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OPTIMIZED CONTROL STRATEGY FOR ICE STORAGE AIR CONDITIONING CONSIDERING ABANDONED WIND CONSUMPTION

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ABSTRACT

By analyzing the comprehensive operation cost of the power supply company and the air conditioner load aggregator and the electricity consumption cost of the air conditioner user, the operation strategy of storing electricity by using the electricity trough, using the power peak and releasing the power with the level section, and adjusting the power of the refrigeration unit to achieve the The optimal scheduling of the ice storage trough output improves the system's ability to dissipate wind. A multi-objective optimization model based on energy efficiency and economy was established to maximize the benefits of power supply companies, air-conditioning load aggregators and air-conditioning users. The non-dominated sorting genetic algorithm-II (NSGA-II) is used to solve the Pareto non-dominated solution set. The generated Pareto solution set is filtered by the fuzzy membership method to obtain the optimal solution. The simulation results of the IEEE - 37 distribution system are used to verify the effectiveness and feasibility of the proposed method.

Keywords: Ice storage air conditioning、curtailed wind consumption、Multi-objective optimization、NSGA-II.

1. INTRODUCTION

In the context of the growing shortage of fossil energy, the development and utilization of wind energy is particularly important. With the large-scale access of wind power, the randomness, uncertainty and intermittentness of its output increase the difficulty of power system dispatching [1]. Literature [2] combines solar energy with cogeneration system to optimize the operation strategy of the co-supply system from the energy and economic perspective to maximize the comprehensive benefits. The literature [3] considers the flexible load and the traditional generator set to participate in the system optimization scheduling, and improves the wind power consumption; the literature [4] takes the minimum energy consumption of the refrigeration unit and the minimum operating cost of the system as the optimization goal, and formulates the ice storage air conditioning control strategy. Based on the above research, this paper takes the ice storage air conditioning as the research object, and constructs the incentive policy of the power supply company to the load aggregator and the incentive policy of the load aggregator to the user, and benefits the power supply company, the load aggregator and the air conditioner user. Maximizing a multi-objective optimization model for the goal.

2. MULTI-OBJECTIVE OPTIMIZATION MODEL AND SOLUTION

Compared with the conventional air conditioning system, the ice storage air conditioner adds a cold storage device, which can convert the electric energy into cold energy and store it for cold storage in other time periods.Figure 1 is a schematic diagram of an ice storage air conditioner.

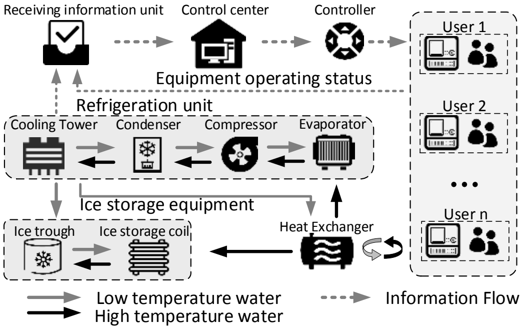

Fig. 1 Ice storage cold air conditioning cooling flow diagram

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2.1 Multi-objective optimization model

2.1.1 Optimization goal 1

Taking the power supply company as the main body of interest and considering maximizing the benefits of the power supply company, the comprehensive operation cost c_1 of the distribution network should be the smallest. The comprehensive operation cost includes: the electricity sales profit of the power supply company f_1, the electricity purchase cost f_2 from the upper power grid and the wind turbine purchase, the abandonment penalty cost f_3,the subsidy cost to the load aggregator f_4.

$$\max c_1 = f_1 - f_2 - f_3 - f_4 \tag{1}$$

$$f_1 = \sum_{t=0}^{T}(\sum_{u=1}^{U} r_t P_z)\Delta t \tag{2}$$

$$f_2 = r_g \cdot P_g + r_f \cdot P_f \tag{3}$$

$$f_3 = \sum_{t=0}^{T}\sum_{i \in S_{DG}} \beta_{DG} P'_{DG,i,t} \Delta t \tag{4}$$

