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Air conditioning dispatching and economic analysis of ice storage in urban power grid

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Abstract. Considering the characteristics of hydropower in Chongqing and the on-grid electricity price of power generation, water and wind power, and the time-of-use electricity price of users purchasing electricity, the model of Chongqing large-scale ice storage air-conditioning is established and is optimized based on the minimum power purchase cost of the power grid and the minimum operating cost of ice storage air-conditioning. The goal is to dispatch generators and ice storage air conditioners to maximize the benefits of the grid and users, while reducing the abandonment of water and wind power. The feasibility and effectiveness of the proposed control strategy are verified by simulating the control of ice storage air conditioning under different cooling load requirements.

1. introduction

The demand for air-conditioning load power in Chongqing is getting larger and larger, which becomes the main factor for seasonally impacting the load and demand balance of power grid load. At the same time, the air-conditioning load is synchronized with the power supply peak and the power supply valley during the day,which further increases the peak-to-valley difference of the power grid. At the same time, there are many rivers in Chongqing with abundant traffic and large water resources. However, due to the small electricity load during the low valley period, the contradiction of water abandonment is prominent. By optimizing the dispatching, the contradiction between the abandoned water and the abandoned wind and the load can be alleviated to some extent, but there is no practical method for real-time dispatching of the power grid specifically for the abandoned water and abandoned wind consumption service.

Ice storage air-conditioning is a kind of equipment that stores cold capacity during the trough of the grid, melts the ice during peak hours, and satisfies the load demand. It has good load transfer characteristics. If the electricity consumption behavior of such equipment can be properly regulated, the peak can be effectively reduced. The load, and thus the grid load characteristics, can also reduce the large amount of abandoned water and wind in the trough.

In this paper, a method for eliminating the abandoned water and abandoned wind based on ice storage system are proposed. The minimum power purchase cost of the power grid and the minimum operating cost of ice storage air conditioning are optimized, and the ice storage system is used to realize the eliminating of the abandoned water and wind. Through comprehensive and detailed modeling of the power system containing ice storage devices, it is possible to achieve the assessment of the ability to dissipate the abandoned water and wind and maximize the capacity of water and wind power consumptiving.

2. Ice storage air conditioning polymerization model

The operation of the ice storage air conditioner can be divided into two periods of cold storage and cooling according to the cooling load demand. During the cold storage period, the air conditioning system works in the unit cold storage mode. At this time, the hourly cold storage capacity of the refrigeration unit is qx; during the cooling period, the working mode of the air conditioning system is combined cooling and cooling of the unit, wherein the refrigeration unit The hourly cooling capacity is qj, and the hourly cooling capacity of melting ice is qr. Due to the huge volume of massive ice storage air-conditioning, it can be seamlessly integrated into the existing dispatch control system by polymerizing and modeling, and the generator set is optimized. The specific parameters of the ice storage air conditioning polymerization model are obtained from the user side feedback according to the smart grid measurement system.

Operating characteristics

$$W_{t+1} = s*W_t + Q_{x,t}*\Delta t - Q_{r,t}*\Delta t \tag{1}$$

Where W_t is the hourly cooling capacity of the cold storage equipment; s is the hourly cooling loss coefficient of the cold storage equipment.

2.1Cold storage constraint

The following analysis of ice storage air conditioning is based on the comfort of the user.

(1) Cool storage period

Time-dependent cold storage constraint:

$$0 \le Q_{x,t} \le Q_{x,t}^{\max} \tag{2}$$

Cooling upper limit constraint:

$$W_r \le W^{\max} \tag{3}$$

(2) Cooling time:

$$0 \le Q_{j,t} \le Q_j^{\max} \tag{4}$$

$$0 \le Q_{r,t} \le Q_r^{\max} \tag{5}$$

$$Q_{j,t} + Q_{r,t} = Q_{k,t} \tag{6}$$

In order to strengthen the demand side management of power consumption, to alleviate the contradiction between peak power consumption and low power consumption, and rationally use economic means to guide power users to shift peaks and fill valleys, Chongqing has implemented a peak price system for peak and vally load, guiding users to avoid the peak and choose the valley, gradually implements the time-sharing electricity price system, and has introduced a series of preferential policies to encourage users to shift peaks and fill the valley. The peak and valley electricity prices are shown in Table 1.

