Control Strategy of Central Air-conditioning Load Participate in Peak Adjustment

LinHong¹ SanNate•saierjiang ²

¹ School of electrical engineering, Xinjiang University. Uramqi 830047 China
² State Grid Electric Power Co. Ltd. Urumqi power supply company. 830011 China

Author brief introduction: Lin Hong(1969-), female, Ph.D., Associate Professor, Research Direction: Power System Stability and Control and Wind Power Generation Technology. E-mail: xjulh69@163.com.

Abstract. At present, the proportion of air-conditioning load on the user side is increasing, and the air-conditioning loads have the ability to store thermal energy. By reasonable controlling air-conditioning loads to participate in peak adjustment, the potential of air-conditioning load regulation can be effectively played. In this paper, a temperature control model of central air-conditioning loads is established based on the calculation method of building cooling load. Fully the periodic paused control strategy for central air-conditioning load is proposed to release the conflict between electricity supplying and demanding in the period of peak load, considering the heat storage and heat dissipation characteristics of buildings and the heat dissipation characteristics of changing flow rate of people, without affecting or less affecting the users comfort. Then, taking a business district as an example, the feasibility of temperature control model of central air-conditioning and the hierarchical strategies periodic paused control strategy is verified.

1. Introduction
At present, with the continuous development of China's power industry, the load of electricity is facing swift growth. Especially, the air-conditioning loads have the tendency of gradual increasing year by year[1]. The thermal storage characteristics of air conditioning loads inside the building can be used as a virtual energy storage device. So the air-conditioning loads can reasonable regulated to participate in the active power dispatch. On the premise of not affecting or less affecting the users comfort, reasonable management and configuration of air conditioning loads are carried out to ensure the balance between supply and demand.

Domestic and foreign scholars have carried out a lot of studies in the area of air-conditioning load modeling and control. Ref.[2] established the equivalent thermal parameter model of air-conditioning load. The bi-level optimal dispatch and control model for air-conditioning load based on direct load control was proposed. Ref.[3] established the equivalent thermal resistance model for building walls and windows to study the air-conditioning loads. However, the internal environmental factors of buildings are not fully taken into account. Ref.[4] proposed a combinatorial regulation model of public building’s air-conditioning loads for jointly participation in day-ahead peak load reduction. Ref.[5] studied the three modes to control the air-conditioning loads: start stop control, periodic pause control and temperature control. The modes of periodic pause control and temperature control have more advantages in saving electricity and satisfying the users comfort requirement. Ref.[6,7]studied
aggregation control strategy of air-conditioning load. The load control strategy for cluster air conditioning based on load diversity maintenance is proposed. In summary, there are few researches on building cooling load modeling methods.

In this paper, the temperature control model of central air-conditioning load is established based on calculation method of building cooling load and taken full account of the internal characteristics of buildings and the characteristics of people in different periods of shopping malls. Secondly, the periodic paused control strategy for central air-conditioning load is proposed to releasing the conflict between electricity supplying and demanding in the period of peak load, without affecting or less affecting the users comfort. Finally, taking a business district as an example the feasibility of load temperature control model of central air-conditioning and periodic suspension control strategy by stages is verified.

2. Building temperature time varying model based on cold load calculation

The relationships of various cooling loads affecting indoor temperature are shown in Fig. 1. A calculation model of various cooling loads in buildings is established based on the law of conservation of energy.

In fig.1 $Q_1$ is hourly cooling load caused by transient heat transfer of enclosure structure; $Q_2$ is the cooling load caused by the heat of the sun through the windows; $Q_3$ is the cooling load caused by heat dissipation of human body; $Q_4$ is the cooling load of indoor equipment and lighting; $Q_5$ is the new wind load; $Q_6$ is building enclosure structure thermal storage; $Q_{ac}$ is of refrigerating main engine cooling; $Q_{melt}$ is ice storage tank cooling.

