Research on Peak Load Shifting Based on Energy Storage and Air Conditioning Load in Power Grid

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Abstract. In order to reduce the difference between peak load and off-peak load in summer and reduce the capacity of traditional energy storage system, an optimization strategy based on the coordinated control of battery energy storage system and air conditioning load was considered. Firstly, the control strategy of energy storage system based on threshold method considering electric storage capacity is proposed, and the dynamic changing process of air conditioning system setting temperature value is established to change the electric power of air conditioning system, that is, the virtual energy storage charging and discharging process of air conditioning system, the strategy of direct reduction and early charging of air-conditioning system are proposed. Secondly, the evaluation index of peak load cutting and valley filling is established, which emphasizes the local key of peak load and valley value. Finally, based on the theoretical analysis, taking a typical daily load forecasting curve of a commercial park as an example, the optimization strategy of coordinated control of battery energy storage system and air conditioning load is compared and analysed to verify its feasibility, it provides a basis for the application of battery energy storage system and air conditioning load in peak shaving and valley filling.

1. Introduction

Since the 21st century, with the advancement of industry and science and technology, the industrial structure has been continuously adjusted, the power grid is facing a further increase in the peak-valley difference, and the peak-adjustment income is low only by the investment and expansion of the distribution network[1-2]. Configuring the energy storage system in the power system can effectively improve the peak shaving capacity and reduce the system peak shaving cost[3]. On the basis of configuring the energy storage system, consider adjusting the demand-side load to further optimize, reduce the peak load through the virtual energy storage of the transferable load, and increase the demand-side flexibility[4]. At present, some scholars have conducted research on regulating the energy storage system and air conditioning load to adjust the peak-to-valley difference of power grid load. Reference[5] explored the effect of peak storage and valley filling in energy storage systems, and proved the feasibility of peak storage and valley filling in energy storage systems. Reference [6] explored the power difference control strategy of the battery energy storage system, improved the flexibility of the energy storage system charge-discharge control strategy, lack of energy storage capacity configuration, and when considering economic indicators, the peak shaving effect is very low. Reference[7] determines the basic methods of power and capacity of energy storage system to
participate in peak shaving and valley filling, but it lacks the study of charge and discharge scheduling strategy.

The above studies lack the establishment of peak-filling evaluation indicators and the influence of demand-side factors on air-conditioning load regulation when using energy storage systems and regulating air-conditioning load to optimize the grid load curve. Especially for summer load, it is an important direction for summer power grid load peaking and valley filling by optimizing energy storage system and demand-side air conditioning load coordination and optimal scheduling, and making use of the complementary advantages of the two to make up for the deficiencies.

In this paper, the threshold value control strategy is proposed based on the consideration of the capacity of the battery energy storage system. The dynamic change process of adjusting the set temperature to change the electric power of the air conditioner is regarded as the virtual energy storage and discharge process of the air conditioner system. The establishment of an evaluation index that not only highlights the local key points of the load peak and valley values, but also comprehensively considers the load, and provides a basis for participation in the practical application of the subsequent battery energy storage system and air conditioning load joint participation in the grid peak and valley filling. Finally, based on the simulation results of a certain city commercial district, the feasibility of the control strategy of the energy storage system and the virtual energy storage of the air conditioning load on the grid load is verified.

2. Threshold control strategy of battery energy storage system

The threshold method draws a typical daily predicted load curve according to the prediction technology, and determines the control power iteration step $\Delta P$ and iteration constant $k=0$ according to the load peak and valley values $P_{\text{max}}, P_{\text{min}}$, and the rated power of the energy storage system is $P_e$, and the discharge Upper threshold value $P_1$, lower charging threshold value $P_2$, when $P_{\text{min}} < P_2$, that is, the battery energy storage system charges the battery with the difference between the load value and the lower charging threshold; when $P_{\text{max}} > P_1$, the battery energy storage system uses the load value $T_o$ to discharge the battery with the upper discharge threshold, the control principle of the threshold method is shown in Figure 1.

![Figure 1. Schematic diagram of threshold method.](image)

The formula for calculating $S_1$ and $S_2$ is as follows:

\[
S_1 = \int_t^{t_1} P_1 - P_2 = \sum_{i=1}^{n} (P_{i+1} - P_i) \Delta t
\]

\[
S_2 = \int_t^{t_2} P_2 - P_3 = \sum_{i=1}^{n} (P_{i+1} - P_i) \Delta t
\]

where, $P_1$ is the continuous load; $P_{1,ij}$ is the non-continuous load; $i, j$ are the non-continuous load numbers when the battery is charging; $m, n$ are the non-continuous load number numbers, $\Delta t$ in the discharge phase;.

