

Practical calculation of asymmetric short circuit current of DFIG connected to distribution network

Pengwu Fu^{1*}, Dongwen Yang¹, Zhi He¹, Zhenfeng Duan¹, Dengmei Wang¹

¹State Grid Loudi Power Supply Company, Loudi 417000, China

Abstract: In view of the existing complex analytic calculations of DFIG short-circuit current are hardly applied in engineering projects, a practical calculation of asymmetric short-circuit current of DFIG is proposed. According to the complex sequence and their Thevenin equivalent model of DFIG network, the composition of each sequence component of DFIG short-circuit current is analysed. Moreover, considering the low-voltage ride through strategy of DFIG, the negative sequence periodic components of short circuit current are well analysed during the crowbar activation and deactivation, and the formula of the negative sequence periodic components of short circuit current are derived. On the basis of positive and negative sequence open circuit voltage, calculating impedance and rotor current, the judgement of crowbar activation is established. The pre-calculated surfaces of negative sequence periodic components of short circuit current are proposed, and the procedure for calculating the asymmetric short-circuit current of DFIG is designed. Finally, the proposed method is verified by simulation.

1 Introduction

In response to the development of clean energy and economy of checks and balances relationship between resources and environment, wind power cumulative grid installed capacity of more than 210 million kw till 2020 [1], the way of China's wind power industry is combining centralized development and decentralized. However, Double Fed Induction Generator (DFIG) with high permeability will have a profound impact on the protection setting of distribution network. Therefore, it is of great theoretical and practical significance to further study the fault characteristics of DFIG access to distribution network and the practical calculation method of short-circuit current.

According to the influence of rotor excitation and protection on the short-circuit current characteristics of DFIG unit, the transient calculation model of DFIG three-phase short-circuit current including crowbar protection and DC unloading protection was analysed in literature [2-3], but the influence of crowbar removal time on the short-circuit current was not considered. Considering network side converter, the formulas for calculating short-circuit current was deduced under the symmetrical fault in literature [4], but without considering the rotor side converter reactive compensation phase. Above studies the impact of short-circuit current is only applicable to power grid symmetrical fault happens, the power grid in the asymmetric fault occurrence frequency is much higher than symmetric [5]

In this paper, considering the LVRT control and the crowbar switching, the equivalent model of the distributed DFIG positive and negative sequence short-circuit calculation under the asymmetric fault of the power grid is established. And the calculation formula of the negative sequence component of the DFIG short-circuit current when the crowbar is put into or not put into operation is derived. And based on the open circuit voltage, the negative sequence periodic component surface of the calculated impedance, and further combined with the crowbar action criterion, the practical calculation method of DFIG asymmetric short-circuit current is proposed. Finally, the simulation is compared in MATLAB/Simulink to verify the proposed practical calculation methods.

2 Basic principle of asymmetric circuit calculation method for doubly-fed induction generator

It is assumed that modes 1 to m_1 in the power grid are connected to conventional generators, and nodes m_1+1 to m_1+m_2 are connected to DFIG. As shown in figure 1(a), node f in the illustration is the fault point. The transfer impedance network of figure 1(b) is obtained by retaining the fault point and access point of different types of generators and eliminating other intermediate nodes. Only the DFIG access node K is given in the illustration. Using the node impedance matrix Z of the fault component network of the figure 1(a), the transfer impedance $z'_{ij}=z_i Z_{ji}/Z_{ij}$ between the generator node i and the fault

*Corresponding author's e-mail:594283274@qq.com

point or DFIG access point j is obtained. Z_{ij} and Z_{ij} are the self-impedance and mutual impedance of matrix Z and z_i is the equivalent impedance of generator to node i . In order to calculate the short-circuit current of NO.K DFIG, the nodes 1 to m_1 of the conventional generator were

merged to obtain the equivalent network for short-circuit calculate in figure 1(c), In the figure, $Z_{kf}=z'_{kf}$, Z_{sf} and Z_{sk} are the parallel transfer impedance of conventional generator to fault point and DFIG access point.

