

# Analysis of Short-circuit Current Calculation Method in Wind Power Plant Design

Mingyang Liu<sup>1</sup>, Wenxia Pan<sup>1,2</sup>, Gang Yang<sup>1</sup>, Hanjiang Liu<sup>1</sup>, Di Wu<sup>3</sup>

1. College of Energy and Electrical Engineering, Hohai University, Nanjing210098,China hhlumy@126.com

2. Research Center for Renewable Energy Generation Engineering Ministry of Education, Hohai University, Nanjing210098, China

3. State Grid Nanyang Power Supply Company, Nanyang473000, China

**Abstract**—Due to the differences between wind power plant and normal power plant in mathematical model and network structure, it will lead to great discrepancy between the results worked respectively by the practical method of normal short-circuit current calculation and the international popular IEC60909 method in engineering design. Therefore this paper analyzes the differences between the two methods and put forward an improved practical method. Finally with the simplified modeling of collection lines, the effectiveness and feasibility of this method is verified by the actual wind power plant data and simulation results with ETAP. This method offers some ideas to the establishment of uniform standards of short-circuit current calculation method of wind power plant in our country.

**Index Terms**—Short-circuit calculation, practical calculation method, IEC60909, wind power plant.

## 1. INTRODUCTION

At present, the clean energy has been paid great attention by the countries all over the world. And with the continuous innovation of technology, the development of wind power has attracted worldwide attention [1][2]. However there are many differences between wind power plant and normal power plant in the unit arrangement, system composition, system configuration and equipment selection [3], therefore the practice of normal power plant cannot be completely copied, in the design of the wind power plant, to avoid large design errors.

In electric power engineering design, short-circuit current calculation is the foundation for electrical equipment selection, conductor selection, relay protection setting and checking, and the results will directly affect the electrical system safety, reliability and cost of the project. [4-6] analyzed the effects of different wind turbine models on short-circuit current, and derived the corresponding expressions which was cumbersome in the actual engineering application. However there are not a unified standard to analysis or calculate the short-circuit current of wind power plant at home and abroad. In foreign countries, the short-circuit current calculation method based on IEC60909 standard (IEC60909 method) is usually used [7-9], while the short-circuit current calculation method in national standard (practical method) is adopted in our country [10]. Due to the different models and methods of calculation, the results of short-circuit calculation of wind power plant are quite different. Therefore the similarities and differences of the two methods were analyzed, then an improved engineering practical

calculation method was proposed in this paper, and the efficiency of this method was verified by using actual wind power data and ETAP.

## II. SHORT-CIRCUIT CURRENT CALCULATION METHOD IN WIND POWER PLANT DESIGN

The structure of collector system and generator is the main difference between wind power plant and normal power plant. At present, the mainstream models of wind power plant are doubly fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG), which are different from the traditional turbine, such as steam turbine and hydro-turbine, in the unit structure and calculation model. And the generator wiring is generally in a chain structure inside the wind power plant, while it is unit wiring type inside the traditional power plant. Therefore, this paper analyzed the calculation method of short-circuit current of wind power plant, and proposed a improved practical calculation method which is more suitable for engineering practice. This section focused on the model analysis of the power supply and the wind power generator.

### A. The Practical method

When calculating the short-circuit current of the power system by the practical method, the impedance of all the equipment (the reactance instead of the impedance is used in the calculation to simplify the calculation) in the network is calculated as the corresponding per-unit value according to the unified power reference value, regardless of the load in the network. Then draw the equivalent system network, simplify the network, obtain the transfer reactance, achieve the short-circuit current of each power supply to the fault point, and the total value of short-circuit current could be obtained by the summation.

In the practical method, the short-circuit current is supplied by the two kinds of power supply, the infinite system power supply and the limited power supply.