3. Air-conditioning load virtual energy storage model and control strategy

3.1. Air conditioning virtual energy storage model
Air conditioning load can respond to superior power commands by changing the temperature. This control method will affect the thermal comfort of the human body. The commonly used thermal sensation vote (TSV) determines the indoor temperature change range. According to the most comfortable temperature of TSV human body $T_{\text{comf}} = 25^\circ\text{C}$, TSV is in the range of $0.5[T_{\text{min}}, T_{\text{max}}]$, that is $[23^\circ\text{C}, 27^\circ\text{C}]$, 90% of people said they can accept\cite{8}. The relationship between the electric power of the air conditioning equipment and the cooling room is as follows:

$$P_{\text{ac}}(t) = \frac{Q_{\text{ac}}(t)}{\eta}$$\hspace{2cm}(2)$$

where, $P_{\text{ac}}(t)$ is the electric power of the air conditioner, kW; $\eta$ is the thermoelectric conversion coefficient of the air conditioner; $Q_{\text{ac}}(t)$ is the air conditioning cooling capacity, kW.

At steady state, the cooling capacity of the air conditioner is equal to the heat transfer between the building and the outside world. The electric power of the air conditioner is calculated as follows:

$$P_{\text{ac, o}}(t) = \frac{Q_{\text{ac}}(t)}{\eta} = \frac{T_{\text{out}}(t) - T_r(t)}{\eta R}$$\hspace{2cm}(3)$$

where, $Q_{\text{ac}}(t)$ is the building heat transfer power, kW; $T_r(t)$ is the room temperature, $^\circ\text{C}$; $T_{\text{out}}(t)$ is the room temperature, $^\circ\text{C}$; $P_{\text{ac, o}}(t)$ steady-state air-conditioning electric power; R is the building equivalent thermal resistance, $^\circ\text{C}/\text{kW}$, typical parameters range 0.001~0.003.

When dynamic, the electric power of the air conditioner is as follows:

$$P_{\text{ac, d}}(t) = \begin{cases} 0, & T_{\text{ac, d}}(t) > T_r(t) \\ P_{\text{rated}}, & T_{\text{ac, d}}(t) < T_r(t) \end{cases}$$\hspace{2cm}(4)$$

where, $P_{\text{rated}}$ is the rated cooling power of the air-conditioning system; $P_{\text{ac, d}}(t)$ dynamic air-conditioning electric power.

Then $T_r$ increases or decreases from $T_{\text{set0}}$ to $T_{\text{set}}$, and the heat $Q$ absorbed or released by the air conditioner-building is as follows:

$$Q = C(T_{\text{out}} - T_{\text{set0}})$$\hspace{2cm}(5)$$

where, $C$ is the equivalent heat capacity of the building, kJ/$^\circ\text{C}$, the typical parameter value range is 47~230.

The virtual charge and discharge power are as follows:

$$P_{\text{ves}} = P_{\text{ac, d}}(t) - P_{\text{ac, o}}(t)$$\hspace{2cm}(6)$$

The demand side response of the virtual energy storage of the air conditioning system can be expressed as follows:

$$P_{\text{dr}} = (P_{o} + P_{\text{ves, sum}})$$\hspace{2cm}(7)$$

$$P_{\text{ves, sum}} = \sum_{k=1}^{N} P_{\text{ves}}(n[k])$$\hspace{2cm}(8)$$

where, $P_{o}$ is the original air-conditioning load; $P_{\text{dr}}$ is the air-conditioning load after the demand side response; $P_{\text{ves, sum}}$ is the aggregate model power of the air-conditioning system. $P_{\text{ves, sum}}$ is the aggregate model power of the air-conditioning system in the $k$ period.

4. Peak-cutting valley-filling optimization model and solution based on battery energy storage and air conditioning load

4.1. Objective function

In this paper, the target function of peak load and valley filling is constructed with the minimum load standard deviation of the battery energy storage integrated into the power grid. The mathematical expression is as follows:

$$\min f(P_{o}, P_{d}) = \frac{1}{T} \sum_{k=1}^{T} (P_{d,k} - P_{o} + P_{d,k} - P_{o}) / T$$\hspace{2cm}(9)$$
where, $P_{t,i}$ is the actual grid load at time $t$; $P_b$ is the charge and discharge power of the battery energy storage system at time $t$.

$P_a$ is the average load after the battery energy storage system and the air conditioning virtual energy storage system are charged and discharged.

$$P_a = \frac{1}{T} \sum_{t=1}^{T} (P_{t,i} - P_{t,i} + P_b)$$  \hspace{1cm} (10)

5. Example analysis

Footnotes should be avoided whenever possible. If required they should be used only for brief notes that do not fit conveniently into the text.

The commercial area of a city in Liaoning Province was selected as an example for simulation. The configuration of the commercial area is as follows: 5000 air conditioners all participate in the demand-side response peak shaving strategy. The air conditioning temperature adjustment range is 23 ℃ ~ 27 ℃, the most comfortable temperature is 25 ℃; The energy storage system is a lithium battery with a rated power of 1MW and a rated capacity of 2MW.h. As shown in Figure 2, the business park's original daily load forecast curve (original load curve), three of which have load values greater than 22MW The load underestimation period is 10:00 ~ 12:00 in the morning, 14:00 ~ 16:00 in the afternoon, 19:00 ~ 23:00 in the evening, and 24:00 ~ 6:00 in the morning, and the load is less than 20MW.

