Market demand assessment of auxiliary services after large-scale wind power access

Qiwang Li¹, Jing Li¹, Dunnan Liu², Ningning Zhao²*, Zhihao Li²
¹ State Grid Hunan Electric Power Company Limited, Changsha, Hunan, 410004, China
² North China Electric Power University, Changping District, Beijing, 102206, China
znn_2016@163.com

Abstract. Since the beginning of the 21st century, wind power has flourished as a major form of new energy. Different from thermal power, hydropower, nuclear power and other power sources, wind power output is characterized by intermittence and volatility, low reliability of capacity, and poor predictability, which will bring additional pressure to the safe and stable operation of the power system, thus restricting its development. In order to improve the consumption capacity of renewable energy, China is building an auxiliary service market based on economic leverage to encourage flexibility resource participation in system regulation services. Demand assessment has also become a key issue in market construction. Therefore, this paper will take the peak regulation auxiliary service market and reserve auxiliary service market under large-scale wind power access as examples to evaluate the peak regulation and reserve demand.

1. The impact of wind power access on demand for peak regulation

The large-scale and centralized development of wind power makes the characteristics of wind power output prominent, and the power system scheduling and operation is facing great pressure. Among them, peak load regulation pressure is the main pressure faced by the system scheduling and operation after large-scale wind power is connected.

At present, the research on the influence of wind power access on system operation is all about treating wind power output as negative load, superimposing it with the actual load of the system to form a new equivalent load of the system, and then simulating the system operation according to the fluctuation characteristics of the equivalent load. Based on the above analysis, according to the different influence modes of wind power on the peak-valley difference of equivalent load of power grid, the influence of wind power intraday output on peak regulation demand can be divided into three situations: negative peak regulation, positive peak regulation and over peak regulation.

1.1. Negative peak regulation

Wind power negative peak regulation refers to the increase and decrease trend of wind power intraday output is opposite to the system load curve, and the peak-valley difference of the equivalent load curve of the system increases after wind power is connected [1]. In fact, the influence of wind power output on system peak regulation most of the time in many regions belongs to the type of negative peak regulation, which is determined by the wind energy resources in each region. In this case, wind power access brings a negative impact on system peak regulation, that is, wind power output is small at load peak, while
wind power output is large at load trough. This characteristic of wind power output will undoubtedly increase the peak load regulation pressure of the system. If there is no corresponding energy storage device and peak load regulation measures, it will be required that wind power is forced to be abandoned to maintain the power balance in load trough, resulting in a large amount of clean energy waste.

1.2. Positive peak regulation
Wind power positive peak regulation refers to the increase and decrease trend of wind power intraday output is basically the same as the system load curve, and the peak-valley difference of wind power output is less than the peak-valley difference of system load, and the peak-valley difference of the equivalent load curve of the system decreases after wind power is connected. When the influence of wind power on system peak regulation is positive, wind power output can play a supporting role in system peak regulation, making full use of wind power to meet user demand can obtain considerable economic and social benefits.

1.3. Over peak regulation
Wind power over peak regulation refers to the increase and decrease trend of wind power intraday output is basically the same as the system load curve, and the peak-valley difference of wind power output is less than the peak-valley difference of system load, and the system equivalent load curve’s peak&valley is inverted after wind power is connected. Over peak regulation can be divided into two situations. One is that the peak-valley difference of equivalent load is smaller than the peak-valley difference of the original system load. At this time, although wind power inverts the peak&trough time of the system load, it actually reduces the peak-valley difference that the system needs to adjust and relieves the peak-valley pressure of the system. The other is that the peak-valley difference of the equivalent load is greater than the peak-valley difference of the original system load. At this time, wind power still increases the peak-valley difference of the system, aggravating the peak-valley load of the system\(^2\). In addition, due to the wind power access which leads to system load peak valley inversion, the system scheduling should adjust the peak regulation strategy. It is worth noting that the over peak regulation of wind power is only possible when the installed capacity of wind power is relatively large relative to the load, so this situation is relatively rare in the power system at present.