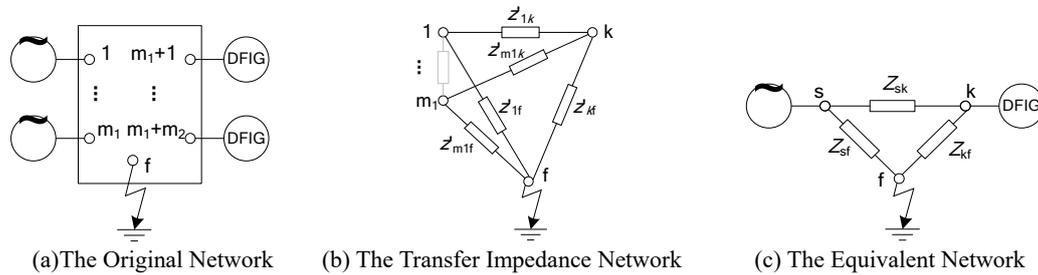


Figure 1 Equivalent networks for short circuit calculation

In the process of asymmetric fault, DFIG injects zero-sequence current into the grid is zero, positive and negative sequence short currents only exist in positive and negative network. When A phase is grounding on node f of Figure 1(c), compound sequence network as shown in Figure 2(a). E_s is the conventional generator equivalent voltage value, i_k^+ , i_k^- are positive and negative sequence short-circuit current component that DFIG inject to grid, i_f^+ , i_f^- and i_f^0 are sequence current of fault point, $Z_{\Sigma 0}$ is the zero sequence impedance related to the

voltage boost wiring of DFIG. According to the positive sequence equivalent criterion, the negative sequence and zero sequence networks of the compound sequence network in figure 2(a) are merged, and their positive sequence augmented network is shown in Figure 2(b). The existence of DFIG negative sequence current results in additional voltage in addition to additional impedance Z_{Δ} . Z_{Δ} and E_{Δ} is related to the fault type. The calculation formula of E_{Δ} is shown in table 1, and the relevant calculation of Z_{Δ} is shown in literature [6].

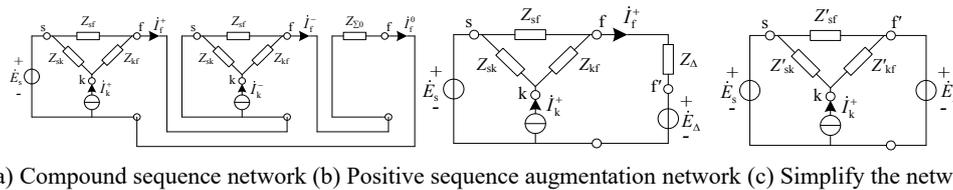


Figure 2 Complex sequence and positive sequence augmented networks for short circuit calculation

The positive sequence short-circuit current of DFIG in figure 2(c) is not only connected to the fault point through the transfer impedance Z'_{sk} , but also connected to the conventional generator through Z'_{sk} . conventional generator will provide voltage support for DFIG after grid fault. According to the compound sequence network (figure 2(a)), the voltage of DFIG access point after fault contains positive sequence, negative sequence and zero sequence components. Since the zero sequence

component do not affect the change of stator flux of the generator, that is, the positive sequence and negative sequence voltages determine the short-circuit current of DFIG. The systems outside the DFIG access point in the positive and negative sequence network are respectively equivalent to thevenin. And figure 2 shows the corresponding short-circuit impedance (equal to Z'_{js}), open circuit voltage \dot{U}_{oc}^+ and \dot{U}_{oc}^- .