![Figure 2. Original load curve.](image)

The specific participation of air conditioning load in peak shaving is shown in Table 1. The air-conditioning set temperature is adjusted from 25 ℃ to 27 ℃ and 23 ℃ to 27 ℃.

| Single air conditioner temperature change(T) | Virtual charge and discharge power of single air conditioner(P) | Virtual charge and discharge time of single air conditioner (T) |
|---------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 25℃ to 27℃                                 | Virtual discharge: 0.35kW                                     | Discharge time: 20 minutes                                    |
| 23℃ to 27℃                                 | Virtual discharge: 0.44kW                                     | Discharge time: 45 minutes                                    |
| 25℃ to 23℃                                 | Virtual discharge: 0.44kW                                     | Discharge time: 10 minutes                                    |

The comparison between the original load curve and the peak load and valley filling daily load curve (energy storage load curve) involving only the battery energy storage system is shown in Figure 3.
Figure 3. Comparison of control effects.

The blue line in the figure is the original daily load curve, and the red line is the energy storage load curve. The grid charges the battery energy storage system from 24:00 to 6:00 in the morning, filling the load valley. The battery energy storage system discharges the power grid from 10:00 to 12:00 in the morning, 14:00 to 16:00 in the afternoon, and 19:00 to 23:00 in the evening to reduce the load peak.

The red line is the load curve of the energy storage system, and the green line is the direct reduction strategy load curve of the combined air conditioning load in the energy storage system. Set the air-conditioning temperature to the most comfortable temperature of the human body from 7:00 to 8:00 in the morning $T_{\text{set0}} = T_{\text{comf}} = 25^\circ\text{C}$. At this time, the air-conditioning load starts to cool, that is, the virtual energy storage charging starts, and the charging is completed when the room temperature reaches the set temperature. From 9:30 am to 11:30 am, when the first peak of the original load curve comes, adjust the temperature of the air conditioner to $T_{\text{set1}} = 27^\circ\text{C}$. At this time, the air conditioner stops cooling, and virtual discharge begins. After the room temperature reaches 27 $^\circ\text{C}$, start low-power cooling to maintain room temperature stability. In addition, in order to meet the virtual peak load capacity of the air conditioner load at the next wave crest, from 12:00 to 13:00, the air conditioner set temperature is adjusted to $T_{\text{set2}} = 25^\circ\text{C}$, which starts virtual charging. From 14:00 to 16:00, the peak shaving effect of energy storage is very good, that is, the air conditioner does not participate in the peak shaving strategy of the second peak of the original load curve. From 19:00 to 23:00 in the evening, $T_{\text{set3}} = 27^\circ\text{C}$, the virtual discharge will start. The next day from 7:00 to 8:00 am, the air conditioner started to store energy again, and so on. The green line is the strategic load curve of the energy storage system combined air conditioning load directly reducing, and the purple line is the strategic load curve of the energy storage system combined air conditioning load early charging control. Due to the energy storage system combined with direct air conditioning load reduction strategy, the full load peak of the original load curve at 9: 30 ~ 11: 30 in the morning and the half load peak at 19: 00 ~ 23: 00 in the evening have been cut off. At 18: 00 ~ 19: 00 in the evening, set the temperature of the air conditioner to $T_{\text{charge}} = 23^\circ\text{C}$. From 19:00 to 23:00 in the evening, the temperature of the air conditioner is set to $T_{\text{set3}} = 27^\circ\text{C}$, that is, the air conditioner load is virtually discharged, and the discharge power is greater than the direct reduction strategy, so as to further cut the peak load peak at night.

It can be seen from the comparison of the blue line and the purple line that the load curve after the threshold method of the battery energy storage system and the pre-charging strategy of the air conditioning load cuts the peak and fills the valley, and the three load peaks are obviously cut off. , Which verified the feasibility of coordinated control of the two control methods.

Table 2 is a comparison table of peak shaving and valley filling evaluation parameters for each different control strategy.
Table 2. Comparison of peak and valley filling of different control strategies.

| Control Strategy                                      | Absolute peak-valley difference(ΔP₁) | Peak-valley coefficient(α) | Peak-valley difference(β) | Standard deviation(f) |
|--------------------------------------------------------|--------------------------------------|-----------------------------|---------------------------|-----------------------|
| No control                                             | 5.16MW                               | 0.78                        | 21.36%                    | 1370                  |
| Threshold method of energy storage system               | 4.16MW                               | 0.82                        | 17.56%                    | 1237                  |
| Threshold method + direct reduction                     | 3.79MW                               | 0.83                        | 16.26%                    | 1209                  |
| Threshold method + early charge                         | 3.53MW                               | 0.84                        | 15.40%                    | 1194                  |

6. Conclusion

Through the combined control of energy storage and air conditioning load, the different control strategies of energy storage system and air conditioning load are analysed in this paper, respectively, and draws the following conclusions:

(1) When the battery storage system is used in the power system and the battery storage threshold method is introduced, the peak-valley difference can be reduced from 21.36% to 17.56% without any control strategy. (2) The threshold method of battery storage system with peak-to-valley difference of 15.40% combined with the strategy of early charging for air conditioning load has the best effect on peak-to-valley load reduction. The effect of Combined Control Strategy is better than that of peak shaving and valley filling only by threshold control strategy of battery energy storage system.

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