Security and Stability Analysis of Wind Farms Integration into Distribution Network

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Abstract. With the increasing share of the wind power in the power system，wind power fluctuations will cause obvious negative impacts on weak local grid. This paper firstly establish electromechanical transient simulation model for doubly fed induction wind turbine, then use Matlab/Simulink to achieve power flow calculation and transient simulation of power system including wind farms, the local synchronous generator, load, etc, finally analyze wind power on the impact of the local power grid under typical circumstances. The actual calculated results indicate that wind mutation causes little effect on the power grid, but when the three-phase short circuit fault happens, active power of wind power decreases sharply and   the voltage of location of wind power into the grid also drop sharply, finally wind farm split from power system. This situation is not conducive to security and stability of the local power grid. It is necessary to develop security and stability measures in the future.

1. Introduction

Twenty-first Century is the century of renewable energy sources. Wind energy, a kind of clean renewable energy source, has been potential and will be never used up .Today，because of the conventional energy resources shortages and the deterioration of environment, wind energy has become one of the world's fastest growing energy. Only effective utilization of wind energy resources in China can reach 25.3 billion kw [1-2]. As the country's emphasis on renewable energy development and implementation of the ''Renewable Energy Law''，more and more wind farms in China access to the power system. For wind farms accessed to the big electric network, the scale of wind farms will not be restricted when installed wind capacity accounted for the proportion of total installed capacity of less than 10% [3]. For the wind farms accesses to the electric distribution network, it is located in the area where it has small load and the network structure is weak that wind speed fluctuation, fault and other disturbance will cause great influence to the wind farm and the reliable operation of the local power grid. In order to be able to make ensure the safe and stable operation of the system, we should do calculation and analysis of stability of the region distribution network which accessed wind power.

2. The main wiring of including wind farm

Figure 1 show the region distribution network system composed of Doubly-fed asynchronous wind turbine of wind farm, a synchronous generator, the power load and so on. The wind farm installed 7 capacities of 1.5 MW doubly-fed asynchronous wind power generators with a total capacity of up to 10.5MW. The electrical power is transmitted from dynamo to booster station by a set of electrical lines and a 50MVA main transformer, and into the 110 kv high-voltage distribution network.
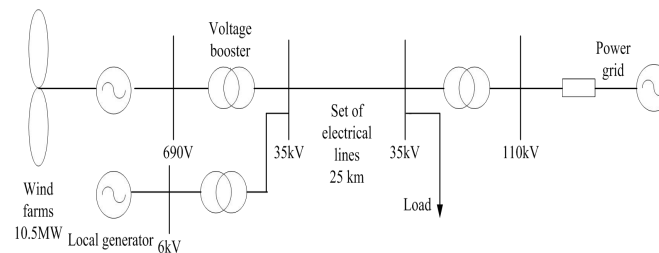

Figure 1. The main wiring of including wind farm

3. The mathematical model of doubly-fed asynchronous wind turbine

At present variable speed constant frequency doubly-fed asynchronous wind turbine is a new technology of the hot spot of international wind power [4-5], it accounted for a significant share of wind turbines in the domestic wind power, and deriving mathematical model is of great significance for studying the characteristics of wind turbine operation.

3.1. The mathematical model of wind turbine

Generally， wind turbines connected with three blades, made from glass fiber reinforced plastic, blade shape and curve is designed according to the principle of aerodynamics for improving wind energy capture, wind energy is converted into a role on the hub of the mechanical torque and the relationship between the speed and torque can be expressed as[6]:

$$M_w = \frac{1}{2}\pi\rho c_p \frac{R^3 V_w^2}{\lambda}\frac{\Omega_N}{p_N}\times 10^{-3} \tag{1}$$

In which M_w is the mechanical torque of wind turbine blades; ρ is the air density; c_p is the wind-power utilization coefficient; R is the radius of the blade; λ is the tip speed ratio; Ω_N is the rated mechanical angular velocity of the blade; p_N is the rated power of the wind turbine.

3.2. Transferring structure model

The transferring structure of wind turbine consists of the wheel hub, shaft, and gear box. It is generally acknowledged that transferring structure belongs to the rigid components with large inertia, often said by first-order inertia link:

$$\frac{dM_t}{dt} = \frac{1}{T_j}(M_t - M_w) \tag{2}$$

In which, M_t is the output torque of drive mechanism(PU); T_j is the inertia time constant of wheel hub; M_w is the input torque of transferring structure.