Where r_t is the real-time electricity price; U is the number of users participating in the aggregator's response regulation; P_z is the real-time power of the refrigeration unit; r_g is to buy electricity prices from the upper grid; P_g is the power purchased from the upper grid; r_f is the price of electricity purchased from wind power equipment; P_f is the power purchased from wind power equipment; β_{DG} is the cost coefficient for the abandoned wind unit power; $P'_{DG,i,t}$ is the abandonment of the i-node fan power generation at time t; S_{DG} is the set of the wind turbine access points, $T = 23$.

$$f_4 = b\Delta p^2 + b_1 \Delta p \tag{5}$$

where b and b_1 are the regulation benefit characteristic coefficient of the load aggregator; Δp is the regulation power of the load aggregator (See formula 5).

2.1.2 Optimization goal 2

Taking the load aggregator as the main body of interest, consider the maximum operating benefit of the load aggregator c_2, and the comprehensive operating cost of the load aggregator includes: the subsidy fee for the power supply company is f_4, the subsidies of air-conditioning users participating in the dispatch is v.

$$\max c_2 = f_4 - v \tag{6}$$

Under the premise of not changing the user's temperature comfort, the length of time that the load aggregator performs regulation is Δt, and the scheduling potential of the aggregator is:

$$\Delta p = p_r - \frac{\sum_{t=0}^{T_r}\sum_{t=1}^{U}(q_{d,u,t} - \overset{*}{q}_{m,u,t})\Delta t}{\eta} - p_{DG} \tag{7}$$

where p_r is the power of the refrigeration unit before regulation; $\overset{*}{q}_{m,u,t}$ is the ice cooling capacity of the ice storage equipment after regulation; $q_{d,u,t}$ is the cooling capacity of the refrigeration unit, and η is the energy efficiency ratio indicating equipment of the refrigeration unit under the air conditioning condition. The cooling capacity under unit power consumption, p_{DG} is the fan output used by the refrigerator for cooling.

The subsidy fee for the load aggregator to the user is:

$$v = J_1\Delta p + J_2(\Delta p - \Delta p_0) \tag{8}$$

where J_1 and J_2 are two subsidy levels. When the regulation power of the load aggregator at the peak period is not greater than Δp_0, the compensation is performed according to J_1. When the transfer load is greater than Δp_0, the excess is compensated according to J_2.

2.1.3 Optimization goal 3

In order to minimize the benefits of air-conditioning users, air conditioning users should be considered to have the lowest total electricity costs.The total electricity cost of the air-conditioning users participating in the regulation c_3 as follows:

$$\min c_3 = f_1 - v \tag{9}$$

2.2 Constraint condition

2.2.1 Cooling balance constraint

$$\sum_{u=1}^{U} q_{r,u} = \sum_{u=1}^{U} q_{m,u} + \sum_{u=1}^{U} q_{d,u} \tag{10}$$

where $q_{r,u}$ is the total user demand cooling capacity; $q_{m,u}$ is the total melted cooling capacity, and $q_{d,u}$ total refrigeration unit cooling capacity.

2.2.2 Node voltage constraint

$$V_{j,t}^{\min} \le V_{j,t} \le V_{j,t}^{\max} \tag{11}$$

where $V_{j,t}$ is the voltage amplitude at time t of node j, $V_{j,t}^{\min}$ 、 $V_{j,t}^{\max}$ respectively the upper and lower limits of the voltage amplitude of node j.

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2.2.3 Regulating boundary constraints

$$\frac{\sum_{u=1}^{U}(q_{r,u,t}-q_{m,u,t})}{\eta}\le p_{u,t}\le\frac{\sum_{u=1}^{U}(q_{r,u,t}-q_{m,u,t}^{\min})}{\eta} \tag{12}$$

where $q_{m,u,t}$ is the amount of melting ice cooling capacity of the ice storage equipment before optimization and regulation at time t; $q_{m,u,t}^{\min}$ is the minimum melting ice capacity of the user's ice storage device at time t; $p_{u,t}$ is the total users's regulated power at time t.

