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UNIT COMMITMENT MODEL AND BENEFIT ANALYSIS OF IN DEPTH PEAK LOAD CYCLING OF THERMAL POWER UNIT UNDER WIND POWER INTEGRATION

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ABSTRACT

In this paper, the peaking capability of the thermal power unit is maximized, and the wind power accommodation as much as possible. A mathematical model of in depth peak load cycling of the thermal power unit under the condition of wind power integration is proposed, and optimal operation of thermal power unit in depth peak load cycling. Based on the actual data of a provincial power grid in China, the economics of the thermal power unit in depth peak load cycling scheme under large-scale wind power integration are analyzed. The research results show that the adoption of thermal power unit in depth peak load cycling scheme can not only stabilize wind power fluctuation, solve the problem of wind power accommodation, but also save the generation cost of thermal power unit, making it feasible to "depth peak load cycling and wind power accommodation".

Keywords: Peaking capability, Depth peak load cycling, Wind power accommodation

1. INTRODUCTION

After large-scale wind power being integrated into the power grid, the peaking capacity of the power system is severely weakened[1-2]. In addition, the wind power output has the characteristics of intermittent, volatility, anti-peak characteristics, and low prediction accuracy and capacity reliability[3-5], which greatly increases the equivalent load peak-to-valley difference of the system and increases the system peak shaving. Difficulty. With the continuous adjustment of China's industrial structure, China's electricity consumption structure is also constantly changing. At present, the gap between the peak and the valley of the power grid is increasing, which makes the peak amplitude of the power grid increase, and the difficulty increases accordingly[6-7]. The problem of huge amount of wind power curtailment in the winter heating period in Northeast China is particularly prominent, and has become the focus of attention of the whole society[8]. Taking advantage of the large capacity of thermal power units of the power grid, it is an inevitable trend to dig deep into the peaking capability of thermal power units, break through the traditional concept, and improve the utilization of renewable energy.

The problem with the traditional unit optimization combination is that although the total consumption is the smallest or the economic benefit is the largest, it is not considered that when the load is low, the conventional thermal power unit has been adjusted to a lower output. If the wind farm output increases greatly at this time, then Whether the conventional unit can further contribute to the wind power to determine the capacity of the grid to accept wind power, that is to say, the peaking capacity of the conventional unit at low valley load is the key condition to limit the ability of the provincial power network to accept wind power[9-11]. In this paper, the thermal power unit with high peaking capability is selected to supply power, and the peaking capacity of the thermal power unit is improved. When the load is high, the wind power fluctuation is stabilized; When the load is low, the thermal power unit can not only further pressure out the wind power to load, Improve the capacity to accept wind power, but also achieve greater economic benefits.

2. IMPACT OF WIND POWER INTEGRATION ON POWER SYSTEM IN PEAK LOAD SHAVING

The volatility and uncontrollability of wind resources make the wind power output intermittent and volatility. The reliability of wind power capacity is much lower than that of conventional thermal power units. Therefore, these features make the system face a series of complex problems when it receives wind power. Wind power is a kind of auxiliary energy source in the power system, rather than large-scale alternative energy. Therefore, after large-scale wind power is integrated into the power grid, the utilization rate of conventional power sources such as thermal power in the system will be affected. When the system is connected to a large amount of wind power, the thermal power unit needs to reduce its output to accept this part of wind power. Especially in the low load period, whether the thermal power unit can continue to lower its output and the load regulation performance of the power source can not be fully developed will be a manifestation of the peak pressure faced by the system after large-scale wind power access. The fluctuation degree of wind power output is generally much larger than the load change, and its fluctuation trend and load are in opposite states, and there is inverse peak regulation characteristic, as shown in Fig 1.