3.3. The transient mathematical model of doubly-fed induction generator

After deduction and simplification we can get the fundamental equation in d-q-0 coordinates of double fed induction generator:

$$\begin{cases} u_{ds} = R_s i_{ds} + \dfrac{d\psi_{ds}}{w_n dt} - \dfrac{w_{ref}}{w_n}\psi_{qs} \\[2mm] u_{qs} = R_s i_{qs} + \dfrac{d\psi_{qs}}{w_n dt} - \dfrac{w_{ref}}{w_n}\psi_{ds} \\[2mm] u_{dr} = R_r i_{dr} + \dfrac{d\psi_{dr}}{w_n dt} - \dfrac{w_{ref} - w_r}{w_n}\psi_{qr} \\[2mm] u_{qr} = R_r i_{qr} + \dfrac{d\psi_{qr}}{w_n dt} - \dfrac{w_{ref} - w_r}{w_n}\psi_{dr} \end{cases} \tag{3}$$

In which, flux-linkage equation:

$$\begin{cases} \psi_{qs} = (L_s + L_m)i_{qs} + L_m i_{qr} \\[1mm] \psi_{ds} = (L_s + L_m)i_{ds} + L_m i_{dr} \\[1mm] \psi_{qr} = (L_r + L_m)i_{qr} + L_m i_{qs} \\[1mm] \psi_{dr} = (L_r + L_m)i_{dr} + L_m i_{ds} \end{cases} \tag{4}$$

Electromagnetic torque of generator:

$$T_e = \psi_d i_q - \psi_q i_q \tag{5}$$

Rotor motion equations:

$$T_j \frac{ds}{dt} = T_m - T_e \tag{6}$$

In (3), (4), (5), (6), $u_{ds}, u_{qs}, u_{dr}, u_{qr}$ are d-component and q-component of voltage of stator winding and rotor winding; $i_{ds}, i_{qs}, i_{dr}, i_{qr}$ are d-component and q-component of electric current of stator winding and rotor winding; $\psi_{ds}, \psi_{qs}, \psi_{dr}, \psi_{qr}$ are d-component and q-component of synthesis magnetic chain of stator winding and rotor winding; T_m, T are mechanical torque .

4. The analysis of the running state of the distribution network

According to the previous theoretical derivation, calculation model of distribution network which including wind power is established, analysis of several operation modes which are very typical and have serious impact on the system is made [7-8].

4.1.The influence of the change of wind speed on wind farms and grid

When wind speed changed from 8m/s to 14m/s, the output voltage, current, active power and reactive power of wind farm as the Fig.2 shows. As the wind speed increase the current and wind power output of point of common coupling increased, and when the winds reach 14m/s, the power output is kept around rated power 10.5MW. Doubly-fed wind power generator through back-to-back converter to realize the decoupling control of active power and reactive power, the wind power output increasing, the decline of reactive power is not large, wind farm exports voltage basically maintained at 1.0 (pu), reactive power have a tiny fluctuation in the 20s, but little change, basically near 0. A sudden change in wind speed, wind power voltage of including grid remained stable.

The influence of wind speed change on the grid is shown in figure 3. In the simulation figure 3, the partial power grid voltage fluctuation caused by the wind speed changes was not significant, the local power plant slash caused by wind farm output greatly increase the active power, condition changed from providing active power to the system to absorbing active power from system, such power deficiency is provided by the wind power. In addition, in order to compensate the reactive power of

wind farm, reactive power from the local power plants increased obviously. Calculation and analysis show that the wind speed change had no significant effect on the stability of the system operation.
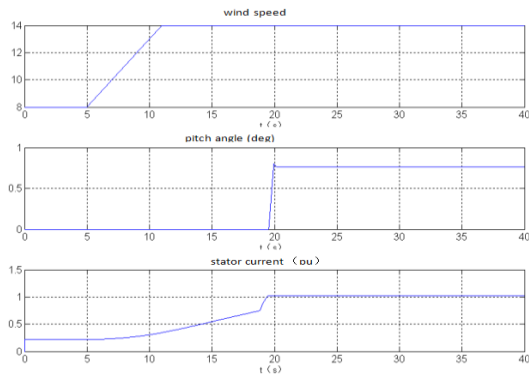

