Analysis of Wind Farm Synchronization Impacted by Short Circuit of Grid Fault

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Abstract. In order to improve operational stability of the island system after grid faults of local weak connection, a wind farm and grid power system model composed of doubly-fed induction generator is built. This paper studies the impact of faults on the wind farm output and the grid bus after the wind farm is connected to the grid, and sets three-phase short-circuit fault in wind farm synchronization. Moreover, we analysed voltage fluctuation of the wind farm connected to the grid and voltage fluctuation of grid bus, as well as changes in output frequency, active power and reactive power of the wind farm. The microgrid voltage and frequency changes are studied in island operation when the fault is removed. The research results lay the foundation for island operation when fault occurs after wind turbine is connected to the grid.

1. Introduction

Rational and efficient use of wind energy has become a focus with the global rapid development of new energy sources. Wind power generation can realize in-situ energy production based on geographical location, thus reducing long-distance transmission of electric energy and improving power source in some areas according to the principle of proximity. Wind farms face problems not only in synchronization, but also in island operations. In recent years, the study on wind farm synchronization effects proceeds from simulation analysis on electromechanical transients and electromagnetic transients [1, 2].

The increasing wind farm capacity coupled with the uncertainty of wind speeds let synchronization become an increasing intense challenge to power systems. At present, doubly-fed wind turbine system is adopted in most areas of China, including applications in wind turbine, transmission shaft, gear box, doubly-fed induction generator (DFIG) and dual pulse width modulation (PWM) frequency converter and control system [3]. There are permanent magnet direct-drive, asynchronous, synchronous generators in terms of wind turbines [4], and there are different grid connection control modes. In grid voltage control, the main method is to make full use of static var compensator (SVC), static synchronous compensator (STATOM) equipment to increase reactive compensation [5]. The relationship between turbine output power and load is controlled by gird frequency [6-7]. Large-scale wind power connect to the gird also affects grid line current and load loss [8].

In this paper, we mainly investigate the impact of wind farm synchronization on bus voltage at common connection points and the output frequency, active power and reactive power of the wind farm under normal operation and three-phase short-circuit fault of the power grid. Changes in output frequency and voltage of the wind turbine amid island operation are also studied. The theoretical analysis and the whole process dynamic simulation of a wind farm in Chongming are carried out. The simulation results are in agreement with the theoretical analysis, and the effectiveness of the model are verified.

2.Mathematical model

2.1 Wind Turbine Mathematical Model

According to a survey on Chongming Wind Farm, the wind farm adopts doubly-fed wind power generation system. The safe and stable operation of the variable speed wind turbine is controlled by detecting power output of the generator and pitch angle to achieve maximum utilization of wind energy. When the wind speed is lower than the cut-in wind speed, the generator has no power output. When the wind speed is greater than the cut-in wind speed and lower than the rated wind speed, the output power is controlled by the wind speed. The actual wind speed is greater than the rated wind speed and lower than the cut-out wind speed. The constant power output and rated power of the output wind turbine is controlled by changing the pitch angle. The wind turbine stops operation when the actual wind speed is greater than the cut-out wind speed.

Wind Turbine Output Power:

$$P_{ref} = K_{opt}\omega_T^3 = \frac{1}{2}\rho\left(R/\lambda\right)^3 C_p(\lambda,\beta)\omega_T^3 \tag{1}$$

where P_{ref} is wind turbine output power; ω_T is wind turbine speed; R is turbine radius; C_p is power coefficient; A is sweep area; λ is tip-speed ratio; β is blade pitch, ρ is the air density.

Wind speed - turbine output power:

$$P_{power} = \begin{cases} 0, & v < v_m, v \ge v_{out} \\ P_N(\mathrm{A}_1 \mathrm{v}^3 + A_2\,\mathrm{v}^2 + A_3\,\mathrm{v} + A_4), & v_{in} \le v \le v_N \\ P_N, & v \ge v_{out} \end{cases} \tag{2}$$

where A_1, A_2, A_3 and A_4 are coefficients; P_{power} is the actual output of the wind farm; P_N is the rated output; v, v_{in}, v_N and vout are respectively actual wind speed, cut-in wind speed, rated wind speed and cut-out wind speed.

The schematic diagram of pitch angle control is shown in Figure 1.