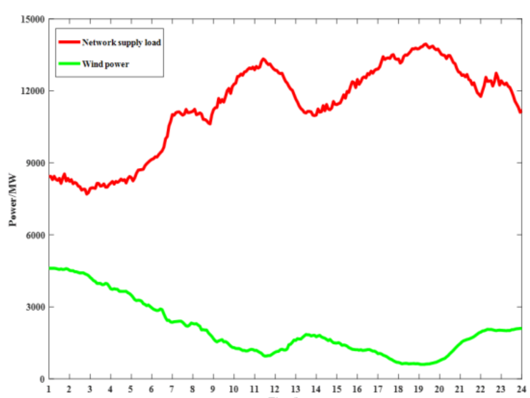

Fig 1 Inverse peak regulation feature of wind power in winter

The inverse peak regulation characteristics of wind power increase the difficulty of peak shaving in the power grid. If the peak regulation capacity is insufficient, there will be a situation in which the wind is abandoned during low load periods. Therefore, the system will face huge peaking pressure after large-scale wind power is integrated into the grid.

3. UNIT COMBINATION MODELING CONSIDERING PEAKING CAPABILITY

3.1 Mathematical model of unit combination

Assuming that the scheduling period is 24 hours, the number of units scheduled in the system is n, and the load at each time point is set to P_{lt}, indicating the total power supply load power at time t, then the mathematical model of the unit combination is:

3.1.1 Objective function

It is required that the system meets the principle of maximum peaking capability of the unit combination and minimum cost in the distribution of power at any scheduling time within 24 hours. The multi-objective function can be written as:

$$\max X_t = \sum_{i=1}^{n} \alpha_i \cdot P_{i\max} \cdot \beta_{it}$$

And:

$$\min F_t = \sum_{i=1}^{n} \Big[\beta_{it} \cdot F(P_{it}) \cdot S_{coal}/10000 + \beta_{it} \cdot (\beta_{it} - \beta_{it-1}) \cdot f_{istart} + \beta_{it-1} \cdot (\beta_{it-1} - \beta_{it}) \cdot f_{ishut}\Big] \qquad (1)$$

In the formula:

$$\alpha_i = (P_{i\max} - P_{i\min})/P_{i\max}$$

$$F(P_{it}) = a_i \cdot P_{it}^2 + b_i \cdot P_{it} + c_i$$

F_t represents the coal consumption and start-stop cost of the unit, and X_t represents the peaking capability of the unit. α_i indicates the peak shaving depth coefficient of the i-th unit; P_{it} indicates the active power output of the i-th unit at time t; $P_{i\max}$ is the rated maximum output of the i-th unit, $P_{i\min}$ is the minimum output of the i-th unit's steady combustion; β_{it} is set to 0 and 1 two values, $\beta_{it}=0$ means that the i-th unit is in the stop state at time t, $\beta_{it}=1$ means that the i-th unit is in operation at time t; $F(P_{it})$ is the coal consumption of the i-th unit at time t, S_{coal} represents coal price; f_{istart} and f_{ishut} are the starting and stopping costs of the i-th unit, respectively.

3.1.2 Power balance constraint

It is required to balance the total power generation with the total load power at each scheduling time, so the power balance constraint equation is:

$$\sum_{i=1}^{n} P_{it} \cdot \beta_{it} + P_{wt} = P_{lt} \qquad (2)$$

In the formula P_{wt} denotes the grid-connected output required by wind power at time t; P_{lt} denotes the total power supply load power at time t. $\sum_{i=1}^{n} P_{it} \cdot \beta_{it}$

accumulates the actual output of all thermal power units at each dispatch time.

3.1.3 Spinning reserve constraints

Considering the spinning reserve capacity according to 7% of the total system load, $P_{lt}+P_{xt}=1.07P_{lt}$, there is

$$\sum_{i=1}^{n} P_{i\max} \cdot \beta_{it} \geq 1.07P_{lt} \qquad (3)$$

In the formula P_{xt} is the system spinning reserve capacity; $P_{i\max}$ is the maximum upper limit of the power generation of the i-th unit.

3.1.4 Unit output upper and lower limit constraints

$$P_{i\min} \leq P_{it} \leq P_{i\max} \qquad (4)$$

$P_{i\min}$ and $P_{i\max}$ respectively indicate the upper and lower limits of the output of the i-th unit.