The thermal balance expression of indoor air temperature during air-conditioning refrigeration period and shutdown period is shown in (1).

$$p_{air}V_kC_pdT_{in} = (Q_1 + Q_2 + Q_3 + Q_4)dt + Q_5dt - Q_6 - Q_{ac}dt \cdot S(t)$$ (1)

Where $Q_1 = K_1 \cdot F_1 \cdot [T_f(t) - T_{in}(t)] + K_2 \cdot F_2 \cdot [T_{out}(t) - T_{in}(t)]$; $Q_2 = F_2 \cdot C_z \cdot C_a \cdot D_{j,max} \cdot C_2$; $Q_3 = q_m \cdot m_0 \cdot C_3 + q_l \cdot m_0$; $Q_4 = (k_e \cdot N_e + k_i \cdot N_i) \cdot F_4$; $Q_5 = 1.01G_k \cdot [T_{out}(t) - T_{in}(t)] + 38.5G_k$; $Q_6 = S_0 \cdot F_6 \cdot dT_{in}(t)$; characteristic $K$ ($W/m^2 \cdot k$) is heat transfer coefficient; $F$ ($m^2$) is area; $T_{in}(t)$ ($^\circ C$) is the indoor temperature at the time $t$; $T_{out}(t)$ ($^\circ C$) is the outdoor temperature at the time $t$; $T_d$ ($^\circ C$) is temperature correction value for cooling load calculation; $C_z$, $C_a$, $C_2$, $C_4$ is severally comprehensive shielding factor, effective area coefficient and cold load coefficient of glass windows; $D_{j,max}$ ($W/m^2$) is maximum value of heat factor obtained from solar radiation; $q_m$, $q_l$ ($W$) is severally Sensible heat dissipation and latent heat dissipation of human body; $G_k$ ($g/s$) is fresh air volume of central air conditioning; $S_0$ ($W/m^2$) is wall thermal storage coefficient;
\[ \rho_{\text{air}} = 1.29 \text{kg/m}^2; C_p = 0.28J/\text{kg} \cdot ^\circ \text{C}; S(t) \text{ is the air-conditioning state in opening (} S(t) = 0 \text{) and closing (} S(t) = 1 \text{)}. \]

3. Air-conditioning load aggregation group adjustable capacity

3.1 Air-conditioning closing time and opening time

The relationship formula between temperature change and time in buildings is shown:

\[ T_{in}(t+1) = a \cdot T_{in}(t) + (1-a) \left( \frac{D}{B} - \frac{Q_{ac} S(t)}{B} \right) \]  

Opening time and closing time of central air-conditioner is described:

\[ \tau_{\text{off}} = \log_a \left( \frac{T_{\text{max}} - D/B}{T_{\text{min}} - D/B} \right) \times h \]  

\[ \tau_{\text{on}} = \log_a \left( \frac{T_{\text{max}} - D/B + Q_{ac}/B}{T_{\text{min}} - D/B + Q_{ac}/B} \right) \times h \]  

Where \( a = e^{-B/D} \), \( B = K_1 F_1 + K_2 F_2 + 1.01 G_k \), \( D = \rho_{\text{air}} V_h C_p + S_e F_6 \), \( [T_{\text{min}}, T_{\text{max}}] \) is upper and lower limits of temperature control. Indoor temperature fluctuates is up and down in this section.

3.2 Air-conditioning load aggregation group adjustable capacity

Air-conditioning load aggregation group adjustable capacity is shown as:

\[ \Delta P_i = N P_e \left( \frac{\tau_{\text{on}}}{\tau_{\text{on}} + \tau_{\text{off}}} - \frac{\tau'_{\text{on}}}{\tau'_{\text{on}} + \tau'_{\text{off}}} \right) \]  

Where \( \tau_{\text{on}}, \tau_{\text{off}} \) and \( \tau'_{\text{on}}, \tau'_{\text{off}} \) is severally the start and stop time of the temperature control load before and after control.

4. The hierarchical strategies periodic paused control strategy of air-conditioning load

4.1 Air-conditioning terminal aggregation

The temperature of the rooms inside the building can be controlled by the air-conditioning terminal. Firstly, the switch state and temperature state of the terminal are monitored. Then the terminal grouped. The mode of grouping is shown as:

\[ O^i = \left\{ O^i_1, O^i_2, \ldots, O^i_{n_2} \right\}, C^i = \left\{ C^i_1, C^i_2, \ldots, C^i_{n_1} \right\} \]  

Where \( O_i \) and \( C_i \) is terminal state of opening and closing; \( n_1, n_2 \) is terminal number of opening and closing. Load aggregator is classified into an aggregation group according to the state of terminal devices at a certain time.

A room temperature range that makes people feel comfortable is [22\,^\circ\text{C}, 27\,^\circ\text{C}]. In the process of air-conditioning control, the adjustable range of temperature control range is [22\,^\circ\text{C}, 25\,^\circ\text{C}]- [24\,^\circ\text{C}, 27\,^\circ\text{C}]. The third gear control scheme is respectively [22\,^\circ\text{C}, 25\,^\circ\text{C}], [23\,^\circ\text{C}, 26\,^\circ\text{C}], [24\,^\circ\text{C}, 27\,^\circ\text{C}].
Monitoring switch state and temperature state of air conditioning terminal

The air conditioning terminal is grouped according to switch state and temperature state.

