Research on wind power grid-connected operation and dispatching strategies of Liaoning power grid

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Abstract. As a kind of clean energy, wind power has gained rapid development in recent years. Liaoning Province has abundant wind resources and the total installed capacity of wind power is in the forefront. With the large-scale wind power grid-connected operation, the contradiction between wind power utilization and peak load regulation of power grid has been more prominent. To this point, starting with the power structure and power grid installation situation of Liaoning power grid, the distribution and the space-time output characteristics of wind farm, the prediction accuracy, the curtailment and the off-grid situation of wind power are analyzed. Based on the deep analysis of the seasonal characteristics of power network load, the composition and distribution of main load are presented. Aiming at the problem between the acceptance of wind power and power grid adjustment, the scheduling strategies are given, including unit maintenance scheduling, spinning reserve, energy storage equipment settings by the analysis of the operation characteristics and the response time of thermal power units and hydroelectric units, which can meet the demand of wind power acceptance and provide a solution to improve the level of power grid dispatching.

1. Introduction

As a renewable energy, wind power generation has low cost process, environmental protection and other advantages, compared to the relatively long construction period of hydropower, the wind farm construction period is shorter, and the influence on the environment is relatively less [1]. The wind resource is relatively abundant in China, and the development of wind power has great potential. With the progress of technology and the installed capacity expanding, the cost of wind power generation is dropping rapidly. Increasing the proportion of wind power and other clean energy in the power structure is very beneficial to achieve the goals of energy saving and consumption reduction, and is the final purpose of the priority development of all voltage levels of power grid. The randomness and intermittence of wind power output results in the complexity and uncertainty of the operation characteristics of wind farms compared with conventional power plants such as thermal power units and Hydropower units. Therefore, large-scale wind power grid operation brings greater challenges to the stability of the grid and voltage quality, and also puts forward higher requirements for the peak load capacity of the grid. The power structure of Liaoning power grid is mainly thermal power, and the hydropower units with high peak shaving capacity are relatively small [2]. With the grid-connecting of Hongyanhe nuclear power, during the winter heating period, the contradiction between the system peaking and the wind power consumption is very outstanding, which results in the occurrence of wind power limitation [3].
Therefore, the operation of wind farms makes the power grid dispatching strategies become more complex, and the traditional scheduling models and dispatching strategies have been difficult to match. This paper studies on the effects of wind power on power system dispatching operation, combined with the analysis of the space-time output characteristics of wind farm and the load characteristics, the corresponding dispatching strategies are proposed, which can improve the power system of wind power capacity, in order to adapt to the demand of large-scale grid-connected wind power dispatching.

2. Analysis of grid-connected wind power in Liaoning power grid

2.1. Distribution and installation of wind farms in Liaoning power grid
The effective hours of wind energy resource in Liaoning are more and its distribution is concentrated. In 2016, the effective hours of wind resource in Liaoning power grid were 2219 hours in 6.49% year-on-year growth, and the utilization hours of wind power were 1928 hours, which increased by 148 hours compared with the same period last year [4]. By the end of 2016, Liaoning power grid had 84 wind farms grid-connected, which mainly distributed in the northwest and coastal areas of Liaoning Province. The installed capacity was 6946.86MW in 8.47% year-on-year growth, accounting for 15.10% of the total installed capacity of the whole network. In 2016, nine new wind farms and new capacity of 437.5MW were added. Among them, five wind farms had accessed to the 220kV system with the capacity of 242.5MW; four wind farms had accessed to the 66kV system with the capacity of 195MW [5].

The total amount of Liaoning wind power generation had been completed by 12924GWh in 15.53% year-on-year growth, accounting for 7.46% of the provincial total power generation, and the wind power generation hours was 1928 hours by an increase of 148 hours.

2.2. Analysis of space-time output characteristics of wind farms in Liaoning power grid
The space-time output characteristics of wind farms in Liaoning power grid are related to the time, season and spatial distribution of wind farms, which are the basic data to study on power grid dispatching and wind power accommodation capacity. Although the fluctuation of a single generator could be smoothed and buffered partly by wind farm, but due to the volatility of wind power it can still cause sharp fluctuations in wind farms in a short period of time. With the wind power capacity increasing, when the capacity of wind power reaches a certain scale, this volatility will lead to more mutational load that conventional generators should bear, so we have to arrange more spinning reserve and peak shaving capacity, which increase the cost of power grid operation.