3.1.5 Unit ramp and start-stop power constraints

$$\begin{aligned} P_{it}-P_{it-1} &\leq \beta_{it-1} \cdot A_{iup} + (\beta_{it}-\beta_{it-1}) \cdot A_{istart} \\ P_{it-1}-P_{it} &\leq \beta_{it} \cdot A_{idown} + (\beta_{it-1}-\beta_{it}) \cdot A_{ishut} \end{aligned} \qquad (5)$$

In the formula, A_{iup} and A_{idown} are the uphill power limitation and downhill power limitation of unit i; A_{istart} and A_{ishut} are the starting and stopping power limitations of unit i respectively.

3.1.6 Wind power output constraint

$$0 \leq P_{wt} \leq P_{wt}^{pr} \qquad (6)$$

In the formula, P_{wt} represents the actual output of wind power at time t; P_{wt}^{pr} represents the maximum predicted output of wind power at time t.

In summary, the final mathematical model is:

$$\begin{aligned} &\max \ \text{Formula (1)} \\ &s.t. \ \text{Formula (2)-(6)} \end{aligned} \qquad (7)$$

The above mathematical model is a nonlinear programming problem. This paper uses MATLAB and LINGO to solve.

3.2 Solution method

A hierarchical sequence method is employed. According to the order of multi-objective importance, the unit combination scheme with the highest peaking capability in a single dispatching time is first calculated, and then the unit-combined scheduling scheme with the optimal operating cost is selected from these scheduling schemes.

4. CASE ANALYSIS

4.1 Case conditions

By analyzing the total load of the power network in Liaoning Province from September 22nd to 25th, 2017, and summing up the total contribution of wind power, the typical day is selected from 0:00-24:00 on September 22nd as an example. The hour is a scheduling period. The data curve of the total load of the power network in Liaoning Province on September 22nd, 2017 is shown in Fig 2.

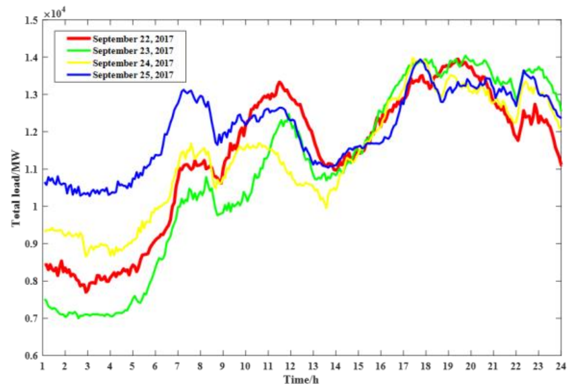

Fig 2 Power network supply load curve of Liaoning province from september 22nd to 25th, 2017

Table 1 Electrical parameters of thermal power units in Liaoning province

Unit number	rated power	Minimum technical output	Climbing rate
1，2	300MW	125MW	3-10MW/min
3，4，5，6	350MW	180MW	4%
7，8	350MW	180MW	4.5MW/min
9，10	330MW	165MW	1%/min
11，12	350MW	100MW	3.5MW/min
13，14，15	200MW	100MW	60MW
16，17	600MW	240MW	6MW/min
18	330MW	165MW	5MW/min
19	330MW	220MW	5MW/min
20，21	220MW	135MW	5MW/min
22	100MW	40MW	2-5MW/min
23，24	150MW	60MW	2-5MW/min
25，26	600MW	300MW	6MW/min
27	119MW	50MW	2-5MW/min
28	135MW	50MW	2-5MW/min
29，30	350MW	145MW	5MW/min
31，32	300MW	140MW	5MW/min
33，34	100MW	60MW	2-5MW/min
35	200MW	11MW	2MW/min
36	200MW	120MW	2MW/min
37，38	350MW	165MW	3.5MW/min

39，40	350MW	140MW	3.5MW/min
41，42，43	300MW	225MW	3MW/min
44，45	320MW	210MW	4.5MW/min
46，47	330MW	115MW	15MW/min

Table 1 is the unit's electrical parameters. Through the analysis of peaking capability and ramping power of each thermal power unit in Liaoning Province, the unit with large rated capacity and large peaking capability should be given priority to power supply, and the unit with small rated capacity and small peaking capability should be removed first when the load is reduced.