For the system with infinite capacity of power supply, the power supply voltage is kept constant during the short circuit, and the per-unit value of the voltage is 1.0. The short-circuit current and short-circuit impulse current are given as follows:

$$I_k' = \frac{1}{x_s} \cdot \frac{S_d}{\sqrt{3}U_d} \quad (1)$$

$$i_{sh} = k_{sh} \sqrt{2} I_k' \quad (2)$$

$$\kappa = 1 + e^{-0.01/T_s} \quad (3)$$

where  $I_k^*$  is the initial symmetrical short-circuit current;  $x^*$  is the short-circuit reactance (the subscript \* indicates that the variable is the per-unit value);  $S_d$  is the reference capacity;  $U_d$  is the reference voltage at fault point;  $i_{sh}$  is the short-circuit impulse current;  $k_{sh}$  is the impact factor;  $T_a = X_\Sigma / \omega R_\Sigma$  is the time constant;  $X_\Sigma$  and  $R_\Sigma$  are short-circuit reactance and resistance respectively.

For the convenience of calculation in engineering,  $k_{sh}$  takes different values directly according to different short-circuit points, instead of using (3). When the short circuit point is the exit of the generator,  $k_{sh} = 1.9$ ; When the short circuit point is the high voltage side of transformer in the power plant,  $k_{sh} = 1.85$ ; When the short circuit point is other location of the high voltage power grid,  $k_{sh} = 1.8$ .

For the system with limited capacity of power supply, generally using the calculation curve method. Since there are a lot of resources describing the method, they won't be covered in this paper. In particular, limited capacity of power supply can be treated as the infinite capacity of power supply when  $x^* > 3.45$ .

In the practical method, the equivalent reactance of the feeder system is estimated based on (4), which is also present in [10].

$$x_{s^*} = S_d / S_k \quad (4)$$

where  $S_k$  is short circuit capacity of the dividing bus of the feeder system.

The wind power generator is processed by the high voltage motor, and the short-circuit current and the short-circuit impact current can be estimated based on (5) and (6).

$$I_{kM}^* = \frac{1}{x_{M^*}} \cdot I_{MN} \quad (5)$$

$$i_{shM} = k_{shM} \sqrt{2} I_{kM}^* \quad (6)$$

Where  $x_{M^*}$  is per-unit value of the motor subtransient reactance, which is equal to the reciprocal of the starting current ratio;  $I_{MN}$  is the motor rated current; generally the impact factor is equal to 1.4-1.6, which is estimated as 1.5 in this paper.

The model and formula of other electric equipments, such as transformers, cables and overhead lines, etc, could be found in national standard. And this paper won't repeat them because of the limited space.

#### B. The IEC60909 Method

In the International Electrical Commission (IEC) the latest promulgated standards (IEC60909), an equivalent voltage source at the short-circuit location is used for calculation. The equivalent voltage source ( $cU_N / \sqrt{3}$ ) is the only active voltage of the system. All network feeders, synchronous and asynchronous machines are replaced by their internal impedances. The impedances of all the equipment in the network are calculated as their actual values instead of the corresponding per-unit value. Then draw and simplify the network to obtain the short-circuit impedances, and the short-circuit current and short-circuit impulse current are given as shown in (7)-(10).

$$I_k^* = \frac{cU_N}{\sqrt{3}Z_k} \quad (7)$$

$$Z_k = \sqrt{R_k^2 + X_k^2} \quad (8)$$

$$i_{sh} = \kappa \sqrt{2} I_k^* \quad (9)$$

$$\kappa = 1.02 + 0.98e^{-3R_k/X_k} \quad (10)$$

where  $U_N$  is the rated voltage of the fault point;  $c$  is the voltage factor corresponding to  $U_N$ ;  $Z_k$  is the short-circuit impedance;  $\kappa$  is the impact factor, which can be estimated based on (10);  $X_k$  and  $R_k$  are short-circuit reactance and resistance respectively.

In the IEC60909 method, at the moment of calculating the maximum short circuit current,  $c$  is equal to 1.05 or 1.1 in low voltage systems (100V~1000V), and 1.1 in medium and high voltage systems ( $\geq 1kV$ ).

The correction factor and different calculation formulas are used to calculate the impedances of the electrical equipments. Only the feeder system and wind power generator are described in this paper, other equipments could be found in the literature [7].

