Electromechanical Transient Modeling and LVVRT Parameter Identification of Large Capacity Full Power Converter Wind Turbines Based on PSASP Program

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Abstract—Full power converter wind turbine is the main type of wind power, so the simulation calculation needs to establish accurate model parameters. This paper analyzes the model structure of PSASP program according to its low voltage ride through control and physical characteristics, and puts forward the parameter identification method of LVVRT characteristics of full power converter wind turbine, and to use the LVVRT data of 5.5MW unit for parameter identification and simulation verification. This paper proposes that the electromechanical transient simulation can ignore the part of the generator model of the full power converter wind turbine, and simulates the grid side converter with the controlled current source. The main characteristics of LVVRT are determined by the control system of the converter. In order to do the parameter identification, it is necessary to calculate and analyze the control characteristics of multiple measured data. First, determine the control mode, then determine the control parameters to complete the parameter identification. In this paper, the modeling conditions and model structure of the full power converter wind turbine are confirmed. The correlation between the parameters during the LVVRT fault and the parameters during the LVVRT recovery period and the LVVRT characteristics is analyzed. In this paper, a parameter identification method is proposed to analyze the active current and reactive current during the LVVRT fault, which has strong physical significance and operability. Based on the actual LVVRT characteristics of 5.5MW wind turbine, the parameter identification and simulation are carried out to verify the correctness of the method.

1. Introduction

Wind power in China has developed rapidly in recent years. At present, it is mainly concentrated in the three north areas. A large number of wind turbines connected to the power grid will have an all-round impact on the power grid, including overvoltage, low voltage, power angle stability, dynamic stability and subsynchronous oscillation[1-10]. Electromechanical transient analysis is still the main technical means of power grid simulation. Large scale full power wind power access brings stability problems. Firstly, electromechanical transient analysis needs to be carried out. After finding the problems, electromagnetic transient analysis can be carried out according to the situation. Therefore, the electromechanical model parameters of wind turbine, especially the low voltage ride through
model parameters, are the basic conditions for accurate simulation. According to the current development trend, full power converter wind turbine is mainly used for full power wind power. For accurate simulation, it is necessary to identify the model parameters of typical high-capacity full power converter, especially the low-voltage ride through parameters.

Over the years, a lot of research has been carried out on the modeling and parameter identification of full power converter wind turbine and full power wind power at home and abroad [11-19], many test and identification methods are proposed. Based on the general model structure of direct drive permanent magnet wind turbine, document [14] proposes a method using particle swarm optimization algorithm for parameter identification, and obtains parameters with good adaptability, but it does not analyze multiple faults and is not related to the actual physical process. Reference [15] proposed a method to identify the model parameters of doubly fed induction generator based on short-circuit current, which can better identify some doubly fed machine parameters, but did not identify the LVRT model parameters. Reference [16] proposed a new method for decoupling identification of grid side control parameters of doubly fed wind turbine based on frequency domain method. Reference [17] proposed a frequency domain identification method for rotor side controller of doubly fed wind turbine by adding pseudo-random signal. However, in general, these documents mainly model and identify the parameters of the wind turbine, and do not measure and model the most important low-voltage ride through characteristics of the wind turbine. Therefore, their results can not solve the most urgent needs of simulation calculation.

Starting with the physical structure and general control logic of full power converter wind turbine, this paper analyzes the basic structure of full power converter wind turbine model in PSASP program. Finally, combined with the actual characteristics of LVRT, the simulation model parameters are identified, and the simulation measurement is checked, and more accurate results are obtained.

2. Control model of wind turbine with full power converter

The most considered faults in electromechanical transient simulation are various types of short-circuit faults, which are low-voltage ride through faults of various types and amplitudes for wind turbines. Therefore, in this sense, the accurate simulation of low-voltage ride through control is the most concerned in electromechanical transient simulation.

According to the above and PSASP instructions, the control logic of the grid side converter in electromechanical transient simulation is shown in Figure 5.

![Fig. 1 Overall diagram of converter control model](image)

1) The active power control model is shown in Figure 2. In the figure, $U_{dc, ref}$ is the DC voltage reference value, $U_{dc}$ is the DC voltage feedback value, $T_i$ is the DC voltage measurement time constant, $K_{pdc}$, $K_{idc}$ are the PI control parameter of the voltage outer loop, $I_{d,max}$, $I_{d,min}$ are the maximum and minimum limit amplitudes of the d-axis current, $I_{d,grid,ref}$ is the d-axis current command of the grid side current source. It can be seen from Figure 6 that the active power control of the grid side converter is not directly based on the active power command, but by maintaining the stability of the DC bus voltage. At the same time, it also controls the DC bus voltage to avoid deviation under normal operation;
2) The reactive power control model is shown in Figure 3, which is divided into two control modes. One is the terminal voltage control mode in the upper part, which calculates the reactive power setting value according to the deviation between the terminal voltage setting $V_{ref}$ and the terminal voltage feedback $V_{reg}$; There is also a more commonly used power factor control mode, as shown in the following half. According to the active power $P_{gen}$ and power factor $PF_{ref}$, the given value of reactive power under the current power is calculated. Further, the given value of reactive power is converted into reactive current value to control the q-axis current of grid side converter.