4.2 Optimization model result analysis

Considering the peaking capability, the unit combination optimization scheduling results for each scheduling time period are shown in Fig 3.

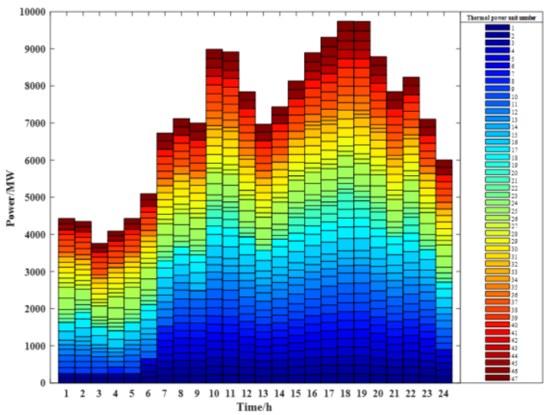

Fig 3 Thermal power unit combined scheduling result considering peaking capability

Using LINGO software, the cost of traditional scheduling schemes in 24 hours is 59,079.48 yuan, while the cost of scheduling schemes considering peaking capability is 6,6317.91 yuan. Compared with traditional scheduling schemes, although the cost of scheduling schemes considering peaking capability is increased, when both schemes are in depth peak load cycling, the traditional scheduling schemes have some shortcomings compared with scheduling schemes considering peaking capability.

4.3 Benefit analysis

4.3.1 Benefit analysis of "depth peak load cycling"

For thermal power enterprises, in the range of peaking capability, with the increase of peaking depth, according to the consumption characteristics of the unit, the coal consumption cost of the unit is reduced, the number of start and stop is also significantly reduced, and the start-stop cost is reduced, so the total operation Reduce costs.

As shown in Fig 4, a comparison between traditional scheduling schemes and scheduling schemes considering peaking capability is shown in the "depth peak load cycling" chart.

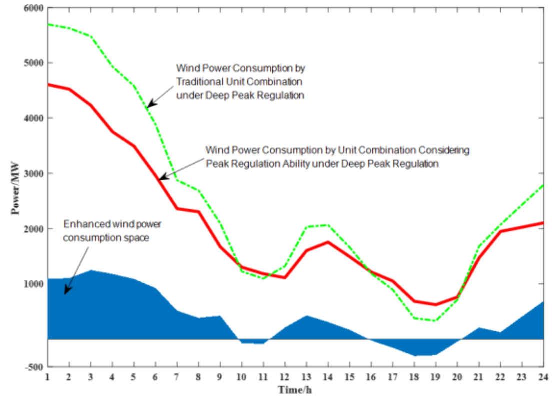

Fig 4 Contrast of "depth peak load cycling"

It can be concluded that the coal consumption cost of the unit combination scheme considering peaking capability is lower than that of the traditional unit combination scheme when using "depth peak load cycling":

$$W_f = \sum_{t=1}^{T}\sum_{i=1}^{n}\left[a_i \cdot P_{Git}^2 + b_i \cdot P_{Git} - a_i \cdot P_{Dit}^2 - b_i \cdot P_{Dit}\right] \cdot S_{coal} \tag{8}$$

P_{Git} denotes the "depth peak load cycling" active power output of each thermal power unit in each dispatching time under the traditional operation mode, and P_{Dit} denotes the "depth peak load cycling" active power output of each thermal power unit in each dispatching time under the combined operation mode considering the peaking capability. T is 24, representing the total number of scheduling time points. n is 47, indicating the number of thermal power units.

For wind power enterprises, with the increase of peak shaving depth of thermal power units, the amount of wind power connected to the grid increases. Wind power enterprise's income is proportional to the utilization ratio of wind power. Wind power enterprise is the most direct beneficiary of depth peak load cycling of thermal power unit.

