Impact of wind power grid connection and interline short circuit faults on power grid

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Abstract. With the gradual increase of electricity demand in China, wind power and other power generation has developed rapidly, which makes the structure of power grid more complex. The complex structure increases the risk of short-circuit fault of power grid. The rapid development of wind power intensifies the randomness of power grid operation. This paper uses MATLAB/Simulink to model power system, construct simulation, and analyse the influence of grid-connected wind power and short-circuit faults on grid stability. The results show that the fluctuation and impact of the active power on the user side are significantly weakened compared with those of the single wind power grid when the high-power stable power supply is connected to the wind power grid. The single-phase short-circuit fault has no disturbance to the user of the grid, and the two-phase short-circuit and three-phase short-circuit have greater impact on the voltage, current and speed of the user end.

1. Introduction

With the increasing attention of renewable energy [1-3], in 2017, China's hydropower reached 1,194.5 billion kWh, an increase of 1.7%; wind power 305.7 billion kWh, an increase of 26.3%; photovoltaic power generation of 118.20 billion kWh. At the same time, the growth rate was 78.6%; the biomass power generation was 79.4 billion kWh, a year-on-year increase of 22.7%. China's power supply demand continues to expand, various energy power plants continue to increase, resulting in more and more complex power grid structure, the randomness of transmission line short-circuit faults is further increased [4], short-circuit faults of power lines to grid system users Side voltage, current and equipment speed will also have certain influence. In 2002, China once counted the short-circuit fault data of 220 kV power transmission line. Among them, single-phase short-circuit fault accounted for 96.7%, and two-phase short-circuit fault accounted for 2.1%. Phase short-circuit faults account for about 1.2%. With the expansion of China's power grid and the development of China's power technology, China's short-circuit faults have been greatly alleviated, but the lateral development of power grids has caused frequent short-circuit faults, and the probability of three-phase short-circuits is not high. However, its risk is higher, single-phase short circuit is the most common, accounting for about 65% to 70% of the total fault of the short circuit [5].

In recent years, more and more attention has been paid to the impact of wind power Grid-connected and short-circuit faults on grid stability. Sulla F [6] and others analyzed the short-circuit current changes of squirrel cage doubly-fed induction generators; Gu Wenhao [7] analyzed the impact of wind power
Grid-connected on the grid and improvement measures; Guo Jiahu [8] and others analyzed the response and protection of doubly-fed wind power generation system under three-phase short-circuit faults of the grid; Morren J [9] et al. analyzed the short-circuit current of doubly-fed induction wind turbines; Liran [10] et al. studied the excitation characteristics of doubly-fed induction generators under short-circuit faults of power grids; Jiangling [11] et al. analyzed the supporting effect of distributed power injection on Grid-connected point voltage when symmetrical short-circuit faults occurred in power grids, in order to ensure the safe and stable operation of power grids [12-13]. He Shan [14] et al. simulated the electromagnetic fields of various short-circuit faults in Doubly-fed Wind turbines.

In summary, it is necessary to analyze the influence of wind power Grid-connected and inter-line short-circuit faults [15] on power grid stability. Based on Mtlab/Simulink, the power model is built, and the short-circuit fault device is installed at the input end of three-phase line of user transformer to analyze the influence of each phase short-circuit fault on the fluctuation of power grid operation parameters. By using the high-power stable power supply as the control variable of simulation model, the stability of power grid operation parameters is observed when the wind power plant is connected to the grid separately and jointly with the stable power supply.

2. Wind power Grid-connected model

There are three main types of wind power generation: Cage Asynchronous Wind Turbines, Doubly Fed Induction Generator (DFIG) and Permanent Magnet Synchronous Wind Turbines. This paper mainly uses DFIG, which is consists by wind turbines, gearboxes, asynchronous generators and regulators. Wind turbines convert wind energy into mechanical energy by wind energy, and gearboxes connect wind turbines and doubly-fed asynchronous motors. The generator converts the obtained mechanical energy into electric energy, the generator stator circuit is directly connected to the power grid, and the rotor circuit is connected to the power grid through the frequency converter, and its structural schematic diagram is shown in Fig. 1.

![Figure 1. Wind turbine grid-connected structure](image)

3. Summary and simulation analysis of wind power Grid-connected model

3.1. Model of Joint Grid Connection of Stable Power Supply and Wind Power

The 120 kV power supply (considered as thermal power) is directly connected in parallel to the input of the power system. In the models of the two systems, the wind turbines are controlled at the same time and the wind speed with the same cut-in variation of the fan is the same, and the other wind power parameters are unchanged. The B575 and B2300 intelligent monitoring devices receive the output power of the wind turbine and the input voltage, current and electric power of the user. The output data of the two models are compared to observe the stability of the parameters after the combined generation. The simulation model of the combined generation is shown in Fig. 2.
3.2. Model of Joint Grid Connection of Stable Power Supply and Wind Power

In the 15s-24s after the normal operation of the simulation system, the wind speed of 15m/s-25m/s is cut into the wind turbine side, and the perturbation of wind power Grid-connected to the grid system is analyzed. In this simulation, whether or not the high-power stable power supply is connected to the grid as a variable, and the changes of system parameters are observed. Intelligent instrument B575 is installed on the generator side to measure the change of active power output of wind power, B2300 is installed on the user side to measure the change of active power, voltage and current parameters of the user side, and the rotor speed of the motor is output on the motor side. The variation of parameters is shown in Fig. 3 when wind power is connected to the grid alone and in Fig. 4 when wind power and stable power are connected to the grid.

