Simulation Analysis of Wind Turbine Grid Operation Based on PSCAD

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Abstract: With its advantages of pollution-free and low cost, wind power has considerable market and huge development space in many new energy power generation systems. With the increasing installed capacity of wind power, the grid's acceptance of large-scale wind power has become a new problem. It is very necessary to study the operation characteristics of wind turbines and the related characteristics of grid-connected wind turbines. By analyzing the basic structure and working principle of wind turbine, this article studies the grid-connected control system with permanent magnet motor as the core, designs the corresponding grid-connected control circuit and simulates the grid-connected situation of wind turbine by building PSCAD model.

1. Introduction
Wind power has a lot of advantages, such as low development cost, mature technology and remarkable scale effect. However, due to its inherent fluctuation and intermittent characteristics, it brings many problems to the security, stability and economic operation of the grid receiving wind power. It is very meaningful to study the model of wind power Grid-connected and analyze the impact on power system after grid-connected and provide a reference standard for wind capacity planning.

2. Basic Principle of Wind Turbine and Grid-connected Control

2.1 Basic Principles and Characteristics of Wind Turbines

2.1.1 Operating Principle of Double-fed Fan
The stator windings are directly connected to the target power grid and the rotor windings are connected to the power grid through dual PWM converters. The operation schematic diagram is shown in Figure 1-1.
2.1.2 Operation Principle of D-PMSG
D-PMSG wind turbine is composed of two back-to-back voltage source inverters. The fan structure is shown in Figure 1-2.

2.2 Wind Turbine Connection Analysis
The grid-connected vector control system of fan is shown in Figure 1-3.

Proportional integration PI (proportional integration PI) is used in all controllers. D and Q branch control voltage UDR and UQR are compensated by feedforward decoupling term. Three-phase AC control voltage signal is formed by coordinate transformation, and then the inverter is driven by pulse width modulation link to excite the rotor to meet grid-connected conditions.

Figure 1-1 Variable Speed Constant Frequency Operation Principle of Double-fed Fan

Figure 1-2 D-PMSG basic structure diagram

Figure 1-3 Permanent Magnet Motor Grid-connected Vector Control System
3. Wind Turbine Connection Modeling

3.1 Establishment of Wind Turbine Model

PSCAD/EMTDC software is used to build the wind power system, as shown in Figure 2-1.

The whole power generation system consists of analog wind source, wind turbine components, wind turbine governor components, synchronous generator model, matching control signals and output channels.

![Figure 2-1 Permanent Magnet Wind Power Generation Simulation System](image1)

The first element in the figure above is the simulated wind source (as shown in Figure 2-2), which mainly simulates each condition of the wind. For wind turbines, the following three wind characteristics are important:

- Average wind speed: The rated characteristics of generators and generators are determined by the average wind speed. Economic research is also based on this speed. In general, the average wind speed is about 13 m/s.
- Cut-in wind speed: When the wind speed is higher than the cut-in speed, the mechanical brake is released and the generator rotates. Generally speaking, the cut-in speed is 4 m/s.
- Cut-out speed: When the wind speed is higher than the cut-out wind speed, in order not to damage the generator blades, the rotation of the generator stops. Generally, the cutting speed is about 25 meters per second.

![Figure 2-2 Simulated Wind Source](image2)

In the analysis, we first consider the case of constant wind. The wind speed is set to 13 m/s.

Then there is the wind turbine component (as shown in Figure 2-3) which mainly converts the kinetic energy of wind into mechanical energy and inputs it into the synchronous generator as power. Considering the constant wind speed of 13m/s at the beginning of simulation, combined with the \( C_p \) efficiency model and fan model in PSCAD, we can get the turbine parameters.

![Figure 2-3 Wind Turbine](image3)

Next is the governor of the wind turbine (Figure 2-4), which adjusts the output power of the
generator by automatically adjusting the beta according to the wind conditions.

According to the parameters of the wind turbine set before, the specific settings can be obtained.

![Figure 2-4 Fan Governor](image)

Finally is the synchronous generator model (Figure 2-5), in PSCAD, all internal values are defined as standard unitary values and it also allows simulation to start when the generator is used as a power source or its rotor speed is constant. The parameters of the synchronous generator are also adjusted according to the settings of the previous components.