Based on the statistical data of seventeen typical regional meteorological stations in Liaoning Province, Suizhong, Beipiao and some wind farms, the monthly average wind speed was as shown in Figure 1. From March to May, the wind speed curve was at the high position in a year. The maximum appeared in April, and the monthly mean wind speed reached 7.2m/s; the wind speed curve in summer from July to September was at the low position, which was the lowest in August, and the monthly average wind speed was about 4.7m/s. In July and August of each summer is a peak load of Liaoning power grid, which is the maximum load period, however the wind power capacity of wind farms is at a minimum.

![Figure 1. Monthly mean wind speed statistical curves at 10m height in Liaoning (unit: m/s).](image-url)
For power grid dispatching when the wind power output is larger and the electricity load is at valley period in power system, in order to absorb the wind power output as more as possible, it can only change the number and output of the grid-connected conventional units, which will transfer part of load from the thermal power and hydropower units with low production cost to the units for frequency modulation and dispatching with high production cost, thereby affecting the economy of unit operation.

2.3. Prediction and error analysis of wind power
The large-scale grid-connected wind power brings great challenges to the stability of power system, and its uncertainty is very unfavorable to the power grid dispatching and operation, which puts forward higher requirements for the reliability of power system. Compared with wind power and other new energy, traditional load forecasting is more accurate, although there are also forecast errors, we have mature coping experience to solve them; for the fault of hydropower and thermal power generating units and other uncertain factors, there are also mature coping measures. The significance of accurate wind power forecasting in power system mainly has the following points [6]: firstly, the spinning reserve capacity with higher running cost can be reduced, and the operation cost of power grid will be decreased; secondly, dispatchers can optimize the operation and maintenance time, increase the wind power consumptive capacity, so as to reduce the occurrence of "abandoned wind".

According to the definition of prediction accuracy in two detailed rules, the prediction accuracy of monthly average wind power in Liaoning power grid in 2016 was 84.359%, in which more than 85% were Tieling Longyuan, Fuxin Zhangwu, Kangping, Huaneng Pingdingpu, Guodian Hefeng and other 25 wind farms; in which less than 80% were Liaoaneng Xiehewanji, Tianrun Liulonggou and other three wind farms. The monthly average wind power prediction accuracy of Tieling Longyuan wind farm was the highest, which was 89.858%; The Lowest was Huarun Yimachi wind farm, which was 74.178%. The month of the highest monthly average wind power prediction accuracy was July, up to 88.579%; and it was the lowest with 79.550% in May. The overall prediction qualified rate of all wind farms reached 98.33%, as shown in Figure 2.

![Figure 2. Diagrammatic sketch of monthly average wind power prediction accuracy of partial wind farms.](image)

2.4. Analysis of wind power curtailment condition in Liaoning power grid
The power supply structure of Liaoning power grid is characterized by a high proportion of thermal power units, accounting for more than 67% of the total installed capacity, and heat supplying units are accounting for more than a half. The hydropower units with high peak shaving capacity are accounting for a relatively small proportion, less than 7%. With the nuclear power units continuously being in grid-connected operation, the peak load regulation capacity of Liaoning power grid is greatly restricted.
• Affected by the power structure, load characteristics and the increasing scale of wind power, the wind power accommodation capacity is insufficient in Liaoning power grid, which is more prominent during the heating period.

• For load characteristics, the load growth is slow, by the end of 2016, Liaoning's total social electricity consumption was 2.65% year-on-year; the annual power grid peak spinning reserve was sufficient, with the daily average about 1000MW. The overall situation of Liaoning power grid was oversupply,

• For power structure, the flexible peak shaving power is less, and the peaking capacity of the power supply is insufficient. In addition to wind power, the total capacity of direct dispatching units in Liaoning power grid is 21960MW, hereinto thermal power is 21340MW, hydropower is 760MW, and thermal heating power is 12600MW, accounting for 59% of the direct dispatching thermal power capacity.

• The wind power resources are relatively concentrated. The intermittent movement of large-scale wind power will induce larger power flow, which is difficult to adapt to power grid.

• For constraint of power grid, Zhangwu output section is composed of Gaowu #1 Line and #2 Line. When the Zhangwu area stability control device is not in use, considering N-1 of lines on one tower or splitting running, the normal limit of the section is 300MW(Gaowu #2 Line: LGJ-400). When the stability control device is in use, the section has no power flow limit, only to control Gaowu #2 Line's power flow not more than 300MW.