$$Z'_{js} = \frac{Z'_{sk} Z'_{kf}}{Z'_{sk} + Z'_{kf}} = \frac{[Z_{sf} Z_{kf} + Z_{sf} Z_{\Delta} + Z_{kf} Z_{\Delta}] Z_{sk}}{(Z_{sf} + Z_{\Delta})(Z_{sk} + Z_{kf}) + Z_{sf} Z_{\Delta}} \quad (1)$$

$$\dot{U}_{oc}^+ = \frac{Z'_{kf} \dot{E}_s}{Z'_{sk} + Z'_{kf}} = \frac{Z_{sf} Z_{kf} \dot{i}_f^+}{Z_{sf} + Z_{sk} + Z_{kf}} + Z_{\Delta} \dot{i}_f^+ = \frac{[Z_{sf} Z_{kf} + (Z_{sf} + Z_{sk} + Z_{kf}) Z_{\Delta}] \dot{E}_s}{Z_{sf} (Z_{sk} + Z_{kf}) + (Z_{sf} + Z_{sk} + Z_{kf}) Z_{\Delta}} \quad (2)$$

$$\dot{U}_{oc}^- = \frac{-Z_{sf} Z_{sk} \dot{i}_f^-}{Z_{sf} + Z_{sk} + Z_{kf}} = \frac{\delta Z_{sf} Z_{sk} \dot{i}_f^+}{Z_{sf} + Z_{sk} + Z_{kf}} = \frac{\delta Z_{sf} Z_{sk} \dot{E}_s}{Z_{sf} (Z_{sk} + Z_{kf}) + (Z_{sf} + Z_{sk} + Z_{kf}) Z_{\Delta}} = \frac{\delta Z'_{sk} \dot{E}_s}{Z'_{sk} + Z'_{kf}} \quad (3)$$

In the equation: δ is sequence current correlation coefficient (that is, the ratio of negative sequence current and positive sequence current at the fault point), and its correlation calculation formula with fault type is shown in table 1. $Z_{\Sigma 2}$ is the equivalent impedance of negative sequence network in the table. The DFIG asymmetric short-circuit current equivalent circuit is obtained by combining the thevenin equivalence of positive sequence

and negative sequence networks. After the grid fault, \dot{U}_{oc}^+ and \dot{U}_{oc}^- are superimposed, and through the calculation impedance Z'_{js} applied to the DFIG terminal. According to the external impedance and sequence voltage conditions after the fault, positive sequence and negative sequence short-circuit currents are injected into the power grid.

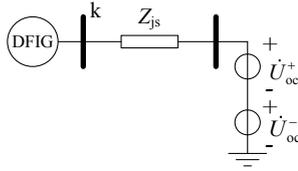


Figure 3 Equivalent circuits for short circuit current calculation of DFIG

In order to calculate the DFIG asymmetric short-circuit current, using positive sequence equivalent criterion. It is considered that the relation between the positive sequence components of the short-circuit current of DFIG at different moments. The DFIG access point's thevenin equivalent voltage and impedance in the positive sequence augmented network (figure 2(b)) is approximately equal to the relationship between the three-phase short-circuit current of DFIG at different moments and the calculation curved surface of Z_{js} and \dot{U}_{oc} . According to figure 2b, the equivalent impedance of the access point of the positive sequence augmented network after DFIG accessed is Z_{js} , which is the same as the thevenin equivalent impedance of the positive and negative sequence network in equation (1). The equivalent open circuit voltage \dot{U}_{oc} of the access point in the positive sequence augmented network after the unit access is,

$$\dot{U}_{oc} = \dot{U}_{oc}^+ + \frac{Z'_{sk} \dot{E}_\Delta}{Z'_{sk} + Z'_{kf}} = \frac{[Z_{sf} Z_{kf} + (Z_{sf} + Z_{sk} + Z_{kf}) Z_\Delta] \dot{E}_s + Z_{sf} Z_{sk} \dot{E}_\Delta}{Z_{sf} (Z_{sk} + Z_{kf}) + (Z_{sf} + Z_{sk} + Z_{kf}) Z_\Delta} \quad (4)$$

According to above equation, after DFIG is connected to the power grid, the open circuit voltage of the access point in the positive sequence augmented network is not only determined by the voltage \dot{E}_s of the conventional