![Figure 2-5 Synchronous Generator](image)

Summing up the above, we get the model of wind turbine generation. Because wind power is intermittent, random and uncontrollable and the grid needs constant voltage and frequency, so we still need to build the corresponding rectifier and inverter equipment to connect the power generated by synchronous generators to the grid.

The whole conversion model is shown in Figure 2-6 which consists of three-phase diode rectifier, DC capacitor bus and 6-pulse thyristor inverter bridge.

![Figure 2-6 Wind Turbine Rectifier Inverter Circuit](image)

Because the speed of wind turbine can not be controlled, its DC capacitor bus needs to protect the system from over-voltage and the safety margin is 10%. In order to ensure bus safety, the rectifier is blocked by a single input level comparator in the case of overvoltage.

In order to cooperate with the over-voltage protection of DC bus, the capacitor can be modeled as short circuit when it is not charged, so we must add a resistor to limit the peak current near the rated value when the voltage is low. At the same time, in order to reduce heat loss, the resistance must be short-circuited after 7.5 seconds, so we have the following coordination and protection action system (Figure 2-7).
Considering that we use a single wind turbine model, the weak impact of wind turbines connected to the grid will start the voltage control of DC buses instead of directly acting on the connecting points. Therefore, we introduce a stabilized voltage selector to maintain the DC voltage of the rectifier system, and use the universal current controller to determine the conduction angle of the inverter bridge according to the output of the stabilized voltage selector.

3.2 Target Power Network Modeling

In this part, we need to build the model of the target power grid. Firstly, after the output of electric energy from the inverter bridge in the wind power generation system, it passes through the steady voltage of the capacitor, and then through the transformer boost to reach the required value of the target grid. The specific parameters are based on the model established before.

After boosting the transformer, the electricity can be input into the target power grid. Here we adopt the distribution network model and open-loop radiation network, as shown in Figure 2-10.

4. Wind Turbine Grid-connected Simulation and Analysis

4.1 Wind Turbine Grid-connected Simulation at Constant Wind Speed
If the constant wind speed is 13 m/s, the rated power will be achieved. According to the internal definition of PSCAD, we take $C_p$ as 0.4 and the rated power of the generator as 3 MVA. Then the radius of the rotor of the wind turbine is 46.2 m and the area of the rotor is 6716 M² (the air density is 1.225 kg/m³). For the control parameters of fan governor, the average value of $K_p$ and $K_i$ based on PI control strategy is 6.2 (the upper and lower limit is (+30). The model pole number of synchronous generator is 100, the rated voltage is 0.69 kV, and the rated capacity is 3 MVA. According to the above settings, we set the simulation time to 30s and the simulation step to 100us.

The simulation results are as follows:

![Figure 3-1 Reactive power at grid-connected points](image1)

It can be seen that the reactive power at the grid-connected point is stable and has better response characteristics when the unit is running at constant wind speed. Next is the change curve of active power at the grid-connected point.

![Figure 3-2 Reactive power at grid-connected points](image2)

The active power value at the grid-connected point is normal, and there is no excessive fluctuation, which indicates that the grid-connected wind turbines have little influence on the stability of the system under the condition of constant wind speed. Next is the change of grid-connected voltage:

![Figure 3-3 Grid Point Voltage](image3)

The smoother curve shows that the grid-connected voltage is stable under constant wind speed. After the start-up of the whole unit, there is no large fluctuation or voltage drop, which shows that the wind power Grid-connected has little impact on the system under constant wind speed, and also fully reflects the excellent control of the control system.

Then we will analyze the relevant characteristics of the unit. The following three diagrams are the DC bus voltage of the generator, the speed of the unit and the trigger angle.
As can be seen from the figure above, the whole operation of wind turbines in the process of grid-connected is relatively stable and there is no large fluctuation and the response characteristics are good.

4.2 simulation results of wind turbine grid-connected under fluctuating wind speed

Next, considering the actual situation of the system, the wind speed is set according to Figure 3-5, which simulates the cut-in wind speed of 25m/s and the cut-out wind speed of 4m/s (stable wind speed is 13m/s).

The simulated natural wind speed is shown in Figure 3-6.
The control mode is set to dynamic pitch control and a new circuit breaker (Figure 3-7) is used to limit the peak current when the wind speed reaches the stable value for the second time. The simulation time is 250 seconds and the simulation step is 100us. The settings of other parts are consistent with the previous ones.