Figure 2. Joint Grid-connected System Simulation Diagram

Figure 3. Variation of wind power Grid-connected parameters
In the power system, the power supply conveys electric energy to the power system. The output of electric energy is negative in the oscilloscope. The user side obtains electric energy, consumes its useful work, and the secondary power is positive in the oscilloscope. From Fig. 3, it can be seen that the power generated by wind turbines is always unstable after the wind turbine is started by a single grid-connected wind power system at 15m/s wind speed. It fluctuates continuously with time. Through long-distance transmission, part of the power is lost in the transmission project, and the power obtained by the client has the same fluctuation form. As a result, the voltage and current on the user side are extremely unstable, and the rotor speed of the motor is also greatly affected, which has a serious impact on the power system.

After 15s-25s wind speed changes, the power of wind turbine is unstable, and the disturbance caused by wind speed increases. When the wind speed stabilizes, the fluctuation gradually weakens. Affected by the output power of the distribution side, the input active power, voltage, current and the rotor speed of the motor of the electrical equipment at the user end fluctuate similarly. The combined grid-connected wind turbine and 2.5MW stable power supply still fail to meet the requirements of grid-connected. It will threaten the undetermined operation of power grid. After adding 2.5MW stable power supply to the wind power grid alone, the input parameters of the fan side are kept unchanged. The output data of the oscilloscope are shown in Fig. 4 (a). From the figure, it can be seen that the active power of the first 10 seconds is gradually increased during the start-up stage of the wind turbine. Under the action of the power supply, the generation capacity of the 10s-15s fan has been maintained at 10MW. But compared with the wind turbine connected to the grid alone, the stability trend is better. When the steady-
point power supply is increased to 3.5 MW and 4 MW respectively, with the power supply increasing gradually, the disturbance of active power emitted by the wind turbine side gradually weakens, and the active power, voltage, current and rotor rotation trend of the motor obtained by the user side gradually stabilizes.

When the power of the stable power supply increases to 5MW, it can be found from Fig. 4 (d) that the active power of the fan is stable after the fan is started, and the active power, voltage, current and rotor rotation of the motor obtained by the user side are stable. The parameters do not fluctuate with time. When the wind turbine and the stable power supply are jointly connected to the grid, with the increase of the active power of the stabilized power supply, the power of the power system is gradually stable. When the power supply is close to 50% of the total power of wind turbine, the electrical parameters of the power system are stable and the power load can work normally.

4. Simulation analysis of Short Circuit Fault Model

The system control ensures the output power of the stable power supply is 5MW, and the wind speed of the wind turbine side is 5-15m/s in 5s-15s to ensure the normal operation of the system. Then the short-circuit fault is analyzed in four cases. Firstly, the short-circuit fault is not set to make the system work steadily. The oscilloscope will sort out the data obtained, and output the transmission voltage, current and the rotor speed of the power-consuming equipment on the user side will change with time. In the case of no fault, the variation of parameters is shown in Fig. 5. Then three-Phase Fault is set to single-phase short-circuit, two-phase short-circuit and three-phase short-circuit fault modes respectively. The fault time is set to 5-6 seconds. The transmission voltage, current and rotor speed of power-consuming equipment output by oscilloscope are observed again. The parameters of different forms of short-circuit fault are shown in three diagrams of Fig. 6.

![Figure 5. Fault-free user-side load data](image)

From Fig. 5, it can be seen that when the system is fault-free and the distributed power supply works normally, the voltage and current obtained by the user side are relatively stable, and the rotational speed of the motor of the electrical equipment is not disturbed, and the system maintains stable operation.

![Figure 6. User-side load data for Short-circuit fault](image)
As can be seen from Fig. 6, different short-circuit faults have different impact effects on power system. When single-phase short-circuit faults occur between transmission lines, the variation of parameters is basically the same as that without faults. It can be seen that single-phase short-circuit faults will not destroy the stability of power grid, but can still ensure the normal operation of power grid. The variation data of parameters are shown in Fig. 6 (a). When two-phase short-circuit fault occurs between transmission lines, the voltage on the user side decreases sharply. When the fault disappears, the voltage will suddenly increase, and then gradually restore to a stable state. When the fault occurs, the current at the user end will be unstable instantaneously, the current will increase during the fault period, and the increasing rate will gradually decrease. When the fault disappears, the current will increase sharply. After the fault is removed, the current will gradually restore the initial stability value. After the fault occurs, the rotor speed of the generator of the user-side electrical equipment decreases gradually, and the reduced speed increases gradually. After the fault is removed, the speed will gradually restore. The parameter change data are shown in Fig. 6 (b). When the three-phase short-circuit fault occurs between transmission lines, the voltage and current obtained by the user are rapidly reduced to 0. During the fault period, the user is in a power-off state, the electric energy is cut off, and the rotate speed of the motor of the electrical equipment is gradually reduced. When the circuit fault disappears, the voltage and current of the user increase sharply, and the voltage and current gradually recover to a stable initial state after the fault is relieved. The speed of motor rotor is gradually recovered, and the recovery time is longer than that of two-phase short circuit. The parameter change data are shown in Fig. 6 (c).

