

A Wind Farm Short-Circuit Current Calculation Practical Model Applied to High Voltage Power Grid Simulation

Xiaohai Wang , Xianxian Pan , Jiang Wan , Jun Qi , Hongguang Zhang , Shitong Li

¹Inner Mongolia Power Dispatching and Communicating Center, Inner Mongolia Autonomous Region, Hohhot 010020, China

²State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources(North China Electric Power University), Beijing 102206, China
Email:15120025056@163.com

Abstract—With the increasing of wind generators and the scale of wind farm, it is urgent needed to establish a model which is proper and practical to short circuit current calculation. Firstly, this article analyzed the characteristics different types of wind generators' short-circuit current and put forward different types model of wind generators short-circuit current calculation. Secondly, considering the different types of wind generators and the influence of collecting system, this article established a wind farm short-circuit current calculation model which is suitable for engineering application and based on the simulation requirements of 35kV and above high-voltage power grid. The simulation showed that the short-circuit current results used this model is similar to the results adopted detailed model, proving that using this article's model can meet the engineering need and provide important reference value for power grid planning personnel in the grid short-circuit current calculation and the analysis of the restrictive measures.

Keywords-wind farm; short-circuit; current calculation; practical model; simulation

I. INTRODUCTION

In the study of short-circuit current calculation model of wind farms, early method is to simply regard wind field as a load without considering the short-circuit current it provided. In fact, wind farm is power source in the electrical network and it is inappropriate to think that wind generators do not provide current at the instantaneous short-circuit point when large-scale wind farm accessed system^[1]. Another method is to analyze wind generator as a synchronous motor, but in fact wind generator is a asynchronous generator and its provided current is not same to synchronous'. The article[2]gave a wind farm short-circuit current calculation method which aimed at the characteristics of wind farm combined short-circuit capacity. The article[3]analyzed short-circuit current features of doubly-fed wind power generator when the stator occurs three phase short-circuit and deduced the analytic expression of short-circuit current. The article[4]gave a short-circuit current estimation method which is provided by the squirrel-cage induction wind generators. The article[5]proposed a three-phase short-circuit current analytic calculation model of the double-fed wind power generator which is based on the analysis of the

physical process after doubly-fed wind power generator voltage completely fell. The article[6]established a wind generator electromagnetic transient mathematical model according to the analysis of the electromagnetic transient process of wind power system. From the point of view of the large power grid simulation calculation, it is unnecessary to establish an accurate model to reflect all the characteristics of wind generators' electromagnetic transient when calculating the short-circuit current, as we cannot change the existing algorithms of the simulation. Based on the analysis of the characteristics of wind farm short-circuit current and the control principle of wind generators, the paper established a practical model which is suitable for large-scale wind farm short-circuit current simulation from the angle of engineering application.

II. SHORT CIRCUIT CURRENT CALCULATION MODELS OF DIFFERENT TYPES OF WIND GENERATORS

At present, according to generator types, the wind generators are divided into four types: Fixed Squirrel-cage Induction Generator (FSIG), Wound Rotor Induction Generator (WRIG), Doubly Fed Induction Generator (DFIG) and Permanent Magnet Synchronous Generous (PMSG)^{[7][8]}.

A. A Short Circuit Current Calculation Model of FSIG Wind Farms

Compared with the synchronous generator, FSIG has no single field winding and cannot produce any reactive power. FSIG establish the motor armature magnetic field though the reactive power provided by system or compensation capacitor in parallel on the generator terminal. When three-phase short-circuit occurred at the generator terminal, the voltage of FSIG's terminal is close to zero and the short-circuit current will not exist due to the loss of excitation source. However there is still exist magnetic field in the generator in short-circuit instantaneous, stator and rotor circuit will appear high impact current due to stator and rotor winding's flux linkage cannot change instantly. The impact current will flow to the point of failure until the rotor flux, the stator current and the steady short-circuit current decay to 0 finally^[9].

When three-phase short-circuit occurred at the generator terminal, FSIG's short-circuit current is related to the equivalent reactance of the generator (ignoring resistance). Short-circuit current calculation model is shown in Figure 1.

Where X_s is the stator reactance, X_r is rotor reactance reduced to the side of stator. The calculation of equivalent reactance is as follows:

$$X' = X_s + X_r \quad (1)$$

The short-circuit current provided by FSIG is (effective value):

$$I_{sc} = \frac{U'}{X'} = \frac{U'}{X_s + X_r} \quad (2)$$

Where U' is the normal voltage of generator terminal.