Table 1. Time-of-use tariff policy table

	time	Electricity price policy (yuan / degree)
Peak hours	8:00-12:00.19:00-23:00	0.9965

Valley hours	23:00-7:00	0.3322
Flat section	7:00-8:00 12:00-19:00	0.6643

The aggregate air-conditioning model is optimized with the minimum daily operating cost as the optimization goal, combined with the time-of-use electricity price, and obtain the operation plan of the polymerization air conditioner at every moment.

Objective function:

$$\min f1 = \sum\left(\frac{Q_{j,t}}{cop1} * m_i + \frac{Q_{x,t}}{cop2} * m_i\right) \quad (7)$$

m_i : time-of-use electricity price;

3. Generator set scheduling

Through the optimization of the daily running cost of the ice storage air conditioning polymerization model, the operation plan of the air conditioner 24 hours a day is obtained, and the operation plan is used as a constraint, and the dispatching unit is optimized with the minimum power generation fee of the generator set.

Due to the high output of wind power and hydropower during the period of low load, in order to avoid a large amount of abandoning of wind and water power, wind power and hydropower have the willingness to reduce the price. Therefore, it is possible to divide the on-grid price of wind power and hydropower into flat and low-valid electricity prices.

Table 2. Unit online time-of-use tariff

	Thermal power	Hydropower	wind power
Low valley (yuan/degree)	0.3964	0.1500	0.2900
Flat section (yuan/degree)	0.3964	0.3000	0.5800

The operation plan is issued to each power plant, and the optimization of the power purchase cost of the power grid is optimized.

3.1 Objective function :

$$\min f2 = \sum(P_G * e_G + P_H * e_H + P_W * e_W) \quad (8)$$

m_i : time-of-use electricity price; e_G, e_H, e_W respectively, thermal power, hydropower, wind power on-grid price;

3.2 Restrictions

(1) Power balance constraint:

$$\sum_{i=1}^{N_t} P_{G,i,t} + \sum_{j=1}^{N_h} P_{h,j,t} + \sum_{k=1}^{N_w} P_{w,k,t} = P_{D,t} \quad (9)$$

$P_{G,i,t}$ for the thermal power unit output; $P_{h,j,t}$ for the hydropower unit output; $P_{w,k,t}$ for the wind farm output; $P_{D,t}$ for the ice storage system electrical load. The network loss and network restrictions are not considered, and the system is capable of accepting a certain proportion of wind power to enter the network in full.

(2) System backup constraint

$$\sum_{i=1}^{N_t}(P_{G,i,\max} - P_{G,i,t}) + \sum_{j=1}^{N_h}(P_{h,\max,j} - P_{h,j,t}) \ge k_d P_{D,t} + k_w \sum_{k=1}^{N_w} P_{w,k,t} \quad (10)$$

$P_{G,i,\max}$ is the maximum output power of the thermal power unit; $P_{h,\max,j}$ is the maximum output power of the hydropower unit; k_d 、 k_w is the load fluctuation coefficient and the wind power fluctuation coefficient.

(3) Thermal power output upper and lower limits

$$P_{G,i,\min} \le P_{G,i,t} \le P_{G,i,\max} \tag{11}$$

(4) Thermal power output climbing constraint

$$-r_{di}\Delta t \le P_{G,i,t} - P_{G,i,t-1} \le r_{ui}\Delta t \tag{12}$$

(5) Hydropower generation capacity constraint

$$P_{h,\min,j} \le P_{h,j,t} \le P_{h,\max,j} \tag{13}$$

(6) Hydropower conversion relationship

$$P_{h,j,t} = A\eta_j Q_{jt} h_{jt} \tag{14}$$

A is the hydroelectric conversion constant; η_j is the hydropower station efficiency; h_{jt} is the reservoir head height.

(7) Daily flow integral constraint

$$Q_{\min,j} \le \int_{t=1}^{T} Q_{jt} dt \le Q_{\max,j} \tag{15}$$

$Q_{\min,j}$ 、 $Q_{\max,j}$ are the minimum and maximum water allocation of the reservoir on the dispatch day, that is, the upper and lower limits of the daily flow integral.