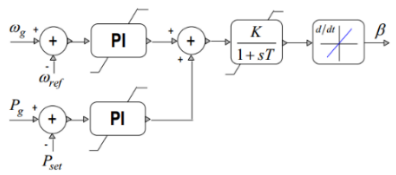

Figure 1. Schematic diagram of pitch angle.

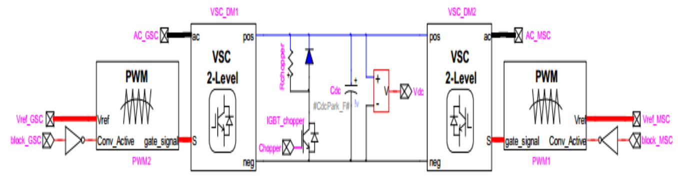

Figure 2. Circuit diagram of frequency converter.

2.2 Transmission Shaft Mathematical Model

Large wind farms adopt variable speed wind turbines to increase energy capture and reduce transmission system stress [9]. The transmission mechanism of the wind turbine consists of a hub, a transmission shaft and a gearbox. The transmission mechanism is a rigid device, the gearbox is set as an ideal rigid gear set, and the transmission shaft has an inertia equivalent to that of the generator rotor. First-order inertia is used to indicate the transmission mechanism characteristics, and the transmission operation is given as:

$$\frac{dT_m}{dt} = \frac{1}{T}(\mathrm{T_e} - \mathrm{T_m}) \tag{3}$$

where T_e is the input torque of the transmission shaft; T_m is the output torque of the transmission shaft; T is the inertia time constant of the hub.

2.3 Mathematical Model of DFIG

The output of the permanent magnet synchronous generator is connected to the grid through the AC-DC-AC frequency converter, and the rotor side implements active and reactive decoupling control. The active power of the generator stator is linear with the torque component of the rotor current. The reactive power of the stator is linear with the excitation component. The active power and reactive power are adjusted by controlling the rotor current and the excitation component, thus realizing decoupling control. Expression of active power and reactive power of the generator stator is:

$$\begin{cases} P_s = -n_p \omega_T i_{qr} (\mathrm{L_m} \psi_s / \mathrm{L_s}) \\ Q_s = n_p \omega_T \psi_{ds} (\psi_{ds} - \mathrm{L_m} i_{dr}) / \mathrm{L_s} \end{cases} \tag{4}$$

where P_s is generator stator active power; Q_s is generator stator reactive power; ω_T is hub speed; i_{dr}, i_{qr} are d, q axis rotor current; L_m is winding mutual inductance; L_s is d-axis stator self-inductance; ψ_{ds} is d-axis stator flux linkage.

3. WIND TURBINE MODEL

3.1 Frequency Converter Model

PWM duty cycle is adjusted by adding a proportion-integral-differential (PID) controlled feedback voltage and frequency signal to improve output frequency and voltage stability [10-11]. The wind turbine is connected to the grid via the frequency converter, and the frequency converter fulfills dual PWM control. The wind turbine output three-phase voltage controls the insulated gate bipolar transistor (IGBT) switch via the PID circuit, the grid side grid bus voltage signal forms a feedback to the frequency converter to control the grid side IGBT switch. Figure 2 shows the circuit diagram of frequency converter.

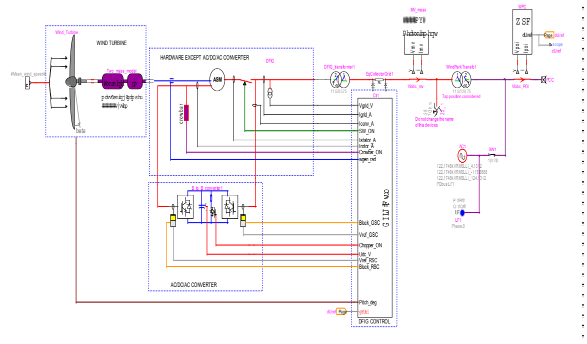

Figure 3. Circuit diagram of wind turbine.