5. Conclusion

This paper mainly studies the influence of short-circuit faults and wind power Grid-connected on the stability of power grid. Single-phase short-circuit faults are more common in power grid operation, followed by two-phase short-circuit faults, three-phase short-circuit faults are less, short-circuit faults and wind power Grid-connected have greater randomness. Through simulation, the number of short-circuit faults is changed, and its impact on the end of power grid is analysed. By analysing the fluctuation of electric parameters, the following conclusions are drawn:

1). Single-phase short-circuit faults of transmission lines basically do not change the stability of voltage, current and motor rotor speed at the user side; two-phase short-circuit and three-phase short-circuit faults gradually increase their perturbation, increase the risk of power grid operation, increase the impact of electric energy on user-end equipment, and affect its normal operation.

2). Wind power is random. When wind power is connected to the grid alone, the power of wind power generation is unstable, which is affected by wind speed, resulting in unstable output power. After the combination of stable power supply and wind power supply is connected to the grid, with the gradual increase of power supply, the fluctuation of electrical parameters in the power system decreases gradually. When the active power of the power supply reaches about 50% of the rated power of the wind turbine, the power system can operate stably.

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References

[1] Dong Bo, Xu Xiaoyan, Ma Shuo, et al. Study on the influence of wind power access on system frequency control based on long process dynamic simulation [J]. Power system protection and control, 2014, 42 (12): 57-64.

[2] JIANG Cheng, LIU Wenxia, ZHANG Jianhua, et al. Risk assessment of generation and transmission systems considering wind power penetration[J]. Transactions of China Electrotechnical Society, 2014, 29(2): 260-270.

[3] WANG Shenzhe, GAO Shan, LI Haifeng, et al. Evaluation of power quality in grid planning scheme with wind power integration[J]. Transactions of China Electrotechnical Society, 2013, 28(8): 56-65.
[4] Zhang Wanjie, Wang Chao, Zhou Dazhou, et al. Single-phase grounding fault location method for 10 kV feeder under low current grounding [J]. Science and Technology and Engineering, 2018, 18(5): 236-241.

[5] Zhang Songlan. Application of MATLAB in power system line fault analysis [J]. Automation technology and application, 2011, 30 (10): 76-79.

[6] Sulla F, Svensson J, Samuelsson O. Symmetrical and unsymmetrical short-circuit current of squirrel-cage and doubly-fed induction generators [J]. Electric Power Systems Research, 2011, 81: 1610-1618.

[7] Gu Wenhao. Analysis of the influence of wind turbine connected to power grid [J]. Communication power supply technology, 2018, 35(3): 125-129.

[8] GUO Jia-hu, ZHANG Lu-hua, CAI Xu. Response and protection of DFIG system under three-phase short circuit fault of grid [J]. Power System Protection and Control, 2010, 38(6): 40-44.

[9] Morren J, Han S W H. Short-circuit current of wind turbines with doubly fed induction generator[J]. IEEE Trans on Energy Conversion, 2007, 22(1): 174-180.

[10] Li Ran, Li Zenghui, Wang Yihe, et al. Study on electromagnetic characteristics of DFIG under short circuit fault of power grid [J]. Power system protection and control. 2013, 4 (10): 13-19.

[11] Jiangling, Liu Bangyin, Duan Shanxu. Supporting effect of power injection of distributed power supply on Grid-connected point voltage in case of symmetrical short-circuit fault [J]. Power grid technology, 2014, 38 (3): 670-674.

[12] Vilathgamuwa D M, Loh P C, Li Y. Protection of microgrid during utility voltage sags [J]. IEEE Trans on Industrial Electronics, 2006, 53(5): 1427-1436.

[13] Kong Lingguo, Cai Guowei, Yang Deyou, et al. Modeling and coordinated control of grid-connected PV generation system with energy storage devices [J]. Power System Technology, 2013, 37(2): 312-318.

[14] HE Shan, WANG Weiqing, ZHANG Xinyan, et al. Simulation study of multiple short-circuit fault electromagnetic field about DFIG in wind power [J]. Power System Protection and Control, 2013, 41(12): 41-46.

[15] Mesut E B, Ismail E-M. Fault analysis on distribution feeders with distributed generators [J]. IEEE Transactions on Power Systems, 2005, 20(4): 1757-1764.