Characteristics Analysis of Wind Power Output - Based on Historical Data of a Province

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Abstract. Compared to conventional units, the inherent stochastic nature of wind power requires additional flexibility during power system operation. It is necessary to analyze the characteristics of wind power fluctuations. Based on the investigation of the actual operating data of province, this paper presents a comprehensive analysis of the wind power output characteristics from different dimensions, including daily output characteristics, seasonal output characteristics and probability distribution of wind power output. The research results could be available to predominate wind power operation characteristics for the planning and scheduling of the power grid. Analysis shows that the relevance between the output of wind power and the time is weak. And the fluctuation of hour-scale wind power is large, while summation of the outputs from different wind farms regional apart could effectively decrease the fluctuation of wind power. The peak-valley difference also will be increased after the wind farms are connected.

1. Introduction

Recently, environment pollution and energy shortages have become increasingly severe. Replacing traditional fossil fuels with “no-emissions, no-pollution, and renewable” energy sources is an inevitable demand for social and environmental progress [1, 2].

This paper takes a province of China as a case for the research object. The province has comparatively abundant wind resources, the average annual wind speed is 4.9-5.8\,m/s at the height of 70m. And the areas with rich wind resources are mainly concentrated in the eastern, southwestern and northern regions, which are roughly distributed in the northeast-southwest direction. The installed capacity of wind power was about 2.32 million kilowatts till July 2018. As mentioned in the “13\textsuperscript{th} Five-Year Plan”, it plans to reach 2.6 million kilowatts, which of the maximum output will reach above 15\% of the provincial load.

The wind power output has inherent characteristics of randomness and intermittency, for that reason, it will bring great impact on grid reliability, power quality, peak shaving and dispatching operations [3-5]. Based on the historical operation data, this paper statistically analyzes the output characteristics of the wind power. The research results could be available for further study on the development model of the large-scale wind farms and its coordinated development with the power grid.
2. Analysis of wind power output characteristics

2.1. Daily output characteristics

In order to master the daily variation of the wind power, this paper selects three typical days in different cities of the areas with larger wind installed capacity to do the statistics, the results are shown in Figure 1. It’s obviously that the output trends of wind farms in different areas vary greatly. The per-unit output in S area is always relatively small. The maximum output of the three days only reaches 46.3% of the installed capacity. On the contrary, it’s large in X area, which indicates wind resources are abundant there. The wind farm output has high randomness and big peak-to-valley difference from the curves, but they all have large output in the night. It can be seen from the Figure 3(c) that at the winter solstice day, the curves trends are about the same, and the output is small at 10:00–16:00, large at 20:00–24:00. Comparing the same wind farm can better reflect the change of output caused by the difference of meteorological conditions on different typical days. Figure 2 shows the output of the wind farm on different typical days in different areas.

Figure 1. Wind farm output curves of different days

![Wind farm output curves of different days](image)

Figure 2. Wind farm output curves of different areas

![Wind farm output curves of different areas](image)
It’s not difficult to judge that the wind farms are greatly affected by meteorological conditions, the output differ widely in different days even in the same area. However, all areas have less output on December 22nd, and larger on March 20th. In the same way, the per-unit output in S area is relatively small, and the output curve of two days is below 31% from Figure 2(a). And the curvilinear trend is about the same, and the output is small in the interval from 10:00 to 16:00 on each day from Figure 2(b).

2.2. Seasonal output characteristics
In order to maintain the seasonal variation characteristics of the wind power output, the average daily output curve is calculated according to the season, as shown in Figure 3. Meanwhile, the average monthly power of wind power is counted, showing in Figure 4.