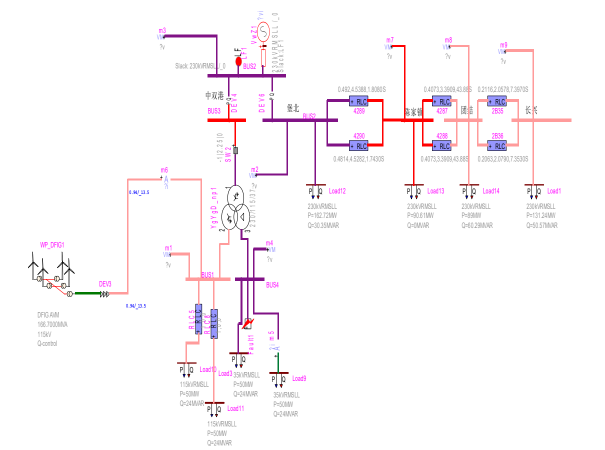

Figure4.Circuit diagram of wind turbine synchronization.

3.2Wind Turbine Model

The wind turbine model mainly consists of wind turbine, transmission shaft, gearbox, DFIG, dual PWM frequency converter, control systems and reactive power compensation [12,13]. The generator output is boosted into the grid via the transformer. The circuit diagram of wind turbine is shown in Figure 3.

4. WIND TURBINE SYNCHRONIZATION MODEL

The wind farm has 40 1.5MWA doubly-fed wind turbines with a total capacity of 60MW. The wind farm generator and the outlet transformer adopt one-generator-to-one-transformer wiring, and a total of 40 box-type transformers are adopted. The transformer has a capacity slightly larger than the installed capacity, and the voltage level is 0.69/110kV. The wind farm is connected to the 110KV side bus of the 220kv Huzhong Port Station. The three-phase three-winding transformer of the Huzhong Port substation has a voltage ratio of 220/110/35kV and the wine turbine is connected to the 110kV side bus. The wind farm simulation model is established based on the regional power grid structure. The right side of Huzhong Port is connected to Baobei, Chenjiazhen, Tuanjie and Changxing substations to detect changes in the voltage and frequency of the wind turbine when it is directly and indirectly connected to the bus. The simulation model is shown in Figure 4.

5. SIMULATION ANALYSIS

There are two simulation ways: normal operation and fault mode. The bus voltage fluctuations of BUS1, BUS2 and BUS4 and the output frequency, active power and reactive power changes of the wind farm are compared under the two operation modes.

In the built power system model, the fault point simulation is set at 35KV bus of 220KV Shuanggang Station. The simulation duration is 2.5s. The bus BUS4 has a three-phase ground short-circuit fault at 2.2s, the grounding resistance is 1Ω, and the fault lasts for 0.05s. That is, the fault disappears at 2.25s. The 220/110/35KV transformer is removed to remove the fault in island operation of the wind farm.

5.1 Bus Voltage Fluctuations

The bus voltage fluctuations of BUS1, BUS2 and BUS4 during normal operation are shown in Figure 5, Figure 6, and Figure 7.

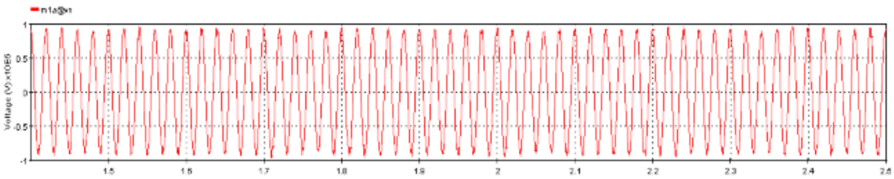

Figure 5. BUS1 voltage during normal operation.

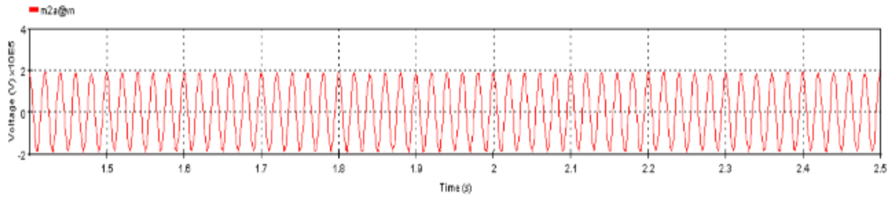

Figure 6. BUS2 voltage during normal operation.