In the case of "depth peak load cycling", considering the combined operation mode of the thermal power unit with peaking capability compared with the traditional thermal power unit combined operation mode, the economic benefits of wind power improvement are:

$$E_w = \sum_{t=1}^{T}\sum_{i=1}^{n}\left[\left(P_{Git} - P_{Dit}\right)\times 1000\right] \cdot \left(S_u - S_c\right) \tag{9}$$

S_u and S_c respectively indicate the pool purchase price and cost electricity price of wind power; the unit is: yuan/(KWh).

Table 2 Benefit analysis table under "depth peak load cycling"

Operation mode	Thermal power coal consumption cost (yuan)	Improve the power consumption of wind power(MW)	Improve the economic benefits of wind power(yuan)
Traditional way	52567.74	*	*
Consider peaking capability	50450.92	9516	5709600

As shown in Table 2, in the case of "depth peak load cycling", compared with traditional dispatching schemes, unit commitment schemes considering peaking capability not only reduce the coal consumption cost of thermal power units, but also improve the profits of wind power enterprises, so as to optimize the overall benefits.

4.3.2 Suppressing the fluctuation of wind power

Wind power has volatility and intermittent output characteristics. Especially when the load is high, the output of the thermal power unit is high. At this time, if the output of the wind power is greatly reduced, there will be a situation in which the thermal power unit cannot continue to output the load.

Compared with traditional schemes, unit commitment schemes considering peaking capability not only reduce the amount of abandoned wind power during "depth peak load cycling", but also improve the capacity of thermal power units to cope with the dramatic decline of wind power at higher loads.

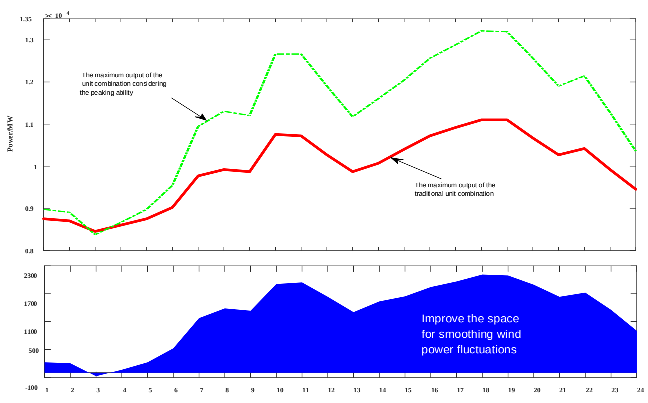

Fig 5 The space of suppressing the fluctuation of wind power

As shown in Fig 5, compared with the traditional unit commitment, the maximum output of unit commitment with peak load regulation capability improves the space for wind power fluctuation suppression:

$$E_f = \sum_{t=1}^{T}\sum_{i=1}^{n} P_{i\max} \cdot (\beta_{it} - X_{it}) \quad (10)$$

In the formula, X_{it} represents the operating state of the i-th unit at time t in the traditional unit combination mode.

When the load is high, the unit combination scheme that considers the peaking capability increases the space for suppressing wind power fluctuations to 30566 MW.

5. CONCLUSION

In order to improve the power system adjustment capability and increase wind power curtailment consumption space, this paper proposes to use the thermal power unit depth peak load cycling stage to reduce the output of the thermal power unit, increase the space of wind power integration, and ensure the new energy acceptance and dispatching of the system is safe and stable. Considering the influence of wind power on system peak shaving, system peak load regulation capacity requirement and wind power accommodation capability, a unit combination optimization model considering the "peaking capability-cost" joint constraint is constructed for power network architecture and grid characteristics. Analyze and compare the wind power accommodation capability and the space of suppressing the fluctuation of wind power under the condition of "depth peak load cycling" in the combination of traditional thermal power unit combination and unit combination considering peaking capability. The example shows that under the condition of "depth peak load cycling", the optimized scheduling model not only improves the wind power consumption space of the system, but also increases the power generation income of wind power enterprises, and can also reduce the coal consumption cost of thermal power units, so that the total utility benefit optimal.

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