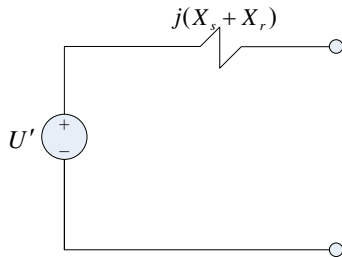


Figure 1. FSIG short-circuit current calculation model

B. A Short-Circuit Current Calculation Model of WRIG Wind Farms

WRIG is similar to FSIG, but the difference is that WRIG's rotor winding inserted a variable resistor controlled by frequency transformer through a slip ring. By changing the resistor and the pitch angle control technology, WRIG strengthened the function of speed and improved the efficiency of power generation^[10]. But this kind of wind generators' variable speed range is very limited, WRIG can run only in a small range of variable speed higher than the synchronous speed, therefore it still belong to the fixed speed wind generator^[11]. Similar to FSIG, WRIG has no separate field winding and cannot produce reactive power. When the external rotor resistance short circuit, the short-circuit current provided by WRIG is same to FSIG. When operating generator under the condition of a large slip, it is needed to adjust the external rotor resistance higher than zero. The greater the slip (absolute value), the smaller the short-circuit current is. The impedance of WRIG short-circuit current calculation model should consider the external rotor resistance value. The calculation method of the equivalent impedance is as follows:

$$Z' = R_{ext} + j(X_s + X_r) \quad (3)$$

The short-circuit current provided by WRIG is:

$$I_{sc} = \frac{U'}{Z'} = \frac{U'}{\sqrt{R_{ext}^2 + (X_s + X_r)^2}} \quad (4)$$

C. A Short-Circuit Current Calculation Model of DFIG Wind Farms

DFIG uses the present domestic most common doubly-fed induction generator. Its stator winding is directly connect to the power grid and the rotor circuit connect to the grid through double pulse width modulation (PWM) converter in order to realize the decoupling control of active and reactive power^[12]. When three-phase short-

circuit occurred at the generator terminal, stator voltage will suddenly reduced to zero, but the stator flux linkage remain constant^[13]. Because of the stator voltage suddenly reduce, the stator winding will appear a DC component of flux which is amplitude unchanged and does not change with time. At the beginning of the short circuit, the converter of DFIG is still in working state and DFIG short-circuit current features is similar to the synchronous generator but it attenuate slower with a smaller maximum^[14].

Because the electronic equipment in the DFIG converter is sensitive to overvoltage, it is needed to install protective device in the rotor side converter in order to protect the inverter^[15]. At present, the commonly used method is to short the rotor circuit by installing Crowbar circuit in DFIG rotor side so as to transfer the short-circuit current in the rotor winding and protect the inverter^[16]. In the process of short circuit, the rotor winding is actually shorted by a Crowbar adjustable resistance- R_{CB} . The short-circuit current contain damped DC and AC component and will eventually reduce to zero, similar to the general asynchronous wind generator. The difference is that the initial value of the fault current is small and the rotor decay time constant is small. The calculation of DFIG short-circuit current is similar to the first two kinds of wind generator, as shown in Figure 2.

The calculation method of the equivalent impedance is as follows:

$$Z' = R_{CB} + j(X_r + X_s) \quad (5)$$

The short-circuit current provided by DFIG is:

$$I_{sc} = \frac{U'}{Z'} = \frac{U'}{\sqrt{R_{CB}^2 + (X_s + X_r)^2}} \quad (6)$$

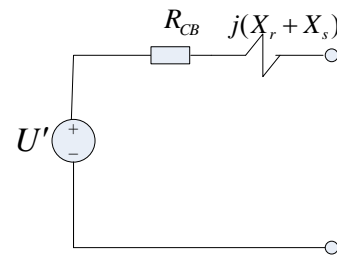


Figure 2. DFIG short-circuit current calculation model with the protection of Crowbar circuit

At present, a common protection method is using break-chopper circuit to protect rotor side converter. During the fault time, break-chopper circuit will keep the converter working and has a better support function for grid such as low voltage through, but it is still need to limit current in order to protect sensitive power electronic devices. In general, the max enter design current of converter is 1.1 (p.u.). At this point, the DFIG short-circuit current calculation model is similar to a current source. The maximum of this current source is shown in Figure 3.

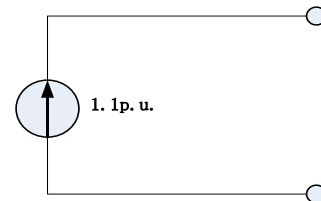


Figure 3. DFIG short-circuit current calculation model with the protection of break-chopper circuit

D. A Short-Circuit Current Calculation Model of PMSG Wind Farms

PMSG is decoupling connect to the grid through AC-DC-AC full power converter and all the power flow to grid through the converter. Due to the decoupling control of inverter, short-circuit characteristics of PMSG is mainly decided by the characteristics of line side converter and control model^[17]. Similar to DFIG, PMSG also need to use break-chopper circuit to protect the power electronic devices in the inverter^[18]. The equivalent short-circuit model is shown in Figure 3.