Figure 2. （A) The influence of wind speed change on the wind farm
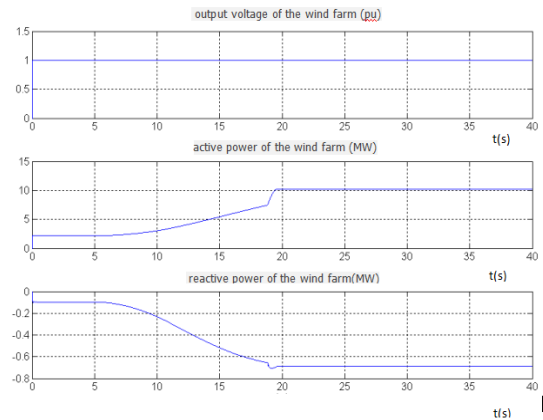

Figure 2. (B) The influence of wind speed change on the wind farm
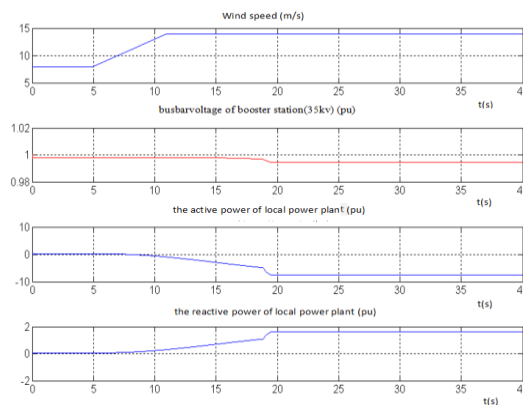

Figure 3. The influence of wind speed on the grid

4.2. The influence of single-phase earth fault on wind farm and power grid
Assuming that single-phase earth fault occurred at a point of set the wire, time is t= 5s, fault duration is 150 ms, the operation of wind farm and power grid is shown in figure 4 and 5.
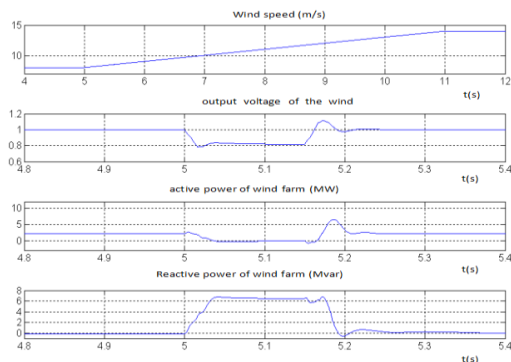

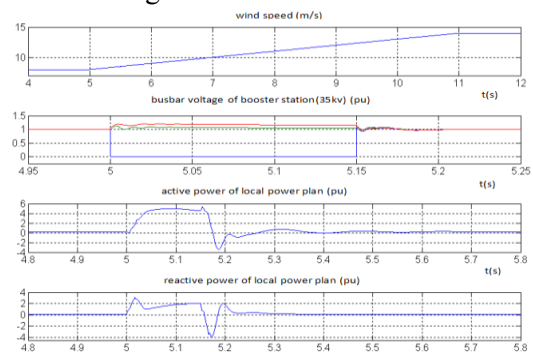**Figure 4.** The influence of single-phase grounding

Figure 5. The influence of single-phase grounding on power grid

As figure 4 and 5 show, after single-phase earth fault occurs, wind farm export voltage quickly dropped to 0.79 (p.u.), but still higher than wind turbines voltage protection threshold 0.75(p.u.), after excision of a single-phase earth fault, wind farm output voltage increases to 1.0(p.u.) with the control of converter; During single-phase grounding fault, the active power of wind power generating become zero, the local power plant rapidly enhance active power to realize the balance of power system, at the same time wind power absorb reactive power from the grid to maintain the parallel operation. Visible, when short-circuit ground fault of collecting power lines occurs at some point, the voltage fluctuation at the point of common coupling of wind electricity is very big, wind farms need to absorb reactive power from the grid side; After the fault is removed ,wind farm and power grid eventually return to normal operation, but, when the local has a greater percentage of installed capacity of wind power than the local total installed capacity, single-phase grounding fault will bring influence to power grid.