Current research shows that wind power output in most cases is the negative peak regulation characteristics. The negative peak regulation characteristic of wind power will further aggravate the pressure of peak regulation after the grid is connected, and further increase the demand of peak regulation capacity of the system, bringing great difficulties to the grid dispatching operation. The flexible adjustable capacity of the system is one of the prerequisites for the system to accept wind power.

2. The impact of wind power access on reserve demand
In the actual operation of the power system, there will be a certain deviation between the actual load value and the predicted load value. Therefore, in order to ensure the safe operation of the system and reliable supply of electricity, the operation department should not only adjust the generation plan in real time according to the ultra-short-term load prediction results, but also arrange enough rotary reserve and strong load tracking ability to deal with sudden changes in load and unexpected power imbalance.

Intermittent power supply, such as wind power, is a special kind of power, which has certain intermittency and uncertainty. In order to maximize the use of intermittent power generation equipment and maintain the safe and reliable operation of the power system, the operation mode of the power system needs to be adjusted appropriately, which brings some additional reserve costs.

In terms of function, reserve capacity can be divided into load operation reserve and accident reserve. Among them, load operation reserve, namely rotary reserve, is used to set the reserve capacity due to load prediction deviation. The more accurate load prediction is, the smaller the load operation reserve capacity is. Emergency reserve is used to ensure that power users are not seriously affected by accidental accidents of power generation equipment and maintain the normal power supply of the system. It is
generally about 10% of the maximum power generation load, but not less than the capacity of the largest generator set of the system [3].

Under the current dispatching strategy, the generating power of intermittent power units is completely dependent on the wind speed and lighting conditions at that time, and in actual operation, it is regarded by dispatching departments as a negative load rather than a power controllable generating equipment. Therefore, according to the classification definition of reserve capacity, intermittent power generation will increase load reserve capacity without changing accident reserve capacity.

3. Demand assessment of peak regulation after large-scale wind power access

Under normal circumstances, wind power output tends to show the phenomenon of negative peak regulation. When wind power is connected to the power grid in a large scale, the peak-valley difference of load of the system increases significantly, thus increasing the peak regulation pressure of the system. Generally, wind power output is taken as a negative load, and wind power output is deducted from the original load curve to obtain the net load curve of the system. If the prediction of wind power output is accurate, the peak-valley difference of system net load can be used to represent the peak regulation demand of the system, and the peak-valley difference of system net load is the peak regulation demand capacity of the system.

At present, China's wind power forecasting system still needs to be improved, and the forecasting accuracy of wind power still needs to be further improved. Therefore, the forecasting accuracy of wind power output affects the determination of the peak demand capacity of the system. According to different wind power prediction accuracy, this section discusses the determination method of wind power grid-connected system's peak demand capacity $P_{det}$ in three cases, as shown in figure 1. Both basic peak shaving and paid peak shaving are included.

① If the wind power prediction is completely accurate, the peak regulation demand capacity of wind power grid connection system is the peak-valley difference of system net load, that is to say:

$$P_{det} = P_{det2}$$

In this formula: $P_{det2}$ is the peak-valley difference of the net load of the system.

![Figure 1Peak regulation demand after wind power access](image)

② In general, there are some forecasting errors in wind power prediction. According to the Interim measures for the management of wind power prediction and forecast released recently in China, the maximum error of daily prediction curve provided by wind turbine power [4] prediction system should not exceed 25%, and the error of real-time prediction should not exceed 15%. Therefore, the peak regulation demand capacity value of the system is determined according to the prediction accuracy of wind power.

$$P_{det} = P_{det2} + \beta \cdot P_{Np}$$

In this formula: $\beta$ is the prediction error coefficient of wind turbine power, and $P_{Np}$ is the grid-connected capacity of wind power.
If it is considered that the wind power prediction is completely inaccurate or the wind power prediction is not carried out, then when making the unit arrangement, not only the situation that the wind power output is zero in the peak period of daily load, but also the situation that the wind power output is full in the trough period of daily load should be considered. Therefore, the daily peak regulation demand of the system is the sum of the original load peak-valley difference and wind power grid integration capacity.

\[ P_{\text{det}} = P_{\text{det,1}} + P_{N} \]

In this formula: \( P_{\text{det,1}} \) is the peak-valley difference of the original load of the system.