Next, we will analyze the grid-connected operation of wind turbines under variable wind speed and the internal changes of wind turbines. At the same time, compared with the operation of constant wind speed, we will analyze the characteristics of wind turbines grid-connected system and its friendliness to the grid. Figure 3-8 shows the changes of active and reactive power at the grid-connected point under fluctuating wind speed.

From the above figure, we can find that when the wind speed is below the stable value, the active power and reactive power of the grid-connected point are in a stable state. When the wind speed increases beyond the stable value, the active power of the grid-connected point on the system side fluctuates in a certain range, while the reactive power fluctuates in a larger range. With the stability of wind speed, active and reactive power gradually return to the stable value. The voltage at the grid-connected point is shown in Figure 3-9.
From the analysis of the above figures, it can be seen that although the power part of the grid-connected point has a large fluctuation, the voltage is still in a stable range. This also shows that the large fluctuation of reactive power is to maintain the stability of grid-connected voltage. Next, the simulation results of fan system under variable wind speed are discussed.

The change of wind speed will affect the DC capacitance inside the wind turbine and the whole unit will fluctuate to some extent, but it is still flat as a whole. Later, because the wind speed drops from high peak to low peak, the whole wind turbines are locked in inversion because the DC capacitor voltage is lower than the set value. At this time, the wind turbines are driven by the inertia of synchronous generators.

4.3 Simulation results of wind turbines connected to grid with load-side fault
The fault points are all located in the positions shown in Figure 3-11. The specific fault types can be set by adjusting the fault settings. All faults occur at 117s of simulation, and the time of fault removal is 1.5s after the fault occurs.
4.3.1 simulation results of single-phase grounding short-circuit fault on load side
Firstly, considering the single-phase grounding fault, the fault is located in phase A. The simulation time is 250s and the simulation step is 100us. The simulation results are shown in Figure 3-12.

Figure 3-11 Fault Module

Figure 3-12 Characteristic of grid-connected point and internal response of unit when single-phase grounding short-circuit fault occurs at load side
As can be seen from the figure, when single-phase grounding fault occurs on the load side, the selected fault time happens to be in the rising period of large wind speed. However, due to the large capacity of the system and its reliability, the fluctuation of active and reactive power caused by the grid-connected point is not very large. In order to facilitate the analysis of power flow fluctuation during fault, the active and reactive power of grid-connected points are analyzed by intercepting part of the fault time curve. However, there is no particularly large fluctuation in the unit when the fault occurs, which reflects the better stability control of the wind turbine itself.

4.3.2 Simulation results of three-phase short-circuit fault at load side

Next, we will discuss the three-phase short circuit fault which is the most serious of all fault types. The simulation time is 250s and the simulation step is 100us. The simulation results of grid-connected point characteristics and unit internal response are shown in Figure 3-13.

![Figure 3-13 Characteristic of grid-connected point and internal response of unit when three-phase short-circuit fault occurs on load side](image-url)

Combined with the analysis of the above figure, we can get that compared with other types of short-circuit faults, the three-phase grounding short-circuit fault on the load side has the greatest
impact on the active power, reactive power and voltage of the grid-connected point. Active power and reactive power are reduced to zero (the power curve is also the part of intercepting fault time), and the voltage is close to 0 kV in fault time. The internal speed of the unit is still very stable, without too much interference from external faults, and the response characteristics are relatively good.

5. Conclusion
Wind power started early and technology is relatively mature which has considerable market and huge development space in many new energy power generation systems with features of the most advanced concept, the most flexible regulation and the most powerful.

However, due to the volatility and randomness of wind energy itself, there are a series of problems when wind turbines are connected to the grid. Based on the analysis of the basic principles and characteristics of doubly fed and permanent magnet wind turbines, this article deeply explores the control method of wind turbines connected to the grid. According to this idea, a control strategy and its related principles of permanent magnet wind turbines connected to the grid are proposed. Based on this design, the nested PI control strategy is finally established, and the wind turbines are built using PSCAD/EMTDC power system simulation software. The network system model is used to simulate and analyze the grid-connected situation of wind turbines under four conditions: constant wind speed, fluctuating wind speed, single-phase grounding fault, two-phase grounding fault, two-wire short-circuit fault and three-phase short-circuit fault at load side. The grid-connected effect and internal response characteristics of wind turbines under various conditions are discussed, which shows that the grid-connected control of wind turbines has certain excellent characteristics.

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