The equivalent impedance of the feeder system is estimated based on (11).

$$Z_Q = \frac{cU_{nQ}}{\sqrt{3}I_{kQ}^*} \quad (11)$$

where  $Z_Q$  is the modified equivalent impedance of the feeder system;  $U_{nQ}$  is the rated voltage of the point  $Q$ ;  $I_{kQ}^*$  is the short circuit current of the point  $Q$ . Generally if  $R_Q/X_Q$  is unknown,  $Z_Q = 0 + jX_Q$  when  $U_{nQ} > 35kV$ , while  $R_Q = 0.1X_Q$  and  $X_Q = 0.995R_Q$  are used to estimate the resistance and reactance when  $U_{nQ} < 35kV$ .

The wind power generator is processed by the high voltage motor, and its short circuit impedance can be estimated based on (12).

$$Z_M = \frac{1}{I_{LR}/I_{rM}} \cdot \frac{U_{rM}}{\sqrt{3}I_{rM}} \quad (12)$$

where  $Z_M$  is the impedance of the motor;  $U_{rM}$  is the rated voltage of the motor;  $I_{rM}$  is the rated current of the motor;  $I_{LR}/I_{rM}$  is the ratio of the locked-rotor current to the rated current of the motor.

If  $R_M/X_M$  is unknown, the resistance and reactance of the motor could be estimated based on (13).

$$\begin{cases} R_M = 0.1X_M, U > 1kV, P_{rM} \geq 1MW \\ R_M = 0.15X_M, U > 1kV, P_{rM} < 1MW \\ R_M = 0.42X_M, U < 1kV \end{cases} \quad (13)$$

where  $R_M$  and  $X_M$  are the motor resistance and reactance respectively;  $P_{rM}$  is the motor rated power per pair of poles.

The model and formula of other electric equipments, such as transformers, cables and overhead lines, etc, could be found in IEC60909 standard. And this paper won't repeat them because of the limited space.

#### C. The improved calculation method

The influence of resistance on the result and the calculation of short circuit impact factor are neglected in the practical method, the accuracy of the calculation results will be greatly influenced although the calculation process is simplified. So the practical method with faster computing speed is more suitable for the rough and rapid calculation.

Compared to the practical method, the voltage correction factor  $c$ , the resistance, the correction coefficient and the modified calculation formula are considered in the IEC60909 method. Obviously the calculation results will be more comprehensive and accurate with the more complicated calculation process. Therefore calculation speed of the IEC60909 method is more slow, however the detailed and accurate calculation is more suitable for it.

For engineering calculation, the calculation accuracy of the

practical method is not high, calculation process of the IEC60909 method is complicated, so an improved short-circuit current calculation method (improved method) is proposed in this paper, based on the index of the calculation accuracy and the goal of the fast and convenient calculation.

The equivalent voltage source method used in IEC60909 method is similarly used in the improved method. The source is the only active voltage of the system. The electric potential of other power supplies are regarded as zero and replaced by their own internal impedance. After modified the impedance of all the equipment in the network, they will be calculated as the corresponding per-unit value according to the unified power reference value. Then draw and simplify the network to obtain the short-circuit impedances, and the short-circuit current and short-circuit impulse current are given as shown in (14)-(15).

$$I_{impk}^* = \frac{1}{Z_{k*}} \cdot \frac{cS_d}{\sqrt{3}U_d} \quad (14)$$

$$i_{impsh} = k_{impsh} \sqrt{2} I_{impk}^* \quad (15)$$

where  $I_{impk}^*$  is the initial symmetrical short-circuit current (the subscript *imp* means the improved method);  $c$  is the voltage factor, its value is the same as the IEC60909 method;  $Z_{k*}$  is the short-circuit impedance;  $S_d$  is the reference capacity;  $U_d$  is the reference voltage at fault point;  $i_{impsh}$  is the short-circuit impulse current;  $k_{impsh}$  is the impact factor.