Open terminal group in ascending order by temperature
Shut down the terminal group in descending order of temperature.

Calculate the controllable time, controllable capacity and the state change time that the air-conditioning terminal does not participate in the regulation.

According to the control strategy of this paper, the temperature regulation of air conditioning terminal is realized.

Orders issued by the power grid
Turn on the air conditioning terminal temperature control section O
Shutdown air conditioning terminal temperature control group C

Fig.2 Central air-conditioning terminal control strategy flow chart

5. Example verification
This paper takes a comprehensive business district in Urumqi including 3 shopping malls and 4 hotel buildings as an example to verify the strategy. A typical daily load curve of regional grid is shown in Fig. 3, the morning rush hour (10:30-14:15) is taken to analyze. The load reduction instruction is 18000kW and the maximum load deviation is 100kW in the control period.

Fig.3 Regional typical daily load curve

The heat transfer coefficient of external walls and windows of business district is respectively $0.6W/(m^2\cdot k), 5.8W/(m^2\cdot k)$; the comprehensive shielding factor and effective area coefficient of glass windows are respectively $0.75, 0.93$; the heat storage coefficient of the wall is $7.92W/(m^2\cdot k)$; the sensible heat dissipation and latent heat dissipation of human body are respectively $69.78W, 111.65W$; ratio of window and wall is $0.75/0.25$; the amount of heat dissipation per unit area of electrical equipment and lighting equipment is respectively $17.75W/m^2, 42.5W/m^2$; the fresh air volume of central air conditioning is $30m^2/h$. The different direction parameters of the building are shown in Table 1.

| Tab.1 | The different direction parameters of the building |
|-------|---------------------------------------------|
|       | orientation | east | west | south | north |
| $T_j(r) + T_d$ | $T_a$  | 39   | 35.6 | 39.4  | 39.4  |
| $D_{j,max}$     |       | 531  | 531  | 195   | 145   |


Using the third section method in the paper, it gets the terminal equipment grouping, starting and stopping time, controllable capacity and controllable time. The fourth section describes the central air conditioning load drop control strategy and the air conditioning system divided into 3 files control scheme of this paper. The start and stop time of refrigerating main engine in public buildings during the morning peak regulation period is shown in Tab.2.

| Tab.2 Terminal device startup and shutdown group control table |
|-------------------------------------------------------------|
| building name                                             |
|                                                           |
|                                                                 |
| [22,25] °C       [23,26] °C       [24,28] °C               |
| τ_{on}/min       τ_{off}/min       τ_{on}/min       τ_{off}/min       τ_{on}/min       τ_{off}/min       |
| Maket 1          4.5              3.2              9.0              7.5              15.3              12.7              |
| Maket 2          5.1              3.8              9.4              7.1              16.1              12.1              |
| Maket 3          4.2              4.2              7.6              7.6              12.9              12.9              |
| Hotel 1          11.0             11.0             24.0             24.0             41.0              41.0              |
| Hotel 2          10.3             10.3             23.5             23.5             40.1              40.1              |
| Hotel 3          11.2             11.2             24.1             24.1             41.2              41.2              |
| Hotel 4          11.3             11.0             23.5             22.1             40.5              39.1              |

Fig.4 The load contrast at peak hour

The comparison diagram before and after peak load regulation is shown in Figure 4. It can be seen from the diagram that the load after the regulation of the regional grid has been effectively reduced. The amount of load reduction after early peak hours is shown in Fig.5. The electrical energy saving of the regional power grid can be visually obtained from the graph. The feasibility of temperature control model of central air-conditioning and the hierarchical strategies periodic paused control strategy is verified.

6. Conclusion

In this paper, a temperature control model of central air-conditioning loads is established based on the calculation method of building cooling load and the thermal comfort model of human being, and then the hierarchical strategies periodic paused control strategy is adopted to participate in peak adjustment. Finally, the central air-conditioning loads are participated to adjust peak load in the morning rush hour (10:30-14:15) at a comprehensive business district Urumqi as an example, and the simulation results are analyzed. These analysis shows that the strategy has a good regulation effect. The load of the regional grid has been effectively reduced. The feasibility of temperature control model of central air-conditioning and the hierarchical strategies periodic paused control strategy is verified.

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