermal parameter model

The above model can be simplified to obtain:

When the indoor temperature falls below the comfort limit, the air conditioning system stops working and the indoor temperature changes as follows:
When the indoor temperature is higher than the comfort temperature upper limit, the air conditioning system starts to work, and the indoor temperature changes are as follows:

$$T_{in}^{t+1} = T_{in}^{t} - (T_{out}^{t} - T_{in}^{t}) \cdot e^{-\frac{\Delta t}{RC}}$$

(2)

Where, $R$ is equivalent thermal resistance; $C$ is equivalent heat capacity.

Because the building wall has a certain thermal inertia, the indoor temperature can be adjusted within a certain range on the premise of satisfying the user's comfort. If the user's comfortable temperature range is $[T_{min}^{in}, T_{max}^{in}]$, assuming that the outdoor temperature remains unchanged, the relationship between indoor temperature and air-conditioning cooling power is shown in formula (4):

$$T_{in}^{min} = T_{out}^{t} - (T_{out}^{t} - T_{in}^{min}) \cdot e^{-\frac{t_{off}}{RC}}, s = 0$$

$$T_{in}^{max} = T_{out}^{t} - Q_{R} - (Q_{R} - T_{in}^{max}) \cdot e^{-\frac{t_{on}}{RC}}, s = 1$$

According to formula (4), it can be calculated that the on time $t_{on}$ and off time $t_{off}$ of HVAC system control are:

$$t_{on} = -RC \ln \frac{T_{out}^{t} - T_{in}^{min} - Q_{R}}{T_{out}^{t} - T_{in}^{max} - Q_{R}}$$

$$t_{off} = -RC \ln \frac{T_{out}^{t} - T_{in}^{max}}{T_{out}^{t} - T_{in}^{min}}$$

(5)

A controlling period $t_{c}$ of the air conditioner system is, then

$$t_{c} = t_{on} + t_{off}$$

(6)

2.1.2 Aggregate operation of air conditioning clusters with load balancing as the goal

Due to the limitation of its own start and stop conditions, the operation characteristics of a single air conditioning system have time variability and volatility, and its regulation ability is limited, but the aggregation of a certain scale of air conditioning systems, its regulation effect will be considerable.

When the air conditioning system starts and stops naturally, the operation characteristics are as follows:
The operation characteristics of a single air conditioner change periodically with the change of indoor temperature. When the indoor temperature reaches the lowest value, the air conditioner is closed. When the indoor temperature reaches the maximum value, the air conditioner starts. This operation characteristic of the air conditioner makes the operation power curve of the air conditioner be a discontinuous rectangular wave, the air conditioner start time is $t_{on}$, the control period is $t_c$, and the duty cycle of the air conditioner load operation is $\frac{t_{on}}{t_c}$. When the number of such air conditioning load reaches a certain scale, it is bound to form a huge load fluctuation without reasonable aggregation regulation. The thermal inertia of the building wall can be used to delay the opening of air-conditioning load, and the indoor temperature will not change greatly. The effect of shifting load can be achieved within the acceptable range of user comfort, as shown in Fig 3:

From Fig 3, regarding $\frac{t_c}{t_{on}}$ (integer) as a control unit, in the control period, the unit of air
conditioning load delays time $t_{on}$ to open, When the control period $t_c$ is an integer multiple of the start time $t_{on}$ of the air conditioner, the aggregation effect is the best, and the duty ratio of the air conditioner in one control unit is 1. The control unit of the air conditioning load average power is $P$. When an air conditioner aggregate has $n$ air conditioners and the $n$ air conditioners are divided into $t_{on}/t_c$ control units, the aggregation effect of air conditioning loads is the superposition of the average power of air conditioning loads of all control units, and the aggregation characteristics of air conditioning loads are as follows:

$$P_c = \frac{t_{on}}{t_c} nP$$  \hspace{1cm} (7)

3. Results & Discussion

According to the data in reference [14], taking a typical summer day as an example, the outdoor temperature is 36°C in the period from 11:00 to 13:00 when air conditioning load is most used. The scale of the air conditioning cluster is 10000 units, the thermal resistance $R_1$ is 5.56, the heat capacity $C_1$ is 0.18, and the user side comfort range is different, respectively 23°C-29°C and 23°C-27°C, air conditioning power is 2.5kW and energy efficiency ratio is 2.7, comparing the aggregation effect of air conditioning load. According to formulas (4)-(6), the opening and closing time of air conditioning and the control cycle of air conditioning load are solved:

$$\begin{align*}
  t_{on} &= 10 \text{ min} \\
  t_{off} &= 20 \text{ min} \\
  t_c &= t_{on} + t_{off} = 30 \text{ min}
\end{align*}$$

$$\begin{align*}
  t_{on}' &= 4 \text{ min} \\
  t_{off}' &= 13.5 \text{ min} \\
  t_c' &= t_{on}' + t_{off}' = 17.5 \text{ min}
\end{align*}$$

The aggregation effect of air-conditioning loads is shown in Fig 4:

The black line and the red line in the figure respectively represent the aggregation effect of air conditioning loads when the user’s comfort level is 23°C-27°C and 23°C-29°C. It can be seen from the
figure that the aggregation of the air-conditioning load under the two comfort levels is relatively high. Ideally, at 23°C-29°C where the user's comfort level is tolerable, the air-conditioning load curve after polymerization has a smaller discontinuity angle. Compared with the 22°C-27°C situation where the tolerable range of comfort is smaller, the average power of the air conditioning load is aggregated to a lower level by sacrificing user-side comfort, and the aggregation capacity of the air conditioning load is further explored.

4. Conclusion
This paper proposes a simple aggregation method of large scale air conditioning group, use of building wall thermal inertia and thermal storage air conditioning load capacity, delay will have a certain number of air conditioning open, constitute a minimum control unit, realize the air conditioning load duty ratio is 1, so as to reduce air conditioning load fluctuations, increase the average load rate. Based on the minimum control unit, a large number of control units are superimposed to form the aggregation model of large-scale air-conditioning system.

Since the opening time and control period of air conditioning load are related to indoor temperature, the aggregation effect of air conditioning load corresponding to the comfort tolerance range has an important influence. When the comfort tolerance range is large, the average power of air conditioning load aggregation can reach a lower level, which is also more conducive to the economic operation of the user side. By controlling the upper and lower limits of indoor temperature, the ratio of the control cycle to the opening time can be relatively close to the integer, so that the discontinuous Angle of the air-conditioning load curve after polymerization can be as small as possible, and better polymerization effect can be achieved. The study in this paper is only a beginning, and further research can be carried out in the future on the aggregation characteristics of air conditioning loads under the premise of the diversity and responsiveness of air conditioning loads, as well as the fully controllable opening and closing time.

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