Short-term planning and design of wind power base based on MATLAB power flow calculation method

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Abstract. At present, wind power generation technology is an environmentally friendly, mature technology, low cost and scale-efficient green technology. It is also the fastest growing new energy power generation technology form. The main research of this paper is to consider the spatial and temporal characteristics of wind resources, select a wind farm development combination, build a wind farm, and connect wind power to the grid through large-scale centralized development and long-distance high voltage. The experimental model used in this paper is an IEEE-57 node system. In MATLAB, the power flow calculation method is used to study and analyze the access point combination of the grid connection and the line expansion scheme after the grid connection.

1. Introduction

The development of large-scale wind power bases is an important form of wind power development in China at present. Electric power is incorporated into the large power grid through high-voltage and long-distance transmission. The short-term planning and design of the wind power base needs to consider the combined development form of the wind farm, and the stability and tidal current distribution after the wind farm is connected to the system. At the same time, it also needs to consider and complete the system expansion plan.

At present, there are many models and methods in power system planning and design. Literature [5] studies the random characteristics of wind energy resources and the distribution of wind energy in wind power bases, and uses Monte Carlo sampling to discuss the reliability and capacity expansion of wind power bases. Literature [6] studied the output characteristics of new energy power generation systems, comprehensively considering the capacity of wind power and other new energy power generation systems to access the power grid, access points and power grid planning issues. Literature [7] studied the installed capacity of neutron wind farms in large-scale wind power bases, and proposed a method of wind farm grid connection nodes and capacity ratio based on the power flow calculation method.

In view of these methods, this paper proposes a power system planning method including wind farms based on the analysis of the results of the power flow calculation method. In the model verification, the loss of the system branch caused by the change in the output of the grid-connected combined wind farm is analyzed. The system expansion plan is proposed.
2. Another section of your paper
Between several adjacent wind farms, they will be affected by the same airflow, which leads to a correlation between their output. The spatial correlation in the wind power base is that the wind farms at different positions have a certain correlation in the output. The research on the spatial correlation can provide a certain basis for the development sequence of new wind farms in the wind power base and determine a reasonable wind farm Development portfolio. The time correlation is the change characteristic of the wind farm output sequence, that is, the correlation of wind power itself. According to the situation of wind resource assessment, the selection of regions with complementary wind resources will be prioritized for combined development in short-term planning, which can reduce the volatility of combined wind farms. Figure 1 shows the assessment results of wind energy resources in a certain area.

![Figure 1. Distribution of wind energy resources in a place.](image)

Although the output of a single wind turbine is fluctuating, when it is on a longer time scale, the wind will cause the output of each wind farm in the wind power base to show a consistent change characteristic, showing a strong correlation Sex. When a large-scale wind power base has a large positive correlation between its small wind farms, the wind power base ‘s output will show great uncertainty and volatility, which is not conducive to the adjustment of the power grid. Peak and dispatching affect the normal and stable operation of the power grid system.

3. Power system planning with wind farm
Power system planning is divided into three types: short-term, medium-term and long-term planning according to time. The short-term planning time is within 5 years, the mid-term is about 10 years, and the long-term planning is more than 15 years. Long-term planning is mainly based on national strategic development and policies for planning of major domestic networks. In the medium term, the economic development at that time is mainly considered, and the capacity of the power supply is reasonably configured. The short-term plan mainly solves the recent expansion of the power grid, balances the increase in local load, and maintains the stable operation of the power grid. This article mainly discusses the problem of short-term planning and design of large-scale wind power bases. The wind farm access and expansion plans are obtained through the use of power flow planning methods.

Before the wind farm is connected to the grid, it is necessary to obtain the network topology and specific parameters of the established power grid in the area, complete the compilation of the power flow calculation sub-function, and perform the power flow calculation to verify the accuracy of the parameter input. According to the structure of the power grid, find suitable multiple grid connection points, combine these grid connection points to form different access schemes, select different grid connection schemes, and determine the grid connection point according to the voltage amplitude level of each bus in the power flow calculation result Whether the choice is reasonable. After getting the grid connection plan, you need to consider the expansion plan of the line after the grid connection. After the large-capacity wind farm is connected to the system, it will cause overload of the line, which will greatly increase the loss of the line, change the output between the wind farms, and record the line. The number
of the line with excessive loss is obtained after multiple simulation calculations and the expansion plan of the line after the wind farm is connected to the grid. The entire planning process is shown in Figure 2.