III. A PRACTICAL MODEL WHICH IS SUITABLE FOR LARGE-SCALE WIND FARM SHORT-CIRCUIT CURRENT SIMULATION

In general, for the grid with a voltage grade of 35kv and above, it is not required to consider wind field wiring when the simulating wind farm's capacity is less than 15% of regional load. The transfer of wind farm reactive (exclude resistance) are represented as,

$$X_{eq} = X_{sub_XFMR} + X_{collect} + X_{pm_XFMR} + X_{WTG} \quad (7)$$

Where X_{sub_XFMR} is the reactance of primary transformer, $X_{collect}$ is the reactance of wind farm collecting circuit, X_{pm_XFMR} is the reactance of unit transformer, X_{WTG} is the equivalent reactance of wind generator, all these reactance take the system capacity as basic value.

IV. EXAMPLE SIMULATION

This paper take the CIGRE B4-39 wind farm grid system as an example to simulate on PSS/E platform which is recommended by the international power grid conference. The simulation system is shown in Figure 4. BUS9 is system balance node, and ZONE1 is the stable system area, and ZONE2 is the wind power grid area, and ZONE3 is the area with heavy load. The wind farm has 18 generators, which is divided into 4 transmission lines connected to the collection points, as shown in Figure 5.

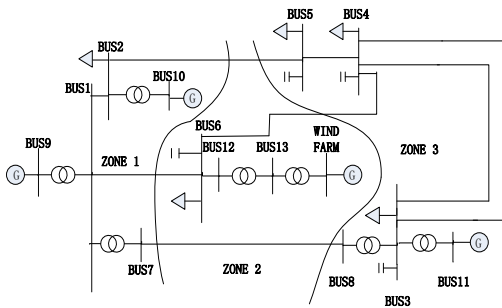


Figure 4. CIGRE B4-39 grid-connected wind farm

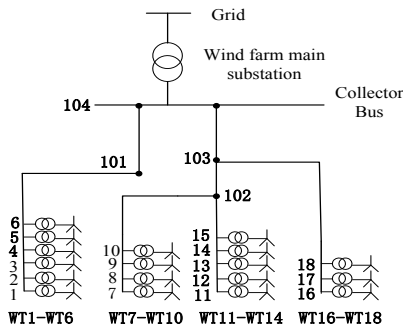


Figure 5. The wind generators system

The parameters of generators in Figure 5 were listed in the following tables. Where ID is the identity of each generator, P is the active power capacity of each generator, U is the rated voltage of each generator, R_2 is the stator reactance, R_1 is the rotor reactance, R_{CB} is the adjustable resistance of Crowbar circuit and R_{ext} is the external rotor resistance.

WT1-WT6 and WT11-WT15 are DFIG which is protected by Crowbar circuit with the parameters shown in TABLE I.

TABLE II. THE PARAMETERS OF DFIG

ID	P(MW)	U(kV)	R_2 (p.u.)	R_1 (p.u.)	R_{CB} (p.u.)
WT1-WT3	3	0.69	0.07	0.17	0.04
WT4-WT6	1.5	0.69	0.171	0.156	0.09
WT11-WT13	0.85	0.69	0.124	0.203	0.0678
WT14-WT15	0.66	0.69	0.04	0.07	0.04

WT7-WT10 are FSIG with the parameters shown in TABLE III.

TABLE IV. THE PARAMETERS OF FSIG

ID	P(MW)	U (kV)	R_2 (p.u.)	R_1 (p.u.)
WT7-WT8	0.6	0.69	0.0989	0.1091
WT9-WT10	0.75	0.69	0.106	0.1216

WT16-WT18 are WRIG with the parameters shown in TABLE V.

TABLE VI. THE PARAMETERS OF WRIG

ID	P(MW)	U(kV)	R_2 (p.u.)	R_1 (p.u.)	Slip	R_{ext} (p.u.)
WT16-WT17	0.8	0.69	0.0628	0.122	-2%	0.058
WT18	0.8	0.69	0.0628	0.122	-3%	0.080

Calculating the equivalent impedance of wind generators and converting to the basic capacity of system (100MVA):

$$R_{WTG} = 0.0022 p.u.$$

$$X_{WTG} = 0.0105 p.u. \quad (8)$$

As shown in TABLE VII, compared with the detailed model, the simulation results of short-circuit current with using the model in this paper is slightly larger, but the error is no more than 1.4385%. With the increasing of the distance between short-circuit point and wind farm, the error decreased. Therefore using the model established in this paper can meet the engineering need.