• For power source and load in the section, there are 220kV Zhangbei wind farm with the capacity of 400.5MW and Lianhe wind farm with the capacity of 346.5MW; the low voltage cross wind power of Zhangwu substation is 199.3MW; the load of Zhangwu substation is about 80MW. In the gale period of March and April, the simultaneity factor of wind power in Zhangwu area is higher, which may lead to the action of stability control device and the occurrence of wind power curtailment during the low load period.

3. Analysis of operation characteristics in Liaoning power grid

3.1. Load characteristics in Liaoning power grid

The load of Liaoning power grid shows obvious seasonal characteristics. During heating period, the load is the largest, with the peak load of 23610MW, and the average light load is 19750MW (excluding the influence of Spring Festival). During peak load of summer in July and August, there is a secondary load peak, with the average peak load of 22000MW, and the average light load of 18040MW. During the alternating spring and summer, the power load is minimum, with the average peak load of 20540 MW, and the average light load of 17090MW.

The maximum full-aperture load of Liaoning power grid has reached a record high of 24740MW, which occurred on December 26th; the minimum full-aperture load was 13410MW, which occurred on February 9th; the maximum accepting-electricity of inter-provincial tie lines was up to 8770MW, which occurred on December 5th.

3.2. Power sources in Liaoning power grid

The total installed capacity of Liaoning power grid (including Suizhong power plant, Jiehe hydropower plant) is 46013.001MW. Among them, the thermal power capacity is 31139.88MW, accounting for 67.68% of the total, reduced by 3.45% compared with the previous year; the nuclear power capacity is 4475.16MW, accounting for 9.73% of the total; the wind power capacity is 6946.86MW, accounting for 15.10% of the total, increased by 0.32% compared with the previous year; the hydropower capacity is 2931.096MW, accounting for 6.37% of the total, down 0.41% year-on-year; the PV plant capacity is 520.005MW, accounting for 1.13% of the total, compared with the previous year increased by 0.75%.
3.3. Analysis of operation characteristics and response time of various units

The conventional peak regulation mode of thermal power units are widely used, and the non-conventional mode is divided into deep pressure output mode and unit start-up and shutdown mode, which need to be planned according to the characteristics and peak regulation capacity of various units. For the first peak shaving mode, the output of the thermal power unit with better performance can be reduced from 70% to 50%; for the second peak shaving mode, 50MW and 100MW units are generally scheduled to start and stop on the same day. The self-adjustment rate of thermal power units is related to the load during operation, and the adjustment speed is more than 5% per minute under the output of 50% to full capacity; under the low output condition, the adjustment speed of the units is decreased, about 3% per minute.

Hydropower has fast response speed, convenient to start and stop and other advantages, so is very beneficial for power grid peak shaving. In the case of sufficient power supply during the light load period, it can operate at low output or shutdown as spinning reserve device of system. Dispatchers generally let some hydropower units grid-connected in advance before peak load coming, and increase the output of hydropower units with load increasing. As shown in Figure 3, it can be seen that the hydropower plant was operating at low output until the peak load at 14 p.m. In order to deal with the load peak, the output of hydropower units can be from nearly 0 to full capacity of 400MW in about 60 minutes.

![Figure 3](image)

**Figure 3.** Diagrammatic sketch of 24-hour power change of one certain hydropower station in Liaoning power grid.

3.4. Correlation analysis of wind power output and load characteristics

Electricity has the characteristics of simultaneous production and consumption, and cannot be stored in large quantities. Wind power is stochastic, and the regional power load varies with season, month, date and even time. Therefore, to accurately grasp the rules of the load variation with time is the basis for power dispatching department to plan the power balance and effectively and economically utilize wind power.

In order to analyze the correlation between wind power output and load change, the correlation coefficient is proposed, and the formula of correlation coefficient is shown as follows:

\[
C = \frac{\sum_{i=1}^{n} (a_i - \bar{a})(b_i - \bar{b})}{\sqrt{\sum_{i=1}^{n} (a_i - \bar{a})^2 \sum_{i=1}^{n} (b_i - \bar{b})^2}}
\]

(1)

Where \(a\) is for the load; \(b\) is for the wind power output; \(\bar{a}\) is for the mean load during statistical period; \(\bar{b}\) is for the mean wind power output during statistical period.

The range of \(C\) is from -1 to 1, and the larger value illustrates the positive correlation between wind power output and load, the smaller value illustrates the negative correlation. The wind power and the grid load power of Liaoning power grid on March 19th were selected as the input data, and the sampling interval was 1 minute. As shown in Figure 4, the correlation between the wind power output and the daily load variation in a typical day during 30 days was analyzed.
Figure 4. Trends of wind power output and typical daily load variation in Liaoning power grid on March 19th.