![Quarterly average output curve in each region](image1)

![Monthly wind power output](image2)
It can be summarized from Figure 3. that the curvilinear trend of the three seasons in each region is about the same, showing obvious peak-valley change process, and the peak and valley values appear at about the same time, the output is smaller at 12:00~17:00, larger at 21:00-24:00 and 00:00-6:00. Also, wind power in all regions has a small output in summer. It can be concluded from Figure 3(a) that the daily average wind power output in the C area has a small peak around 14:00, while the spring and winter seasons have a much larger output; as shown in Figure 3(b), the output of wind power is relatively large in spring, while in winter and summer is relatively small; And the average daily output of each season in X is about the same as shown in Figure 3(c). It can be inferred from Figure 4 that the wind power output value in the S area is higher, while in the C area is relatively smaller; the wind farm output fluctuates greatly every month. Generally speaking, in March and April, the wind power outputs are larger in all regions.

2.3. Analysis of wind power output volatility over multiple time and space scales

Wind power fluctuation refers to the characteristics of point-by-point power in the time series of wind power. The rapid and large fluctuations in wind power output have greater impact on grid security. In order to quantitatively assess the volatility of wind power output, this paper uses $v$ (power change rate) for volatility analysis[6]:

$$v = \frac{p(t+T) - p(t)}{c}$$

(1)

Where, $p(t)$ is the wind power at time $t$; $T$ is the time difference between the two powers; $c$ is the installed capacity.

2.3.1. Analysis of wind power output volatility over multiple times. To analyze the fluctuation characteristics of wind power output, this paper use the annual data to calculate the power change rate $v$ point by point. On this basis, the probability and cumulative probability of $v$ are obtained. The time interval $T=15$min, 30min, 1h, 3h, so as to explore the $v$ at different time scales. The results are as followed in Figure 5.

![Figure 5. Power rate statistics at different time scales](image)

![Figure 6. Power rate statistics at different space scales](image)

The statistical results indicates that the distribution probability diagrams are basically symmetrical distributed, indicating that the probability of increase and decrease in power is substantially equal. The larger $T$ is, the larger the ratio of $v$ with high value is, and the stronger the volatility is. In a word, the $v$ and the volatility are closely related to $T$.

2.3.2. Analysis of wind power output volatility over multiple spaces. In order to analyze the fluctuation characteristics under different spatial scales, a wind farm, regional wind farms and the province's wind farms are selected, and the time interval is fixed to 15min. Calculating the distribution probability and cumulative probability of $v$, the results are shown in Figure 6. It can be deduced that the larger the spatial scale is, the larger the proportion of $v$ with low value is, and the smaller the fluctuation is. In summary, the $v$ and the volatility have an inverse relationship with the spatial scale. The reason is
inferred that the output curves of multiple wind turbines have a phenomenon in which the peaks and valleys cancel each other out, and the total output curve tends to be smooth.

2.4. Analysis of simultaneity factor of wind power output
Simultaneity factor of wind power output refers to the ratio of the maximum possible output of multiple wind farms to total rated capacity in the sampling time:

\[
S = \frac{p_1 + p_2 + \ldots + p_n}{c_1 + c_2 + \ldots + c_n}
\]

(2)

Where, \( S \) is the simultaneity factor. \( p_n \) is the maximum output in the sampling time of \( n \)th wind farm. \( c_n \) is the wind farm installed capacity. The simultaneity factor reflects whether the wind farms increase or decrease synchronously. The higher simultaneity factor will cause greater pressure on the transmission lines and dispatching wind power.

2.4.1. Monthly simultaneity factor distribution characteristics.
The statistics results of the monthly simultaneity factor is displayed in Figure 7, from what, we can see the simultaneity factor is relatively low from June to October, with a minimum of about 0.56; It’s relatively high in January-May and November-December, with a maximum of 0.819. The trend of the simultaneous rate is basically consistent with the trend of the wind resources, and the seasonality is obvious.

![Figure 7. Monthly simultaneity factor](image)

2.4.2 Wind power simultaneous rate probability distribution.
1) Full-time simultaneous rate probability statistics. The probability distribution and cumulative probability of annual wind power simultaneous rate are exhibited in Figure 8. The sampling time is 1h. In general, the probability of low simultaneous rate is large, while the probability of high simultaneous rate is small. The probability of the rate of 0.05–0.15 is the largest, accounting for 27%, which leads to a turning point in curve and presents a small peak. The rest of the curve is smooth and reveals a decreasing trend. The cumulative probability curve signifies the characteristic of convex quadratic curve. The cumulative probability of output less than 0.75 has reached 99.77%. By analyzing the level of simultaneous rate, we can infer whether wind resources are abundant.