**Figure 2.** Planning process considering the power flow calculation method.

4. Selection of grid connection points

In practice, locations with abundant stroke resources and suitable for establishing large-scale wind power bases are generally located in relatively remote areas, such as Gansu Ningxia Wind Power Base and Inner Mongolia West Wind Power Base. When performing wind farm simulation and power flow calculation, it is necessary to consider the appropriate grid connection point of the wind farm. The grid connection points of the wind farm are generally far away from the conventional energy generation system and relatively far from the load center. In the IEEE-57 node system, 20, 34, 35, 41, 49 are selected as the grid-connectable contacts of the wind farm, and the power flow calculation is performed to obtain the voltage deviation after the system is grid-connected, that is, the system voltage stability. Figure 3 is the result topology diagram of IEEE-57 node system.

**Figure 3.** IEEE-57 node topology

Grid connection solution 1: The time series of wind energy resources in three regions A, B and C exhibit complementary characteristics. Establish wind farms in A and B. The wind farm capacity of A
is 150MW and the wind farm capacity of B is 100MW. First, they are connected to nodes 35 and 41, respectively. The wind turbines are all variable-speed constant-frequency generators and operate with a power factor of 1. After connecting two wind farms, the system capacity is 2175.9MW, and the wind power capacity accounts for 11% of the total installed capacity of the system. The power flow analysis of the system connected to the wind farm yields Tables 1 and 2.

Table 1. Power flow calculation results after 35 and 41 nodes are connected to the grid.

| How many?   | How much?       | P (MW)   | Q(MVar) |
|-------------|-----------------|----------|---------|
| Buses 57    | Total Gen Capacity | 2175.9  | -748.0 to 1099.0 |
| Generators 9 | On-line Capacity | 2175.9  | -748.0 to 1099.0 |
| Committed Gens 9 | Generation (actual) | 1466.6 | 401.0 |
| Loads 42    | Load            | 1410.8  | 336.4   |
| Branches 80 | Losses (I^2 * Z) | 55.83   | 200.60  |

Table 2. Bus voltage amplitude

| Minimum | Maximum |
|---------|---------|
| Voltage Magnitude | 0.936 p.u. @ bus 31 | 1.040 p.u. @ bus 46 |
| Voltage Angle | -19.38 deg @ bus 31 | 0.00 deg @ bus 1 |

When the grid connection point is selected to be 35 and 41 nodes, the calculation of Newton's method converges, the total power generation capacity of the system is 2175.9MW, the actual power generation capacity is 466.6MW, and there are 9 generator sets (two are wind farms). The voltage of the wind farm connected to the grid node in the network during normal operation after being connected to the wind farm is between 0.9 and 1.1pu, and the voltage amplitude of the remaining nodes in the system is between 0.95 and 1.05pu. Technical Regulations for Connecting to the Power Grid.

Grid connection plan two: Change the access point of the wind farm and perform power flow calculation again to verify the voltage stability of the system. When the two wind farms A and B are connected to nodes 20 and 49, the calculation results in Table 3 and Table 4 are obtained.

Table 3. Power flow calculation results after 20 and 49 nodes are connected to the grid.

| How many?   | How much?       | P (MW)   | Q(MVar) |
|-------------|-----------------|----------|---------|
| Buses 57    | Total Gen Capacity | 2175.9  | -748.0 to 1099.0 |
| Generators 9 | On-line Capacity | 2175.9  | -748.0 to 1099.0 |
| Committed Gens 9 | Generation (actual) | 1466.6 | 401.0 |
| Loads 42    | Load            | 1410.8  | 336.4   |
| Branches 80 | Losses (I^2 * Z) | 164.06  | 200.60  |