4.3.The influence of three phase short circuit fault on wind farm and power grid
Assuming that the three-phase short-circuit failure happened at the point of collecting power lines, Wind farm and power grid operation as shown in figure 6, figure 7. Figure 6, figure 7 shows that when the three-phase short-circuit fault occurs, wind farm voltage fell sharply to zero and wind power active power is zero, wind farm separate from power grid quickly; Booster station 35 kv voltage fluctuated, after clearing fault the voltage returned to normal gradually; After wind farm separate from power grid , the local power plant active power increase quickly and change drastically; After three phase short circuit fault elimination, local power plants provide the active and reactive power support for the entire system. Visible, three-phase short-circuit fault causing wind farms separate from power grid, causing larger fluctuation of grid, unfavorable to power system security and stability; After fault clearance, grid-connected wind farm is not successful, the system cutting off some part loads, relying on local power plants to achieve supply and demand balance of power system.
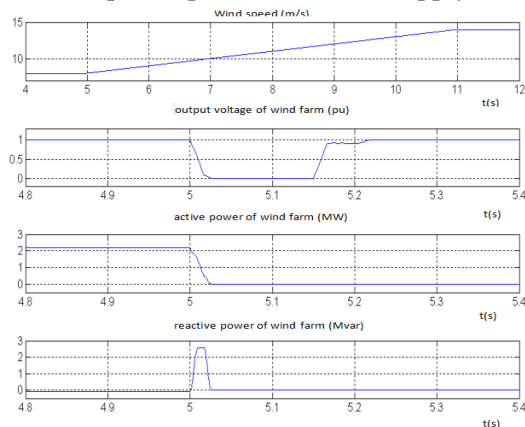

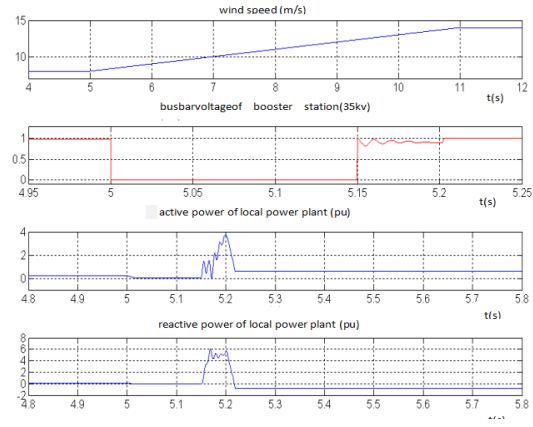**Figure 6.** The influence of three phase short circuit fault of power grids

Figure 7. The influence of three phase short circuit fault on power grids

5. Conclusion
Based on Matlab/simulink to establish a region, containing wind power, grid model. For the three typical operation modes-wind speed change, one-phase ground fault set wire road and three phase short circuit fault, this article first start with the voltage level and the stability of wind farms and local power grid, using dynamic simulation method to analyzes the stable operation of the whole system. In the sudden change of wind velocity case, the output of wind farm, wind power and node voltage will fluctuate, but little influence on the system's normal operation, after the fault clearance wind farms and grid can be back to normal operation; But when in the single-phase grounding and three phase short circuit fault case, wind power and network point voltage drop sharply, wind turbine power down to 0.75 (p.u.), low voltage protection device act mistakenly, wind farms separate from grid column. In

order to ensure the safe and stable operation of wind farms and grid, it is necessary to formulate reasonable stability measures, such as optimizing the neutral node on the low voltage side of wind farm, the wind generator set reasonable, developing wind turbines low voltage protection setting through ability tests, etc., the content will be carried out in a follow-up study.

References

[1]   Yin C 2009, *Current situation and Prospect of wind power generation in China [J],* 170(6):14-15.
[2]   Li X 1999, *Wind power generation and its development in our province [J]* 110(6)23-25.
[3]   Fan Y,Yao Q and Wang Y 2003, Static stability analysis of Buerjin wind power system based on MATLAB. 19:1-7;
[4]   Wang Z and Zhang H 2009, New development of wind power generation and its control technology.
[5]   Pablo Ledesma,Julio Usaola, Doubly Fed Induction Generator Model for Transient Stability Analysis, IEEE Trans. on Energy Conversion, 2005,20(2):388-397.
[6]   Liu G, Yao X, Zhao Y and Xing Z 2006, Study on mathematical model for simulation of variable speed wind turbine [J],126(2):52-54.
[7]   Ni Y 2002, Dynamic power system analysis [M].
[8]   J.F. Manwell,J.G. McGowan, A.L. Rogers, Wind Energy Explained Theory:Design and Application, England: John Wiley & Sons, Ltd, 2002.