It is important to note that the ratio of the short-circuit resistance and reactance is equal to 9999 similarly. In this way, there is no complex number in the calculation so that the calculation process is simplified; on the other hand, the reactance and the impedance are approximately equal in value according to the relationship shown in  $|z_c| = \sqrt{R_c^2 + X_c^2} = |X_c|$ , therefore the calculation accuracy of the results is trustworthy.

With the analysis of the two methods on the short-circuit impact current calculation formulas, it was not difficult to find that the main influencing factor to calculate the short-circuit current between the practical method and the IEC60909 method was the impact factor. Therefore this paper tried to deduce the value of the impact factor in the improved method, which is as shown in Table I, to improve calculation speed. The way is similar to the practical method.

TABLE I. Impact Factors of The Improved Method

| Short circuit point | The exit point of the generator | The high voltage side of package transformer | Other point |
|---------------------|---------------------------------|--|-------------|
| $k_{impsh}$         | 1.53                            | 1.86   | 1.81        |

In the improved method, the equivalent impedance of the feeder system is estimated based on (16).

$$Z_{imps*} = c \cdot S_d / S_k \quad (16)$$

where  $Z_{imps*}$  is the impedance of the feeder system;  $S_k$  is short circuit capacity of the dividing bus of the feeder system.

The wind power generator is processed by the high voltage motor, and its short circuit impedance is given as shown in (17).

$$Z_{impM*} = \frac{1}{I_{LR} / I_{rM}} \cdot \frac{S_d}{S_{rM}} \quad (17)$$

where  $Z_{impM*}$  is the impedance of the wind power generator;  $S_{rM}$  is the rated capacity of the generator;  $I_{rM}$  is the rated current of the generator;  $I_{LR}/I_{rM}$  is the ratio of the locked-rotor current to the rated current of the generator.

The model and formula of other electric equipments could be estimated as the corresponding modified per-unit value according to the unified power reference value, the same as above method in principle.

### III. SIMULATION AND RESULTS

The data of an actual wind power plant was taken to carry out the verification of the improved method with ETAP. The wind power plant contains 38 DFigs with stand-alone capacity of 4MW, and the output voltage of the wind generator is 0.69kV. With the connection form, "one generator and one transformer", each wind power generator is configured with a 4500kVA package transformer. The 38 DFigs are divided into 6 groups, and connected to the 35kV bus of the offshore substation of the wind power plant with 6 collection lines, then connected to the 110kV bus of the onshore substation of the wind power plant with 2 marine cables, and connected to external power grid at last. In order to simplify the calculation, only one set of generating units was retained and the other groups are simplified by the equivalent method proposed by [11]. The wiring diagram of the simplified system is as shown in Figure 1.