Table 4. Bus voltage amplitude

| Minimum | Maximum |
|---------|---------|
| Voltage Magnitude | 0.743 p.u. @ bus 57 | 1.040 p.u. @ bus 1 |
| Voltage Angle | -30.86 deg @ bus 57 | 8.82 deg @ bus 35 |

According to the power flow calculation results in Table 3 and Table 4, after the nodes 20 and 49 are integrated into the wind farm, the voltage amplitude of 57 nodes in the system becomes the level of 0.743pu, which is not in line with the State Grid Corporation's wind farm connection Technical regulations for access to the power grid. And when the two nodes are connected to the grid, the active loss of the system is 164.06MW, which is nearly 3 times the active loss of the system after the 35 and 41 nodes are connected to the grid.
Grid connection plan three: When the grid connection points of the two wind farms A and B are selected at the nodes 34 and 49, Table 5 and Table 6 can be obtained by calculating the power flow.

Table 5. Power flow calculation results after 34 and 49 nodes are connected to the grid.

| How many?         | How much?          | P (MW)       | Q (MVar)   |
|-------------------|--------------------|--------------|------------|
| Buses 57          | Total Gen Capacity | 2175.9       | -748.0 to 1099.0 |
| Generators 9      | On-line Capacity   | 2175.9       | -748.0 to 1099.0 |
| Committed Gens 9  | Generation (actual)| 1467.9       | 405.5      |
| Loads 42          | Load               | 1410.8       | 336.4      |
| Branches 80       | Losses (I^2 * Z)   | 82.32        | 205.15     |

Table 6. Bus voltage amplitude

|                        | Minimum          | Maximum        |
|------------------------|------------------|----------------|
| Voltage Magnitude      | 0.953 p.u. @ bus 27 | 1.043 p.u. @ bus 46 |
| Voltage Angle          | -30.13 deg @ bus 57 | 9.27 deg @ bus 35 |

According to the power flow calculation results of Fig. 9 and Fig. 10, it can be concluded that after these two nodes are connected to the two wind farms A and B, the bus voltage amplitude of the system node is in line with the technology of the wind farm connected to the power grid of the State Grid Corporation of China Regulations. However, the loss of the system is 82.32MW, which is about 1.5 times that of the system after the nodes 35 and 41 are integrated into the wind farm.

Comprehensive consideration of the first two access schemes, the first scheme (35 and 41 nodes merged into the wind farm) and the third access scheme (34 and 49 nodes merged into the wind farm) voltage amplitude complies with national regulations, but the first The loss of a scheme system is minimal. The second access scheme (20 and 49 nodes merged into the wind farm) does not comply with the national wind farm grid connection specifications, so A and B wind farms prefer to connect to the power network at nodes 35 and 49.

5. Line expansion plan

Considering the correlation of the space-time characteristics of the wind farm, this paper adds the correlation of the output of the wind farm when studying the access system of the wind farm. Before development, large-scale wind power bases first evaluate the wind resources in the area, and then, in short-term planning, preferentially select areas where the wind energy space-time characteristics are negatively correlated to establish wind farms, so that their wind farm output also exhibits certain complementary characteristics To reduce the volatility of the wind power base's overall output. After two wind farms are connected to the IEEE-57 node system, the original power flow distribution of the system will change, which will cause the loss of some lines to increase, and will also cause the voltage amplitude of some busbars to fluctuate. According to the scheme of the wind farm access system in the previous section, 35 and 41 nodes were selected to access the IEEE-57 node system.

Due to the changes in wind speed in the wind power base and other factors affecting the output of wind power, it is difficult to reach the full output of the wind farm. It is reasonable to adjust the output of the two wind farms to make them appear to be complementary. The complementary characteristics of wind energy in the situation. After changing the output of the two wind farms connected to the system, the line losses in the power flow calculation results are counted.
5.1. Power generation plan 1
When the output of wind farm A and wind farm B is full, according to the power loss calculation results, record the line loss number in the top five, see Table 7.