![Figure 8. Full-time simultaneous rate probability statistics](image)

![Figure 9. Time-segmented simultaneous rate probability statistics](image)
2) Time-segmented simultaneous rate probability statistics. Probability statistics are performed on the simultaneous rates of the respective periods, as shown in Figure 9. It’s reasonable to deduce that the curvilinear trend of the simultaneous rate at 1-8 and 20-24 is approximately the same, and the trend of the simultaneous rate at 9-19 is about the same. It is obvious that the curves at the time of 1-8 and 20-24 are above the curves at 9-19 in the interval with large simultaneous rate and vice versa. That is, the wind power simultaneous rate is larger at 1-8 and 20-24 hours, but smaller at 9-19, indicating that wind power is mainly concentrated at night and early morning. The cumulative probability distribution curves of each time period are similar and are characterized by a convex quadratic curve.

3. Influence of wind access on load characteristics

3.1. Load characteristic of a province

The four typical days of spring equinox, summer solstice, autumnal equinox and winter solstice are selected to analyse the load characteristics. As shown in Figure 10, the province has good load characteristics, and the typical daily load curves are basically the same, showing the characteristics of “double peak”. During the periods of 6:00-12:00 and 17:00-21:00, the load demand is large, the minimum load of each typical day appears at about 4 am. And the load demand is relatively large in summer and winter, but relatively small in autumn.

![Figure 10. Typical daily load](image)

3.2. The impact on load characteristics

The typical daily data is used to analyze the impact of wind power access on the grid load characteristics. The results are shown in Table 1.

| Category          | Scene                | Autumnal equinox | Winter solstice | Spring equinox | Summer solstice |
|-------------------|----------------------|------------------|----------------|----------------|-----------------|
| Original load     | Maximum load         | 2179.8           | 2556.4         | 2447.8         | 2512.9          |
|                   | Minimum load         | 1773.5           | 1996           | 1803.2         | 1994.5          |
|                   | Peak-valley difference ratio | 18.64%           | 21.92%         | 18.03%         | 19.95%          |
| Payload with wind access | Maximum load         | 2129             | 2525.7         | 2338.3         | 2430.7          |
|                   | Minimum load         | 1747.4           | 1931.4         | 1732.1         | 1971.7          |
|                   | Peak-valley difference ratio | 17.92%           | 23.53%         | 25.92%         | 18.88%          |

According to the analysis above, wind power has a large output at night and early morning, showing obvious anti-peak characteristics. By analyzing the data, it can be seen that due to the small
access capacity of wind power, it has little effect on the overall trend of the load. While, for the spring equinox days with higher wind power output, the access of wind power increases the peak-and-valley rate of load.

4. Conclusion
This paper makes a comprehensive analysis of the output characteristics of wind power in a certain province by using the historical measured data. The following conclusions are obtained: 1) In different load days, there are great differences in the output of wind farms in different regions. And the output is relatively large at night and early morning. 2) According to the seasonal average output curve, the wind farm has the characteristic of "one peak and one valley", with a small output during the day from 12 to 17, and a large output at 21-24 and 0-6. And the wind power output is larger in spring. 3) The probability of upward and downward fluctuations of wind power output is equivalent, and the volatility increases with the increase of time scale and decreases with the increase of spatial scale. 4) The simultaneous rate of wind power was distributed from 0 to 0.85, and is concentrated in 0~0.35, accounting for 78.32%. 5) The load characteristic presents the characteristic of "double peak", in the period of 6-12 and 17-21, the demand for load is large. The peak-valley difference will be increased after the wind farms are connected, and the power supply pressure of the province is increased, which is not conducive to its safe operation.

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