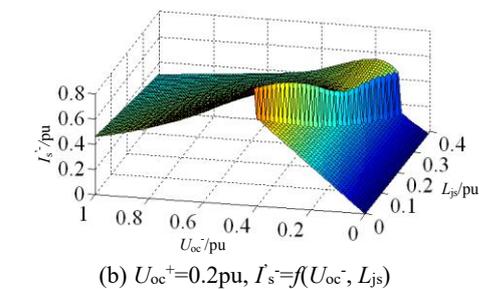
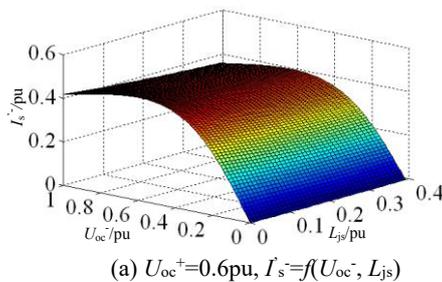


Figure 4 Pre-computed surface for negative sequence periodic components of short circuit current

4 Simulation analysis

Taking the multi-DFIG system of figure 5 as an example, the periodic component of short-circuit current after each DFIG fault under asymmetric fault is calculated by this method, and compared with the simulation results of DFIG electromagnetic transient process in MATLAB/Simulink. In figure 5, the rated capacity of DFIG1 and DFIG2 is 1.5MW, the rated capacity of DFIG3 and DFIG4 is 2MW, and the rated voltage is 0.69kV. The output of each DFIG is $P_{g0} + jQ_{g0} = 1.0 + j0 \text{ pu}$, and the rotor speed is $\omega_r = 1.211 \text{ pu}$. The bar resistance is $20Rr$ (Rr is the rotor resistance), the crowbar action delay T_c is set to 5ms, the rotor current control parameters $kp = 0.6$, $ki = 8$ and

generator through the additional impedance Z partial voltage of the fault point. Also affected by the additional \dot{E}_Δ caused by its own negative sequence short-circuit current \dot{I}_k^- . Therefore, for the practical calculation of DFIG asymmetric short-circuit current, the relationship between negative sequence component \dot{I}_k^- of short-circuit current and calculated impedance Z_{js} , positive and negative sequence open circuit voltage \dot{U}_{oc}^+ and \dot{U}_{oc}^- should be formulated in advance (figure 3). According to different fault conditions look up the table to get DFIG negative sequence short-circuit current \dot{I}_k^- , in equations (2) and (4), the positive sequence augmented network U_{oc} is calculated, and Z_{js} and U_{oc} are substituted into the three-phase short-circuits calculation curve to calculate the positive sequence component of asymmetric short-circuit current of DFIG at different moments.

3 DFIG Asymmetric Short-Circuit Current Practical Calculation Steps and Crowbar Action Area Study

Taking the 1.5 MW DFIG unit's positive sequence voltage as 0.6 pu and 0.2 pu as an example, combined with the above-mentioned boring bar protection action area and the second section, the DFIG asymmetric short-circuit current negative-sequence periodic component calculation surface is developed as shown in figure 4. In figure 4 (a), $U_{oc}^+ = 0.6 \text{ pu} > 0.5 \text{ pu}$, the crowbar protection does not work. And in Figure 4(b) $U_{oc}^- = 0.2 \text{ pu} < 0.5 \text{ pu}$, the crowbar protection active.

$I_{rlim} = 2 \text{ pu}$. Each DFIG is connected to the grid through wind power boosting. The other unit parameters are listed in [7].

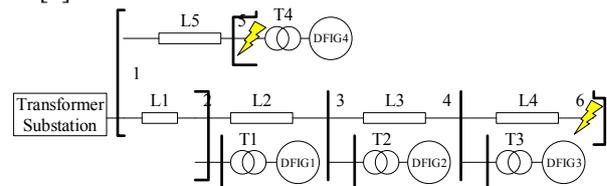


Figure 5 Single-line diagram of multiple DFIG system

Table 1 shows the calculation of the calculated value and simulation value of the positive and negative sequence components of each DFIG short-circuit current when the

bc two-phase short circuit occurs in node 5 (the fault duration is 0.06s). After the asymmetry fault occurs, except for the DFIG4 crowbar protection action, the other three DFIGs are kept off-grid operation and the crowbar protection does not operate, and each DFIG rotor-side converter adopts control to eliminate electromagnetic power fluctuations. the way. After the bc phase asymmetry fault occurs in node 5, the negative sequence current of the crowbar not put into the unit is generated by the converter excitation control. The short-circuit current negative

sequence components of DFIG1 to DFIG3 in table 1 are less than 0.2 pu, and the DFIG4 of the crowbar is put into operation. The negative sequence current component of the short circuit is significantly increased compared with the other three. Regardless of the crowbar switching condition, according to table 1, the error between the calculated value of the positive and negative short-circuit current and the simulated value is between (-11%, 2%), and the positive and negative sequence current errors of DFIG4 are the largest, reaching 4.55% and - 12.00%.