2.2.4 Branch capacity constraint

$$\left|I_{j,t}\right|\le I_j^{\max} \tag{13}$$

where $I_{j,t}$ is the current on branch j at time t, and $I_j^{\max}$ is on branch j maximum allowable current.

2.3 Select the optimal solution value

In this paper, the fuzzy membership degree is used to construct the membership function for each target, which is transformed into the satisfaction of the optimization results. The final solution is found through the satisfaction comparison. Fuzzy membership degree is:

$$\beta(f)=\frac{F_{\min}+\alpha-f(x)}{\alpha},F_{\min}<f(x)<F_{\max} \tag{14}$$

where is the $\beta(f)$ is the satisfaction value of a single objective function in each solution; $F_{\min}$, $F_{\max}$ and α are the minimum and maximum values of the objective function in the Pareto optimal solution set, respectively and function value range.

For each solution in the Pareto optimal solution set, the standardized satisfaction value is obtained, and the solution with the largest standardized satisfaction value is taken as the final selected solution.

3. EXAMPLE ANALYSIS

3.1 Basic data

In order to verify the feasibility and effectiveness of the above analysis, this paper selects the IEEE-37 node distribution network system model for simulation verification. The IEEE-37 distribution network test system is shown in Figure 2.The system load forecasting curve is shown in Figure 3. The predicted of fan output, and the time-of-use electricity price are shown in Figure 4.

Table 1. Distribution network system and air conditioning unit parameters

Parameter name and unit	**Numerical value**
Wind power purchase price/¥	0.1
Upper grid purchase price/¥	0.3
Refrigeration unit rated power/kW	5080
Energy efficiency ratio under air conditioning conditions	5.2
Energy efficiency ratio under refrigeration conditions	3.7
Abandoned wind penalty price/¥	0.02
Air conditioning user response compensation ($0<\Delta P_0\le 1.5MW\cdot h$)/¥	0.006
Air conditioning user response compensation ($\Delta P_0>1.5MW\cdot h$)/¥	0.01

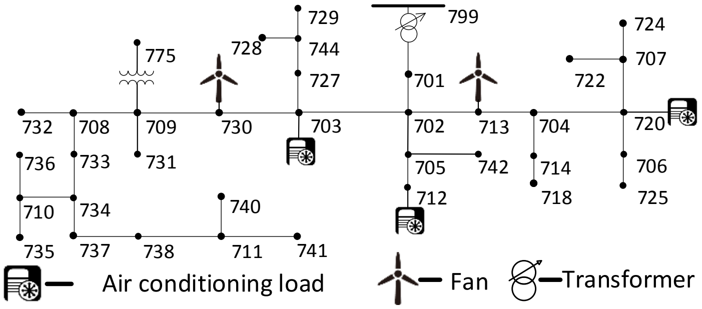

Fig. 2. IEEE-37 Distribution Network Test System

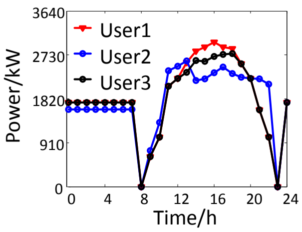

Fig. 3. User load forecast

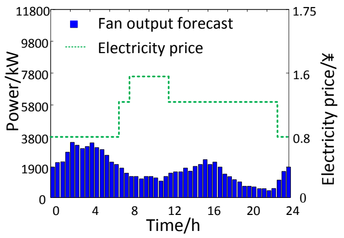

Fig. 4. Abandoned wind forecast and electricity price

3.2 Simulation and analysis

The optimization model is solved using the NSGA-II algorithm. The population genetic algorithm has a size of 200, the number evolution is 500, the probability of intersection is 0.9, and the probability of variation is 0.1. The Pareto frontier obtained by solving three objective functions is shown in Figure 5. The operating revenue before and after optimization of the power supply company is shown in Figure 6.