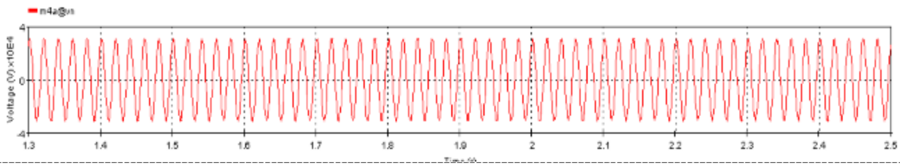

Figure 7. BUS4 voltage during normal operation.

BUS1, BUS2 and BUS4 voltage changes in the case of three-phase short-circuit fault are shown in Figure 8, Figure 9, and Figure 10.

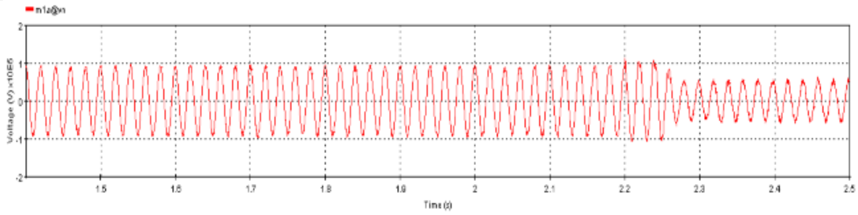

Figure 8. BUS1 voltage in the case of fault.

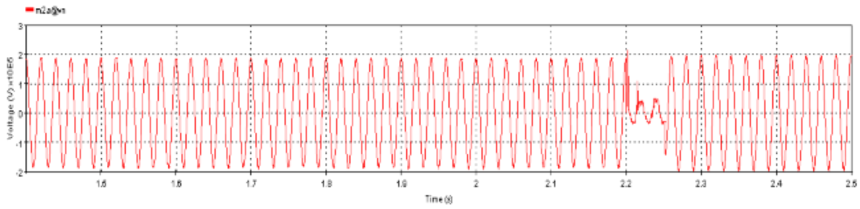

Figure 9. BUS2 voltage in the case of fault.

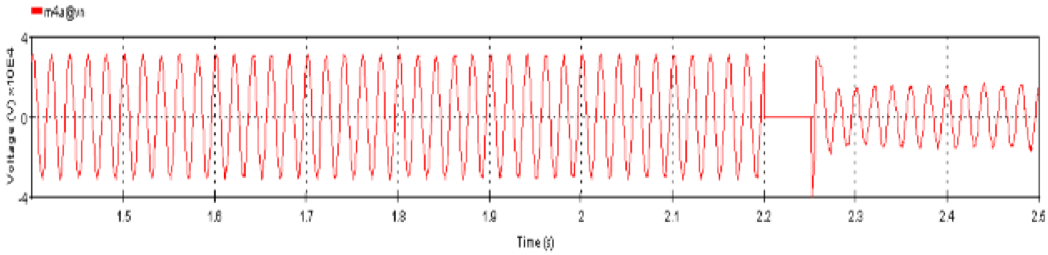

Figure 10. BUS4 voltage in the case of fault.

Under normal operation, BUS1, BUS2, and BUS4 exhibit sine wave. The three-phase ground fault occurs at 2.2s, BUS1 voltage does not change at the fault time 2.2s, but stabilizes at 110kv. The voltage change appears at fault-clearing time 2.25s, with the voltage peak decreased and the new state stabilized. After the transformer is removed, BUS1 load is borne by the wind farm. The voltage of the 230KV BUS2 continues to drop during the fault time. After three-phase ground fault occurs in BUS4, massive power is transferred to the earth through the ground connection. After the fault is removed, BUS2 voltage rises and the bus voltage curve restores the original stable operation state. The stabilized voltage value is slightly larger than that under normal operation. Before voltage fault occurs in BUS4, the voltage is normal. When the three-phase ground fault occurs at 2.2s, the voltage is zero. After the fault disappears at 2.25s, BUS4 voltage value restores another steady state under the effect of BUS1. The stabilized voltage value is lower than that under normal operation.

5.2 Wind Farm Output

Under normal operation, the waveforms of active power and reactive power output from the wind farm are shown in Figure 11.