Table 1 Short-circuit calculation results when two-phase short-circuit occurs

Generator	I_s^+						I_s^-					
	$t=0.01s$			$t=0.02s$			$t=0.01s$			$t=0.02s$		
	Calculati on/pu	Simulation /pu	Error/ %	Calculation /pu	Simulation /pu	Error/ %	Calculation /pu	Simulation /pu	Error/ %	Calculation /pu	Simulation /pu	Error/ %
DFIG1	1.024	1.042	-1.73	0.931	1.005	-7.36	0.075	0.088	-14.78	0.157	0.166	-5.42
DFIG2	1.012	1.038	-2.50	0.942	0.993	-6.08	0.063	0.059	6.78	0.159	0.163	-2.45
DFIG3	1.041	1.028	1.26	0.937	0.988	-5.16	0.067	0.071	-5.63	0.162	0.160	1.25
DFIG4	1.529	1.602	-4.55	1.712	1.778	-3.69	0.374	0.425	-12.00	1.001	1.121	-10.70

5 Conclusion

In this paper, using the Thevenin's theorem and the principle of positive sequence equivalence, the practical calculation method of DFIG asymmetric short-circuit current considering LVRT control protection is proposed and verified by MATLAB/Simulink. By using the calculation method mentioned in this paper, only the impedance and the positive and negative sequence open circuit voltages can be calculated, and the positive and negative components of the asymmetric short-circuit current can be obtained. The calculation amount is small and the error can be further reduced by introducing the correction parameters and simplifying the calculation of the short-circuit current. This paper is suitable for DFIG asymmetric short-circuit current calculation in engineering.

References

1. National Development and Reform Commission, National Energy Administration. "13th Five-Year" energy development planning[R]. Beijing: National Development and Reform Commission, National Energy Administration, 2016 (in Chinese)
2. Pan Wenxia, Yang Gang, Liu Mingyang, Pan Xueping, Yang Jianjun, Sun Ke, Yang Chuan et al. Calculation of Short-Circuit Current of DFIG With the Considering of Crowbar Resistance[J]. Proceedings of the CSEE, 2016,36(13):3629-3634+3382.
3. Pan Wenxia, Liu Mingyang, Yang Gang, Pan Xueping, Zhang Yibo, Guo Jiasheng, The Calculation of Short-Circuit Current of Double Fed Induction Generators Considering Chopper Protection[J]. Proceedings of the CSEE, 2017,37(18):5454-5460+5545.

4. Wang Zengping, Li Jing, Zheng Tao, Zhao Ping, Yang Hao. Calculation and Analysis of Transient Short Circuit Current of doubly-Fed Induction Generator Considering Converter Current Imitation and GSC Current[J]. Transactions of China Electro-technical Society, 2018, 33(17): 4123-4135.
5. Cheng Xuekun, Sun Xudong, Chai Jianyun, Liu Hui, Song Peng[J]. Automation of Electric Power Systems, 2018, 42(09): 120-126.
6. Kong Xiangping, Zhang Zhe, Yin Xianggen, He Maohui Wang Fei. Fault Current Characteristics of DFIG Considering Excitation and Regulation Characteristics[J]. Transactions of China Electro-technical Society, 2014, 29(4): 256-265.
7. Xiong Xiaofu, Ouyang Jinxin. Analysis and calculation of rotor currents for doubly-fed induction generators under short circuits in power grids[J]. Proceedings of the CSEE, 2012, 32(28): 114-121(in Chinese).