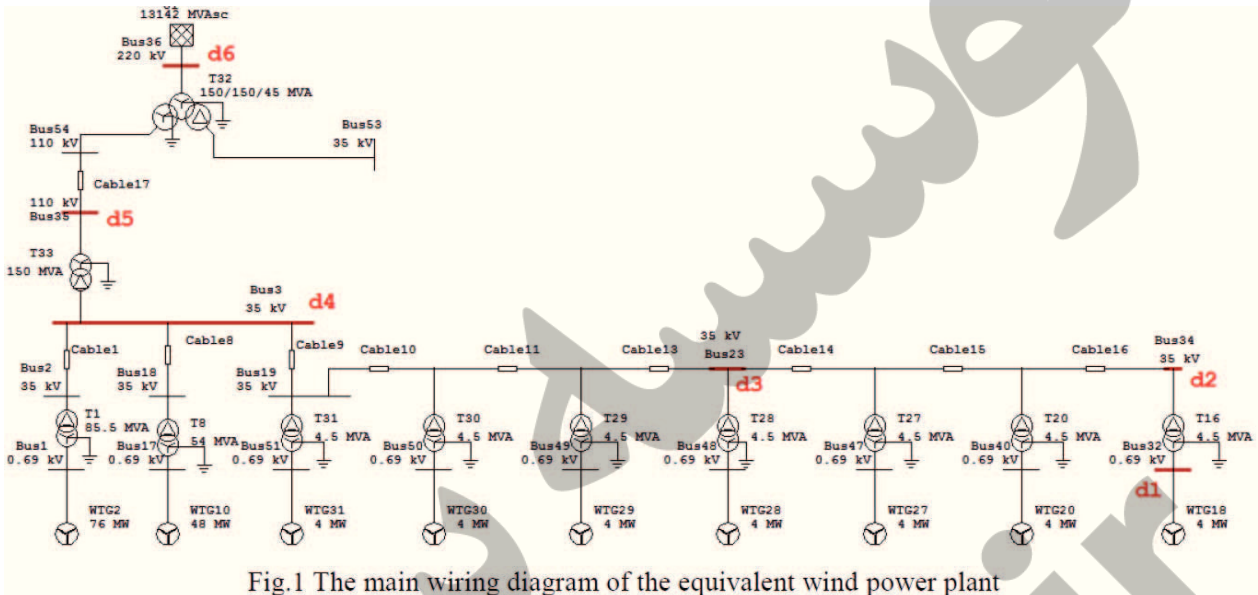


Fig.1 The main wiring diagram of the equivalent wind power plant

In Fig.1, the red lines are the short circuit points, which are shown as follows:

- Point d1 is Bus32, the exit point of the wind power generator, 0.69kV;
  - Point d2 is Bus34, the terminal point of the single collection line, 35kV;
  - Point d3 is Bus23, the middle point of the single collection line, 35kV;
  - Point d4 is Bus3, the low pressure side of the offshore substation, 35kV;
  - Point d5 is Bus35, the high pressure side of the offshore substation, 110kV;
  - Point d6 is Bus36, the high pressure side of the onshore substation (the point connected to external power grid), 220kV;
- Symmetrical short-circuit current of above points were calculated using the practical method (PM), the improved method (IM) and the method in ETAP (the IEC60909 method) respectively,

|             |      |       |        |
|-------------|------|-------|--------|
| d4<br>35kV  | PM   | 20.49 | 52.16  |
|             | IM   | 22.58 | 57.79  |
|             | ETAP | 22.87 | 56.84  |
| d5<br>110kV | PM   | 6.92  | 17.605 |
|             | IM   | 7.67  | 19.525 |
|             | ETAP | 7.76  | 19.53  |
| d6<br>220kV | PM   | 35.30 | 89.86  |
|             | IM   | 35.38 | 90.06  |
|             | ETAP | 35.39 | 94.42  |

TABLE II. Results of Short-circuit Current Calculation

| Short circuit point | Calculation method | short-circuit current (kA) | short-circuit impulse current (kA) |
|---------------------|--------------------|----------------------------|------------------------------------|
| d1<br>0.69kV        | PM                 | 72.41                      | 173.83                             |
|                     | IM                 | 76.01                      | 184.10                             |
|                     | ETAP               | 77.62                      | 179.98                             |
| d2<br>35kV          | PM                 | 6.57                       | 16.926                             |
|                     | IM                 | 6.80                       | 17.448                             |
|                     | ETAP               | 7.249                      | 12.10                              |
| d3<br>35kV          | PM                 | 9.07                       | 23.49                              |
|                     | IM                 | 9.48                       | 24.285                             |
|                     | ETAP               | 10.02                      | 17.94                              |

After analyzing the results of calculation in Table II, the two points are given as follows:

a) The practical method simplifies the calculation process, and it is simple and convenient, however the value of calculation is smaller, so the practical method is more suitable for rough and rapid calculation. The IEC60909 method has detailed calculation, however, its process is cumbersome and complex and the calculation values are bigger, so the IEC60909 method is more suitable for precise and detailed calculation. The calculation results of the improved method proposed in this paper are more closed to the simulation results, while the method is more simple than the IEC60909 method and more accurate than the practical method. The effectiveness and feasibility of this method is verified.

b) The structure of the collection network in the wind plant had great influence on the result of short circuit impulse current. Especially when short-circuit faults occur in d2 or d3 point, there would be a considerable error in the impulse current obtained by different methods, which demand particular attention, and a more appropriate impact factor may be obtained in the further research.