It is noted that the main steel beams of three specimens are supported at the support beam as shown in Fig. 1. Each secondary beam (steel channel)
3. Parameter identification of large capacity full power converter wind turbine

According to the above, the model parameters of wind turbine with full power converter mainly include two aspects:

1) Control parameters of active and reactive power in normal state; Normal state mainly refers to the operation state of voltage and current disturbance corresponding to the terminal voltage between 0.9-1.1 pu during non-LVRT and HVRT. Due to the principle of PQ decoupling control characteristics of wind turbine, this part of characteristics is generally difficult to be obtained by field test.

2) Control parameters of active and reactive power during LVRT. Because the most common faults in power grid are various short-circuit faults, the low-voltage ride through characteristics of wind turbine are the focus of simulation model.

According to the above analysis, the basic principles of parameter identification for large capacity full power converter wind turbine are as follows:

(1) Identification basis and method of control parameters of active and reactive power in normal state: it is difficult to carry out the measurement of these parameters because the wind turbine is normal. Therefore, it mainly refers to the design parameters provided by the manufacturer or the typical parameters provided by the simulation program;

(2) Identification basis of active and reactive power control parameters during LVRT: at present, the LVRT characteristics of wind turbine are mainly carried out by means of voltage drop on the primary side of the generator end with special equipment. This method has high requirements on equipment and high test cost, which is difficult to carry out in a large area. Another method is to connect the relevant control board to the digital analog hybrid simulation platform from the field, test the LVRT control characteristics of the corresponding control board through the test on the digital analog hybrid simulation platform, and carry out parameter identification on this basis. Therefore, the active and reactive power characteristics during LVRT are mainly identified according to the actual characteristics obtained by these two ways.

(3) Identification method of active and reactive power control parameters during LVRT: combined with the active power control structure introduced in the first part of this paper, the measured LVRT process is divided into two parts: fault period and fault recovery. The power and voltage in the two processes are used to convert the current, calculate the unit value of the corresponding active current and reactive current and the corresponding current limit value, and take values based on the calculation results of multiple faults to form stable calculation parameters.

Compared with the doubly fed wind turbine, the large-capacity full power converter wind turbine has been simplified more, but there are still many model parameters, and the parameters are interrelated, so the identification work must be carried out carefully. Combined with the measured characteristics, even if only the LVRT characteristics are considered, there are still up to 16 or even 20 tests to be compared according to the requirements of relevant standards. Each test includes two groups of active and reactive curves, and a total of 32 groups of curves are required to be compared. Finally, up to 32 groups of curves need to be accurately simulated with a set of parameters.

Therefore, the basic flow of wind turbine parameters for large capacity full power converter is as follows:

1) Determine the basic control mode based on the manufacturer's design data and the communication with the manufacturer on the normal / LVRT control strategy;

2) According to the measured characteristics of LVRT, the key control parameters are calculated and analyzed. If the parameters under different working conditions are inconsistent, it is necessary to further verify with the manufacturer and consider the consideration of parameter value;

3) Combined with the measured characteristics of LVRT, the simulation results of model parameters are checked and improved to ensure the accuracy of simulation results.

The standard LVRT characteristics under 16 working conditions are shown in Table 1.
Table 1 6 Typical fault conditions

| No | Voltage dip pu. | Fault time ms | Fault type      | Power level |
|----|-----------------|---------------|-----------------|-------------|
| 1  | 0. 20           | 625           | 3phase/2phase   | Full power  |
| 2  | 0. 35           | 920           | 3phase/2phase   | Full power  |
| 3  | 0. 50           | 1214          | 3phase/2phase   | Full power  |
| 4  | 0. 75           | 1705          | 3phase/2phase   | Full power  |
| 5  | 0. 20           | 625           | 3phase/2phase   | Small power |
| 6  | 0. 35           | 920           | 3phase/2phase   | Small power |
| 7  | 0. 50           | 1214          | 3phase/2phase   | Small power |
| 8  | 0. 75           | 1705          | 3phase/2phase   | Small power |

The measured active power characteristics of the three-phase symmetrical fault of the wind turbine are shown in Fig.5 and Fig.6.

Fig. 5 100% and 20% power three-phase fault, LVRT characteristics

Identify the model parameters of the process. According to the identification principles in the third part of this paper, first determine the active control strategy, and calculate the active and reactive current during the LVRT process, as shown in Table 3.