TABLE VII. THE RESULTS OF WIND FARM SHORT-CIRCUIT CURRENT

Z(p.u.)	I_{sc} (kA)	I_{sc}' (kA)	Error
0	13.6832	13.4891	1.4385%
0.0031+j0.047	9.84120	9.7406	1.0329%
0.0062+j0.094	7.6832	7.6218	0.8056%
0.0093+j0.141	6.3012	6.2598	0.6602%
0.0124+j0.188	5.3405	5.3108	0.5593%
0.0155+j0.235	4.6340	4.6116	0.4851%
0.0186+j0.282	4.0925	4.0751	0.4283%

Where Z is the impedance between short-circuit point and wind farm, I_{sc} is the short-circuit current by using the model established in this paper and I_{sc}' is the short-circuit current by using detailed model.

V. CONCLUSION

With the increasing of generator capacity and the scale of wind farm, it is necessary to calculate the short-circuit current provided by wind farm and short-circuit current calculation model should be practical. From the point of view of the large power grid, it doesn't need to build a detailed model to accurately reflect all the characteristics of wind generators. Based on the analysis of the characteristics of wind generators' short-circuit current and its control principles, considering the different types of wind generators and the influence of collecting system, this article established a wind farm short-circuit current calculation model which is suitable for engineering application. The simulation result proved this model can meet the engineering need and provide important reference value for power grid planning personnel.

REFERENCES

- [1] WANG Chengxi, ZHANG Yuan. Wind Power Generation[M]. China Power Press, 2002.
- [2] MA Xiaoping, SHU Hongsheng, MA Xiaojun. Wind Farm Based on the Short Circuit Capacity of the Grid Short-circuit Current Analysis[J]. Science Technology and Engineering, 2013 (1):170-174.
- [3] Morren J, Haan S. Short-circuit current of wind turbines with doubly fed induction generator[J]. Energy Conversion, IEEE Transactions on, 2007, 22(1):174-180.
- [4] Samaan N, Zavadil R, Smith J C, et al. Modeling of wind power plants for short circuit analysis in the transmission network[C]//Transmission and Distribution Conference and Exposition, IEEE, PES, 2008:1-7.
- [5] SHI Yihui, LU Zongxiang, MIN Yong, et al. Practical Calculation Model of Three-phase Short-circuit Current for Doubly-fed Induction Generator[J]. Automation of Electric Power Systems, 2011, 35(8):38-43.
- [6] WEN Yu-ling, CHAO Qin, TUERXUN Yibulayin. Impact of Interconnected Wind Farm on Power System Protection[J]. Power System Technology, 2008, 32(14):15-18.
- [7] XU Qiong-jing, XU Zheng. A Survey on General Models of Wind Turbine Generators in PSS/E [J]. Power System Technology, 2010, 34(8):176-182.
- [8] LIN Li, ZHAO Huilong, CHEN Ying, LI Dan. Research Summary of Wind Farm Modeling[J]. Modern Electric Power, 2014, 31:1-10.
- [9] MA Zhiyun. Transient Analysis of Generator[M]. Beijing: China Power Press, 1998.
- [10] Fan Gaofeng, Chi Yongning, Zhao Haixiang, et al. Transient Voltage Stability Enhancement of Wind Farm Using STATCOM[J]. Transactions of China Electro-technical Society, 2007, 22(11): 158-162.
- [11] WANG Hongfu. Active Power Compensation and Stability Control for Grid-connected Wind Farms[D]. Hangzhou: ZHEJIANG University, 2010.
- [12] GUAN Hongliang, CHI Yongning, WANG Weisheng, et al. Simulation on Frequency Control of Doubly Fed Induction Generator Based Wind Turbine[J]. Automation of Electric Power Systems, 2007, 31(7): 61-65.
- [13] XIANG Dawei, YANG Shun-chang, RAN Li. System Simulation of a Doubly Fed Induction Generator Ride-through Control for Symmetrical Grid Fault[J]. Proceedings of the CSEE, 2006, 26(10): 130-135.
- [14] LI Xiaotao. Short-circuit Current Calculation and Low Voltage Ride through Capability Analysis of Grid Connected wind Farms[D]. North China Electric Power University (Beijing), 2011.
- [15] SUN T, CHEN Z, BLAABJERG F. Voltage recovery of grid-connected wind turbines with DFIG after a short - circuit fault[C] // 35th Annual IEEE Power Electronics Specialists Conference.
- [16] XU Dian-guo, WANG Wei, CHEN Ning. Dynamic Characteristic Analysis of Doubly-fed Induction Generator Low Voltage Ride-through Based on Crowbar Protection [J]. Proceedings of the CSEE, 2010, 30(22): 29-36.
- [17] Walling R A, GURSOY E, ENGLISH B. Current Contributions from Type 3 and Type 4 Wind Turbine Generators During Faults. Power and Energy Society General Meeting, 2011, IEEE.
- [18] Walling R A, REICHARD M L. Short circuit behavior of wind turbine generators[C]//Protective Relay Engineers, 009 62nd Annual Conference for IEEE, 2009: 492-502.