Table 7. Power generation plan 1 line loss record table  
\begin{tabular}{ccc}  
Branch & f-bus & T-bus & Loss & P \\
8 & 8 & 9 & 8.77MW & \\
16 & 1 & 16 & 6.37MW & \\
77 & 57 & 56 & 4.813MW & \\
45 & 32 & 33 & 3.67MW & \\
17 & 1 & 17 & 2.56MW & \\
\end{tabular}

5.2. Power generation plan 2
After considering the spatiotemporal characteristics, when the output of wind farm A is 60% and the output of wind farm B is 90%, according to the loss of each line in the power flow calculation, record the number of the top five losses, see Table 8.

Table 8. Power generation plan 2 line loss record table  
\begin{tabular}{ccc}  
Branch & f-bus & T-bus & Loss & P \\
20 & 4 & 18 & 7.23MW & \\
8 & 8 & 9 & 5.12MW & \\
50 & 37 & 38 & 4.97MW & \\
77 & 57 & 57 & 4.28MW & \\
62 & 48 & 49 & 3.68MW & \\
\end{tabular}

5.3. Power generation plan 3
After considering the spatiotemporal characteristics, when the output of wind farm A is 30% and the output of wind farm B is 80%, according to the loss of each line in the power flow calculation, record the top five marks of loss, see Table 9.

Table 9. Power generation plan 3 line loss record table  
\begin{tabular}{ccc}  
Branch & f-bus & T-bus & Loss & P \\
8 & 8 & 9 & 6.61MW & \\
20 & 4 & 18 & 5.24MW & \\
77 & 57 & 56 & 3.22MW & \\
50 & 37 & 38 & 3.18MW & \\
58 & 15 & 45 & 2.07MW & \\
\end{tabular}

5.4. Power generation plan 4
After considering the spatio-temporal characteristics, when the output of wind farm A is 90% and the output of wind farm B is 50%, according to the loss of each line in the power flow calculation, record the number of the top five losses, see Table 10.

Table 10. Power generation plan 4 line loss record table  
\begin{tabular}{ccc}  
Branch & f-bus & T-bus & Loss & P \\
50 & 37 & 38 & 5.82MW & \\
39 & 27 & 28 & 5.42MW & \\
8 & 8 & 9 & 3.26MW & \\
20 & 4 & 18 & 2.52MW & \\
77 & 57 & 56 & 2.07MW & \\
\end{tabular}
5.5. Power generation plan 5

After considering the spatio-temporal characteristics, when the output of wind farm A is 70% and the output of wind farm B is 30%, according to the loss of each line in the power flow calculation, record the number of the top five losses, see Table 11.

| Branch | F-bus | T-bus | Loss  | P    |
|--------|-------|-------|-------|------|
| 24     | 11    | 13    | 6.84MW|
| 8      | 8     | 9     | 5.36MW|
| 77     | 57    | 56    | 4.31MW|
| 50     | 37    | 38    | 4.27MW|
| 17     | 1     | 17    | 1.78MW|

The calculation method of line loss is the default calculation formula included in MATPOWER, see Equation 1.

\[ P_{\text{LOSS}} = I^2 \times Z \]  

According to the line loss statistic table obtained from different output sizes of wind farms, the number of occurrences of line loss in the top five for each power flow calculation can be obtained. Among them, the number of branches 8 and 77 is 5 times, the number of branches 20 and 50 is 3 times, the number of branches 17 is 2 times, and the remaining lines are all 1 Times. With reference to the statistical results, it can be concluded that after nodes 35 and 41 are connected to the wind farm, the first line to be rebuilt is the No. 8 and No. 77 branches, and the second line to be rebuilt is the No. 20 and No. 50 branches.

6. Conclusion

In this paper, simulation calculations of calculation examples are carried out on the basis of the IEEE-57 node system, and the method of power flow calculation is adopted when studying the short-term planning of wind power bases. Write different data sub-functions in MATLAB, calculate the voltage stability and system loss of different access schemes, and finally determine the system access scheme. The wind energy resources in large-scale wind power bases have the characteristics of space-time correlation, which also inevitably leads to the complementarity between the output of internal wind farms. Changing the output power of the connected wind farm makes it appear to be relatively complementary. After changing the output power, the loss of the line in the system also changes. The loss of the line is counted, and the expansion plan of the line is finally determined.

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