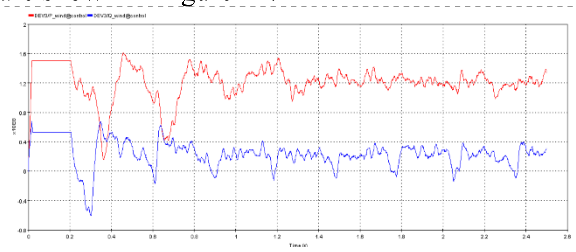

Figure 11. Active and reactive power output from the wind farm during normal operation.

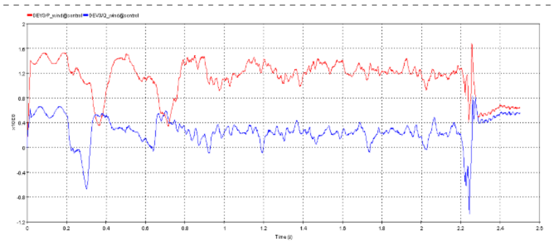

Figure 12. Active and reactive power output from the wind farm.

Changes in active power and reactive power output from the wind farm when BUS4 has a three-phase ground short-circuit fault are shown in Figure 12.

It demonstrates the active power and reactive power output from the wind farm in the case of fault. When the three-phase short-circuit fault occurs at 2.2s, the active output of the wind farm suddenly drops from 130MW to 30MW. When the fault disappears at 2.25s, the active power suddenly increases to 150MW, which is about 20MW higher than that under non-fault operation. When the fault disappears, active output exhibits short-term fluctuation and reaches stable operation by 2.3ss. When the three-phase short-circuit fault occurs at 2.2s, the reactive power absorbed by the wind farm from the power grid increases significantly. During the short-circuit moment, the absorbed reactive power rises from 20MVar to 80MVar, and begins to decrease at 2.25s when the fault disappears. The absorbed reactive power suddenly decreases to zero at 2.26s. By 2.3s, the reactive power curve slowly stabilizes.

The wind farm output frequency pattern under normal operation is shown in Figure 13.

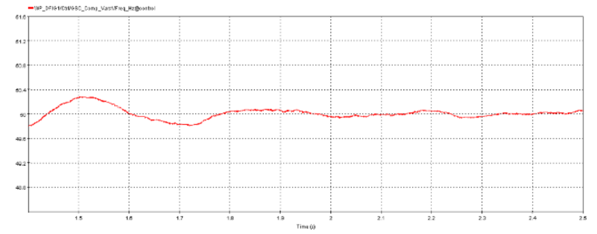

Figure 13. These two figures have been placed side-by-side to save space. Justify the caption.

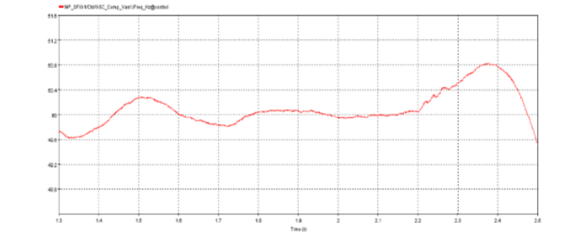

Figure 14. These two figures have been placed side-by-side to save space. Justify the caption.

Changes in wind farm output frequency when three-phase ground short-circuit fault occurs in BUS4 are shown in Figure 14.

It shows the system frequency in the case of normal operation and three-phase short-circuit faults. Under normal operation, the wind farm is connected to the grid, and the output frequency of the wind farm begins to fluctuate, which basically stabilizes at 50 Hz after 1.8 s. When a three-phase ground fault occurs at 2.2 s, the system frequency begins fluctuation, and the fault causes unstable wind turbine output frequency.

6. CONCLUSIONS

When there was no fault in the synchronization grid, the wind turbine output active, reactive power had small fluctuations. The frequency began fluctuation, and finally stabilized at 50 Hz, which was within the stable operation range. When three-phase ground short-circuit fault occurred in the power grid, the grid bus voltage, wind turbine output frequency, active power and reactive power would change. The bus directly connected to the fault point had a voltage of zero in the case of fault, and voltage of other bus also decreased. The wind turbine output active power and reactive power fluctuated greatly after a fault occurred on the grid side. After the fault was removed in time, it began to stabilize. The wind turbine output frequency fluctuated when fault occurred at the grid side, which still decreased when the fault was removed. The grid side fault not only affects the grid side, but also directly affects the operation of the grid-connected wind farm.

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