It can be seen from Figure 4 that the wind power output has the inverse correlation with the load on March 19th, and the grid connection of wind power actually intensifies the peak-valley difference.

4. Dispatching strategies of wind power utilization

4.1. Analysis of thermal power operation and wind power consumptive ability

According to the wind power monthly consumptive proportion in Liaoning power grid during recent five years, during heating period from November to March of the following year, the wind power participated in more peak shaving, and the wind power consumptive ability was poor; during non-heating period, heating unit operation ratio dropped significantly, which improved the thermal power peak regulation capacity, and the wind power consumptive proportion was increased greatly [7]. During the heating period from 2015 January to March, affected by the whole grid load seriously decreasing and the operation of Hongyanhe nuclear power, the wind power consumptive ability had a sharp fall compared to the same period, was the lowest level in history; After the heating period, by adjusting the operation mode and optimizing tie line power consumptive timing, the wind power consumptive proportion increased greatly, which was particularly obvious in April. The valley power balance gap of Liaoning power grid was 800 to 1000MW during heating period. The heating balance, wind power preferential consumption and thermal power deep peak regulation has become the norm at daily operation in Liaoning power grid. During the festival low load period, the system cannot carry the heating unit operation to meet the heating reliability requirements, and is forced to break through the minimum mode, highlighting the contradiction between power grid safety and heating safety.

4.2. Analysis of hydropower operation and wind power consumptive ability

By the end of 2016, the directDispatching hydropower total power generation of Hunjiang valley was 476.13GWh, among them Huanren plant Power generation was 177GWh, Huilong plant was 66GWh, Taipingshao plant was 189GWh, Shuangling plant was 59GWh, Jinshao plant was 78 GWh. The year 2015 was a special dry year to Hunjiang valley, and affected by the bottom water shortage and water regulation, the cumulative annual electricity generation had decreased significantly over the years, reducing by 1000GWh, and compared with the last special dry year 2014 reducing by 384.5GWh, down 44.68%.

4.3. Dispatching strategies of wind power utilization in Liaoning power grid

Due to the shortage of the hydropower capacity with high peak regulation ability, the peak shaving of Liaoning power grid mainly relies on the deep peak shaving and scheduled outage of thermal power units [8]. The conventional units could normally reduce to 60% before, but the peak depth of Liaoning power grid has become normal, the thermal power units can reduce to 40%, which can improve the wind power acceptance. In addition, the following dispatching strategies can be used:
• During heating period, arrange Hongyanhe nuclear plant operation by single unit. Considering #2 unit production planning and #1 unit refuelling arrangement during the winter heating period, schedule single unit operation and duplex running in June to August schedule. Then in the middle heating period, the valley down reserve is expected to reach about 800MW in Liaoning power grid, which can solve the problem of peak shaving during valley periods.

• Reasonably arrange the operating mode of thermal power units, to ensure wind power and other clean energy generation on demand during non-heating period. During non-heating period, schedule duplex running of Hongyanhe nuclear plant. Combined with the dispatching principle of impartiality and openness of thermal power units, set the order table of thermal power unit shutdown by turns. Based on the short-term wind power prediction results, the wind power system can automatically make wind power prediction, and the wind power forecasting data will be transmitted to the provincial power dispatching centre for additive calculation. When the wind power is too large, thermal power units should be shut down in advance; when the wind power is too small, thermal power units should be arranged start-up in advance. By scheduling thermal power unit shutdown by turns to participate in peak shaving, the wind power will be fully accepted during non-heating period.

• Carry out the local power plant grid-connected operation and auxiliary service assessment work, to arouse the enthusiasm of small thermal power units to participate in peak regulation, to excavate the local small thermal power and small hydropower unit potential of peak regulation to share the peak load pressure together.

5. Conclusions

Based on the analysis of power source, peak regulation, the operation characteristics and the wind power utilization in Liaoning power grid, for the contradiction between wind power acceptance, light power peak regulation and power structure, the dispatching strategies were proposed in this paper, including arranging single unit operation of Hongyanhe nuclear plant, reasonable arranging of thermal power unit start-up, carrying out the local power plant grid-connected operation and auxiliary service assessment task. The strategies have been applied in Liaoning power dispatching centre, which provide reference for dispatchers to select reasonable unit operation modes. The further research on the synchronization of load data and wind power operation data will be carried out, combined with AGC and real-time dispatching, in order to enhance the wind power consumptive ability.

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