(8) Wind turbine actual output constraint

$$0 \le P_{w,k,t} \le P_{w,f,t} \tag{16}$$

$P_{w,f,t}$ is the maximum output that can be scheduled for the predicted wind farm.

4. Individual ice storage air conditioning direct load control

In the direct load control of the individual ice storage air conditioner, it is premised on the comfort of the user.

The operation plan of the ice storage air conditioning polymerization model is issued to the mass controlled ice storage air conditioning, using the 0-1 state variable

$x_{i,j,1}$ 、 $x_{i,j,2}$ 、 $x_{i,j,3}$ 、 $x_{i,j,4}$, indicating the i-th unit, the jth control, cooling, ice storage, ice melting, shutdown state, 1 indicates that it is in this state, 0 means not in this state. Optimize the target function by minimizing the deviation between the specific control results of the ice storage air conditioner and the operation plan:

Objective function:

$$\min f3 = \left|Q_{j,t} - \sum q_{ij} * x_{i,j,1}\right| + \left|Q_{x,t} - \sum q_{ix} * x_{i,j,2}\right| + \left|Q_{r,t} - \sum q_{ir} * x_{i,r,1}\right| \tag{17}$$

5. Simulation study

The regional power grid containing ice storage air conditioning users is selected as an example. The air conditioning parameters and cooling load of each generator set and ice storage are as follows. The total daily cooling load is 35620 MWh. Partial ice storage mode is used, and the ice rate is 42%.

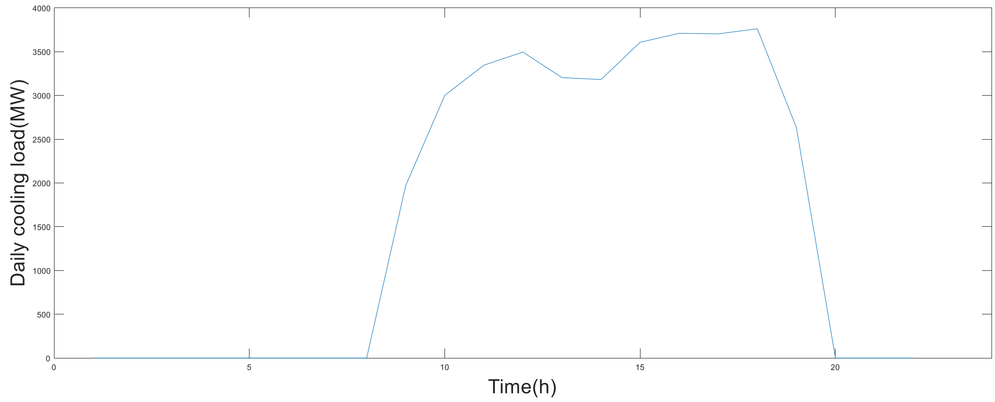


Figure 1. Cold load curve

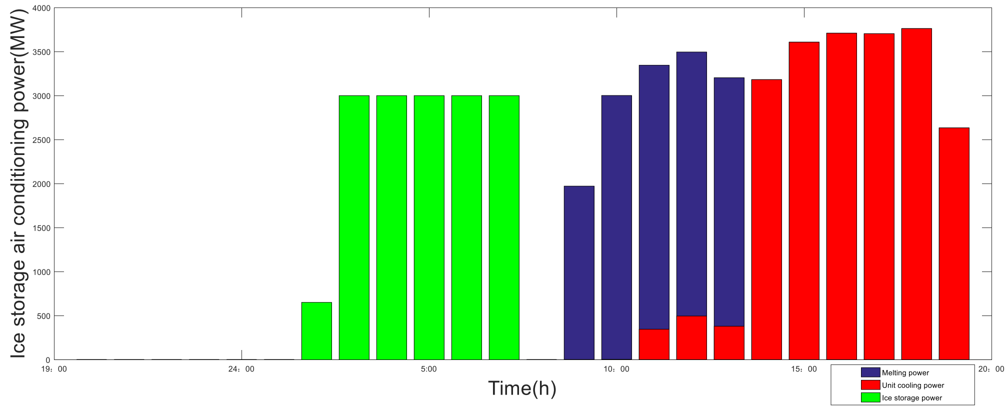
Table 3. Thermal power station basic information

	Maximum power / MW	Minimum power / MW	Maximum climbing ability / (MW / h)
1	200	100	100
2	350	175	200
3	300	150	200
4	200	80	200
5	500	200	300

Table 4. Hydropower station basic information

	Maximum power / MW	Head height/m
6	300	12

According to the actual cooling experience, the four cooling load demand states of 100%, 75%, 50% and 25% based on the typical design daily cooling load are analyzed in the annual cooling period.