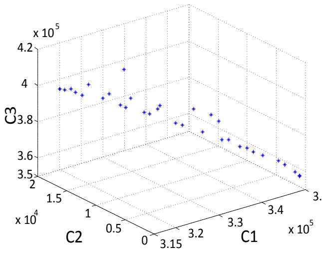

Fig. 5. Pareto frontier

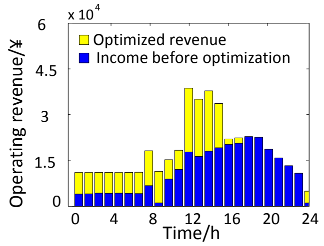

Fig. 6. Revenue

The predicted abandoned wind value and the optimized abandoned wind power, as well as the operating revenue before and after the optimization of the load aggregator are shown in Figure 7. The operation mode of the ice storage air conditioning optimization is shown in Figure 8, where mode 1 represents the single ice storage mode, mode 2 represents the ice melting and cooling mode, and mode 3 represents the single cooling mode.

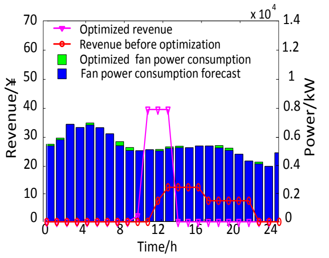

Fig. 7. Load aggregator revenue and abandoned wind

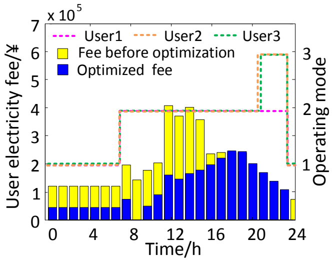

Fig. 8. User electricity fee and Operating mode

According to different user response adjustment amount, the fan output and load aggregator scheduling indicators are allocated. The change of the ice storage capacity of the ice storage device and the power change of the refrigeration unit before and after the optimization control of the user 1, 2 and 3 are as shown in Figure 9.

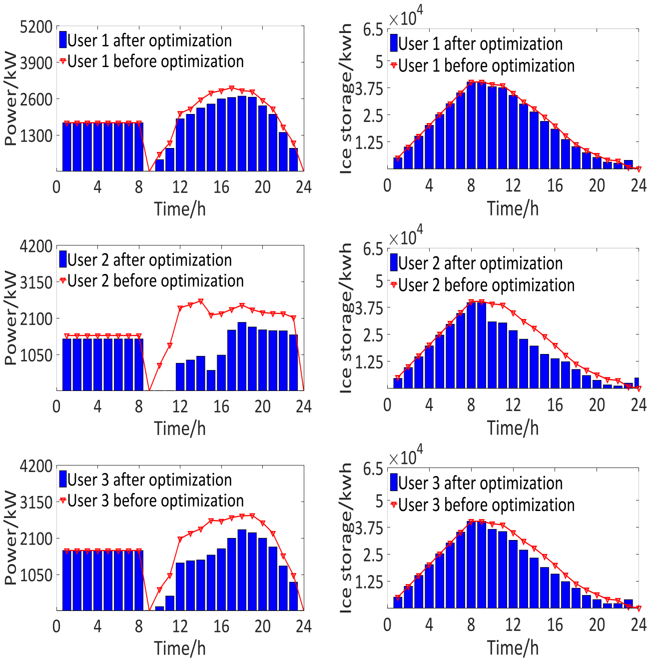

Fig. 9. Refrigerator power and ice storage capacity changes

After optimization the parameters of various stakeholders, as shown in Table 2, it can be seen that both the power supply company and the load aggregator increased revenue, and air-conditioning users reduced the cost of electricity, verifying the method is feasible.

Table 2. Compare the values before and after optimization

optimize the target	**Before optimization**	**Optimized**
Power supply company revenue /¥	253600	348884
Load aggregator revenue /¥	94	121
Air-conditioning user daily electricity fee/¥	234060	358324

4. CONCLUSIONS

In order to reduce the wind power of the distribution network system, first consider the use of the load transfer characteristics of ice storage air conditioning, convert excess wind energy into cold energy storage, and then establish a power generation company, load aggregator operating income and air conditioning users The least-cost multi-objective optimization model is finally solved by non-dominated multi-objective genetic algorithm.

The results show that the control strategy can improve the wind energy utilization rate, increase the elasticity of the demand side based on the user's power comfort.

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