4. Reserve demand assessment after large-scale wind power access

In view of the load prediction error caused by large-scale wind power access, this paper analyses the relationship between wind power prediction error and reserve capacity demand to evaluate the reserve capacity demand meeting the requirements of stable system operation \[5\]. The statistical data show that the probability of random change of load near the predicted value belongs to normal distribution, and the size of variance is related to the accuracy of load prediction \[6\]. According to the probability density function of load fluctuation near the predicted value shown in figure 2, the power shortage probability caused by load fluctuation can be calculated as

\[ P_{\text{LOLP}} = \frac{1}{\sqrt{2\pi} \sigma_{\text{load}}} \int_{-\infty}^{\infty} \exp\left(-\frac{P^{2}}{2\sigma_{\text{load}}^{2}}\right)dp \]

In this formula: \( \sigma_{\text{load}} \) is the standard deviation of load fluctuation around the predicted value, and \( P_{1} \) is the load reserve capacity of the system.

After wind power is connected into the grid, since the prediction accuracy of wind power itself is also normal distributed, \( \sigma_{\text{wind}} \) can be set as the prediction standard deviation of wind power generation, which is generally between 10% and 20%. That is to say:

\[ \sigma_{\text{new}} = \sqrt{\sigma_{\text{load}}^{2} + \sigma_{\text{wind}}^{2}} \]

For the new load prediction standard deviation, in order to maintain the given power shortage probability, the corresponding load reserve capacity can be obtained by using the normal distribution table:

\[ P_{2} = \sigma_{\text{new}} \Phi^{-1}(1 - P_{\text{LOLP}}) \]

In this formula: \( \Phi^{-1} \) is the inverse function of the standard normal distribution.

![Figure 2 Diagram of system reserve demands before and after wind power grid access](image-url)
5. Example

5.1. Peak regulation demand of auxiliary service market in a province

Based on the 24h output process data of wind power on typical days of each month and the power load forecast results from 2020 to 2030, the peak regulation demand of auxiliary service market after large-scale wind power access was assessed.

In 2025, based on the error of wind power prediction, the second peak regulation demand forecasting method mentioned above is adopted. According to the interim measures for the management of wind power prediction and forecast released recently in China, the maximum error of daily prediction curve provided by wind turbine power prediction system should not exceed 25%, and the error of real-time prediction should not exceed 15%. It is expected that the prediction accuracy of wind power will improve in 2025, and the recent prediction error coefficient of wind power is set at 15%. The province is expected to have a grid-connected wind power capacity of 7.8 million KW in 2025, so the monthly peak regulation demand is expected to be.

Table 1 Peak regulation demand of auxiliary service market in a province in 2025 (million kW)

| Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|------|-----|------|------|-----|-----|-----|-----|-----|-----|-----|-----|
| 22.47 | 20.54 | 24.04 | 23.34 | 23.73 | 24.00 | 24.91 | 26.38 | 24.54 | 21.38 | 22.51 | 25.38 |

5.2. Reserve capacity demand of auxiliary service market in a province

According to the reserve demand evaluation method [7], the reserve capacity demand of a province is estimated. According to the operation requirements of the power system, the allowable value of the loss probability $P_{LOLP}$ is 0.14%, and $\Phi^{-1}(1-P_{LOLP})$ is 2.98 obtained by consulting the table. According to the requirements of the interim measures for the management of wind power prediction and forecast, the deviation of wind power prediction is set at 15%, and the predicted wind power installation in a province in 2025 is 7.8 million KW, then the standard deviation of wind power prediction is 1170MW. Refer to Practical requirements and acceptance rules of application software for dispatching automation system of regional power network (trial) and Construction plan of electric power market in Jilin province (trial) before wind power was connected, and take the relative prediction error of provincial network load as 2.56%. The predicted load of this province in 2025 is 57000MW, and the standard deviation of load prediction is 1459.2MW. The load reserve capacity is 1870.3MW.

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