(a) 100% cooling load demand

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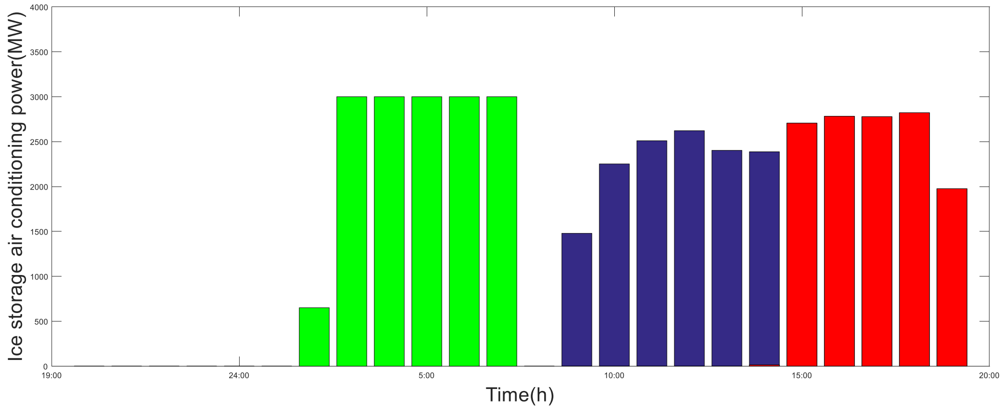
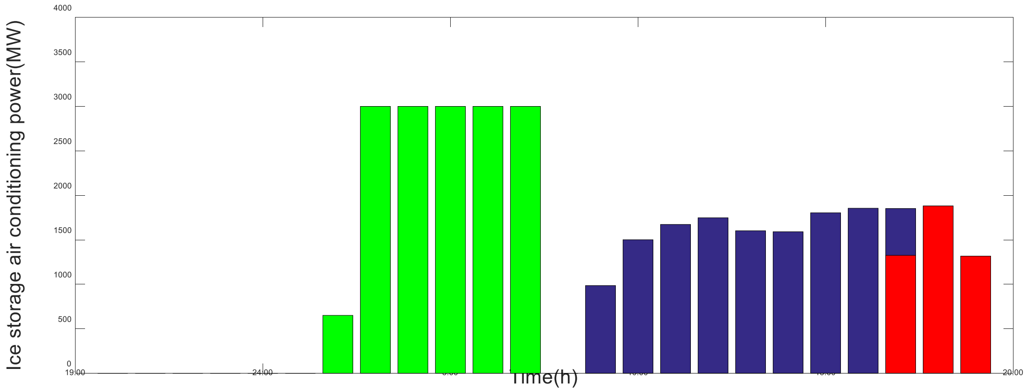
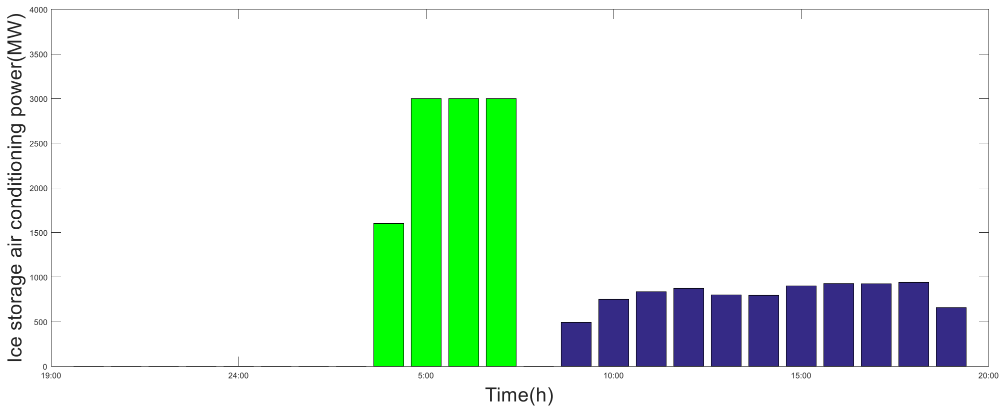