#### IV. CONCLUSION

The similarities and differences between the two methods are analyzed in this paper firstly, and then put forward an



improved practical method based on the index of the calculation accuracy and the goal of the fast and convenient calculation. Finally with the comparison and analysis to the results calculated using the three methods, the effectiveness and feasibility of the improved method is verified. This method offers some ideas to the establishment of uniform standards of short-circuit current calculation method of wind power plant in our country.

#### REFERENCES

- [1] LU Z.Y, LI W.H, XIE B.C, et al, "Study on China's wind power development path-Based on the target for 2030," *Renewable and Sustainable Energy Reviews*, vol. 51, 2015, pp. 197-208.
- [2] SUN S, LIU F, XUE S, et al. "Review on wind power development in China: Current situation and improvement strategies to realize future development," *Renewable and Sustainable Energy Reviews*, vol. 45, 2015, pp. 589 – 599.
- [3] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of the People's Republic of China, "GB/T 19963-2005 Technical rule for connecting wind farm to power network," Chinese Standard Press, 2006. (in Chinese)
- [4] A. K. Elnaggar, J.L. Rueda, I. Erlich, "Comparison of short-circuit current contribution of Doubly-Fed induction generator based wind turbines and synchronous generator," *Proceedings of the PowerTech (POWERTECH), 2013 IEEE Grenoble*, pp: 1 - 6.
- [5] MULJADI E, GEVORGIAN V, "Short-circuit modeling of a wind power plant," *Proceedings of the 2011 IEEE PES General Meeting*, 2011, pp:1-9.
- [6] Xing Luhua, Chen Qing, Wu Changjing, et al, "A practical method to calculate short-circuit current in power system connected with doubly fed induction generators," *Power System Technology*, vol. 37, 2013, pp: 1121-1127. (in Chinese)
- [7] IEC-60909, "International Standard Short-circuit Currents in Three-phase a.c.Systems-Part0: Calculation of Short-circuit Currents," BRITISH STANDARD: IEC 60909-0, 2001.
- [8] IEC-60909, "International Standard Short-circuit Currents in Three-phase a.c.Systems-Part1: Factors for the Calculation of Short-circuit Currents According to IEC60909-0," BRITISH STANDARD: IEC 60909-1, 2002.
- [9] IEC-60909, "International Standard Short-circuit Currents in Three-phase a.c.Systems-Part4: Examples of Short-circuit Currents," BRITISH STANDARD: IEC 60909-4, 2001.
- [10] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of the People's Republic of China, "GB/T 15544-1995 Short-circuit current calculation in three-phase a.c.Systems," Chinese Standard Press, 1996. (in Chinese)
- [11] E. Muljadi, S. Pasupulati, et al, "Method of Equivalencing for a Large Wind Power Plant with Multiple Turbine Representation," *2008 IEEE Power Engineering Society General Meeting*, 2008, pp: 1-9.

**Mingyang Liu** was born in Hebi, China, in 1991. He is currently working toward the Ph.D. degree at the College of Energy and Electrical Engineering, Hohai University, Nanjing, China. His current research interests include the wind power generation technology.

**Wenxia Pan** was born in 1961. She received the Ph.D. degree from Hohai University, Nanjing, China, in 2004. Professor Pan is currently a doctoral supervisor with the College of Energy and Electrical Engineering, Hohai University, Nanjing, China. Her current research interests include renewable energy generation

system and high voltage and insulation technology.

**Gang Yang** was born in 1991. He is currently working toward the M.S. degree at the College of Energy and Electrical Engineering, Hohai University, Nanjing, China. His current research interests include the wind power generation technology.

**Hanjiang Liu** was born in 1991. He is currently working toward the M.S. degree at the College of Energy and Electrical Engineering, Hohai University, Nanjing, China. His current research interests include the wind power generation technology.

**Di Wu** was born in 1990. Her research interests include power system protection and control.