Table 2 Analysis of active and reactive power characteristics of symmetrical fault

| No | Voltage dip pu. | IP. pu. | IQ. pu. | I. pu. | Power level |
|----|-----------------|---------|---------|--------|-------------|
| 1  | 0. 20           | 0. 7    | 1. 43   | 1. 59  | Full power  |
| 2  | 0. 35           | 0. 7    | 1. 45   | 1. 61  | Full power  |
| 3  | 0. 50           | 0. 7    | 1. 45   | 1. 61  | Full power  |
| 4  | 0. 75           | 1. 34   | 0. 79   | 1. 55  | Full power  |
| 5  | 0. 20           | 0. 7    | 1. 43   | 1. 59  | Small power |
| 6  | 0. 35           | 0. 4    | 1. 45   | 1. 51  | Small power |
| 7  | 0. 50           | 0. 29   | 1. 44   | 1. 47  | Small power |
| 8  | 0. 75           | 0. 26   | 0. 77   | 0. 81  | Small power |
The data in Table 2 are analyzed as follows:
1) The active current is not a fixed value in the process of LVRT, so the power control mode should be selected for the active current in the process of LVRT;
2) The maximum unit value of reactive current is about 1.45, and the maximum value of total current is about 1.61. It is determined that the active and reactive current control in the process of LVRT is reactive priority, that is, the current capacity of the converter is allocated according to the reactive demand first, and the remaining capacity is allocated to the active power control;
3) To sum up, it is determined that reactive power is preferred in the process of LVRT, active power is constant power control, reactive current limit value is 1.45, total current limit value is 1.61, and the corresponding calculated active current limit value is 0.7.

Determine the reactive power control strategy, and calculate the reactive power characteristics in the process of symmetrical fault, as shown in Table 3:

| No | Voltage dip pu. | 0.9-V Fault pu. | IQ. pu. | Kq pu. | Power level |
|----|-----------------|-----------------|--------|-------|-------------|
| 1  | 0.20            | 0.7             | 1.43   | 1.99  | Full power  |
| 2  | 0.35            | 0.55            | 1.45   | 2.69  | Full power  |
| 3  | 0.50            | 0.4             | 1.45   | 3.59  | Full power  |
| 4  | 0.75            | 0.15            | 0.79   | 5.28  | Full power  |
| 5  | 0.20            | 0.7             | 1.43   | 1.99  | Small power |
| 6  | 0.35            | 0.55            | 1.45   | 2.7   | Small power |
| 7  | 0.50            | 0.4             | 1.44   | 3.6   | Small power |
| 8  | 0.75            | 0.15            | 0.77   | 5.31  | Small power |

The data in Table 4 are analyzed as follows:
1) The maximum limit value of reactive current is 1.45;
2) The control coefficient of reactive current for different faults is inconsistent, and the maximum value is 5.31. Considering that for other faults, 5.31 multiplied by 0.9-voltage in column 3 in the table will exceed the reactive current limit value of 1.45, which is still consistent with the actual situation, so the reactive current control coefficient can be taken as 5.31.

To sum up, the identification results of active and reactive power control under symmetrical fault are summarized as follows:
1) The active power is constant power control, and the limit value of active current needs to be further determined in combination with asymmetric fault;
2) The reactive current control coefficient is 5.31 and the current limit value is 1.45.

Using the above parameters for simulation verification, the comparison curve between the three-phase fault simulation results and the measured results is shown in Figure 6, which is in good agreement.

![Fig. 6 Active and reactive power simulation vs. measurement](image-url)
1) The active power is controlled by constant power, the limit value of active current is 0.7 for symmetrical fault and 1.26 for asymmetric fault, and the value is 1.26 after comprehensive consideration;
2) The reactive current control coefficient is 5.31 and the current limit value is 1.45.
3) During LVRT, the control is reactive power priority.

From the above analysis, simulation and measured comparison, according to the comparative analysis of measured characteristics of LVRT, the control mode and parameters of large capacity full power converter wind turbine can be determined, and the actual characteristics of wind turbine can be accurately simulated with a set of parameters.

4. Conclusion
Based on the results and discussions presented above, the conclusions are obtained as below:
(1) The electromechanical transient simulation model of large capacity full power converter wind turbine generator ignores the generator, considers the converter as the controlled current source, and takes the active and reactive power control commands as the current directly injected into the power grid, which is more simplified than the physical device;
(2) Large capacity full power converter wind turbines generally use generator double windings and two converters in parallel to achieve high power. In the actual modeling process, the two converters need to be combined and equivalent. This paper deduces the relevant equivalent method;
(3) Based on the actual characteristics of wind turbine LVRT, combined with the manufacturer's LVRT design strategy, the key model parameters of LVRT in the simulation model are identified by analyzing the active current and reactive current in various faults. The method has strong physical significance and small amount of calculation. The identification results can accurately simulate the active and reactive power characteristics of multiple working conditions, and solve the problem of LVRT characteristic identification and accurate simulation, which is the most key problem in power system simulation.

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