(b) 75% cooling load demand



(c) 50% cooling load demand



(d) 25% cooling load demand

Figure 2. Cooling load distribution under optimal control strategy

Table 5. Ice storage air conditioning daily operating expenses

	Ice storage	No ice storage	Cost savings percentage
100% cold load	6320.4	9195.9	31.3
75% cold load	4255.8	6897.7	38.3
50% cold load	2283.2	4597.9	50.3
25% cold load	986.4	2299.7	57.1

It can be seen from the figure that when the cold load demand is low, the system cooling capacity is completely borne by the melting ice. As the cooling load demand increases, the system cooling capacity is shared by the melting ice and the refrigeration unit, and the air conditioning unit stores ice at night. It can be seen from figure 2 that by storing ice, the demand for electricity during peak hours is transferred to the trough period, which can greatly reduce the cost of electricity. Moreover, due to the limitation of the total amount of ice storage, the more the cold load is, the less the operating cost percentage thus saved.

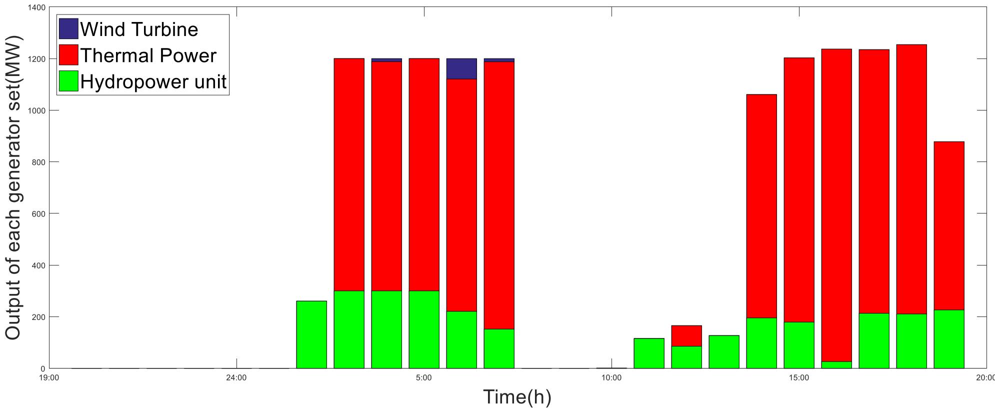


Figure 3. output of each generator set

Table 6. Grid purchase cost

	Ice storage + low valley electricity price	No ice storage
100% cold load	4248.2	4501.8
75% cold load	3116.7	3325.5
50% cold load	1980.0	2153.4
25% cold load	994.9	990.8

It can be seen from Table 6 that by using the ice storage and the low valley electricity price of the generator set, the power purchase cost of the power grid can be reduced when the cold load is large. When the cold load is small, the feed-in tariff is not synchronized with the peak-to-valley price of the user side. The cost of purchasing electricity and the cost of purchasing electricity from the grid cannot be minimized at the same time, and it may not significantly reduce the cost of purchasing electricity from the grid. In addition, when the cold load is small, the ice storage of the unit is concentrated in a certain period of time, which reduces the consumption of abandoned wind and abandoned water power, so that the power purchase cost of the power grid increases.

In summary, the optimized control strategy proposed in this paper can simultaneously reduce the power purchase cost of the grid and the electricity cost of the air conditioner on the user side. At the same time, the peak load of the grid is reduced by the peak-filling effect of ice storage, and the abandoned wind and water power are reduced.

6. Conclusion

In order to solve the problem that the peak-to-valley difference of the power grid and the abandoned water and wind, the double-layer optimization model with the minimum operating cost of the user-side air conditioner and the minimum power purchase cost of the grid is proposed.It can be verified by simulation examples that the power purchase cost and user-side operating cost can be reduced at the same time, and the peak-filling and valley-reducing effects can be achieved.

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