Requirement Analysis of Wind Turbine High Voltage Ride-through Capability Detection and Simulation

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Abstract. With the number of wind farms connected to the power system increasing rapidly, the impact of wind power generation system on power grid system stability is becoming increasingly prominent. Especially when the power grid has transient fault, there will be problems such as reverse power flow, large-area power failure of wind farm and so on. This will directly lead to the power system instability and seriously affect the power grid security and stability. Especially in the stage of voltage recovery after the fault is eliminated, the low-voltage fault of the power grid might lead to a sharp rise in the voltage of power grid and overvoltage on the high-voltage line connected to the power grid with wind farm, resulting in the disconnection of the wind power grid connected system. However, China's current standards do not specify the high-voltage crossing of wind power grid connected system, especially the high-voltage crossing detection device, detection method and detection procedure. Therefore, it is urgent to study the detection technology of wind power high voltage crossing and put forward the detection method. There are many reasons for high-voltage power grid fault, and the interaction between power grid and inverter is more complex in high-voltage fault. If the type test method is used to simulate various high-voltage fault conditions in power system and carry out the test and study on the HVRT (high voltage ride through) performance of wind turbine, the human and material cost is huge and there are many potential safety hazards. At the same time, the grid connection performance of wind turbines are largely related to the control strategy of the controller. Therefore, the semi physical simulation method can be used to research the HVRT detection technology of wind turbine. This can effectively avoid the safety problem of large current and high voltage in the primary circuit, and realize the physical connection between the real controller and the flexible high voltage fault platform model through hardware in the loop simulation. It can simulate the wind turbine capability of high-voltage ride through under various high-voltage fault conditions. It not only has low test cost, but also can deeply study the interaction between power grid and power grid.

1. Introduction
With the number of wind farms connected to the power system increasing rapidly, the impact of wind energy generation systems on the stability of the grid has become increasingly prominent. Especially when there is a transient fault in the power system there are many problems such as reverse power flow and large-scale disconnection of wind farms. This will directly lead to the instability of the power grid and seriously affect the stability and security of the electric power system. With the occurrence of several large mount of wind power off-grid accidents, the LVRT (low voltage ride through) problem of wind farms has attracted great attention from countries all over the world. The China national standard...
GB 19963 "Technical Regulations for Connecting Wind Power to Power Systems" puts forward wind farms capability requirements of fault ride through, the dynamic reactive current compensation amount and active/reactive power recovery speed during the LVRT process when the power grid falls at different depths are clearly defined. However, during the stage of voltage recovery after the fault was eliminated, the power grid low-voltage fault might cause the grid voltage to rise sharply and the over-voltage occurs on the high-voltage line connected to the power system with wind farm, and then cause the wind power grid-connected system to disconnect. For the power system operational safety improvement, some grid operators in foreign country have formulated or under formulating grid-connected technical regulations or grid guidelines based on the characteristics of each grid own design, stable and safe operation and control requirements. These guidelines make clear provisions for high-voltage and low-voltage crossing boundaries of wind power grid-connected systems. Currently, China's current standards do not make clear provisions for HVRT capability of wind power generation that connected to the systems, especially for HVRT detection devices, detection methods, and detection procedures. Therefore, it is urgent to carry out research on HVRT detection technology and propose detection methods of wind turbines.

There are many reasons for high-voltage grid failures, and the interaction between the grid and the inverter during high-voltage failures is more complicated. If the method of type test is used to simulate various power grid high voltage fault conditions to carry out the test research on the HVRT performance of wind power, the manpower and material costs are huge, and there are many potential safety hazards. Meanwhile, the wind turbines grid-connected performance is largely related to the controller control strategy. Therefore, half-physical simulation methods can be used to carry out research on wind turbine high voltage ride-through detection technology. This can effectively avoid the safety problems of high voltage and large current in the primary loop, and realize the physical connection of the real controller and the flexible high-voltage fault platform model through the hardware-in-the-loop simulation. It is able to carry out simulation experiments on the capability of wind turbines HVRT under various high-voltage fault conditions, which not only has low test costs, but also enables more in-depth research of the interaction between the wind turbines and grid under high-voltage fault conditions. These work will provide test platform support for the growing of HVRT detection methods and detection procedures for wind turbines.

2. Research Status and Progress

2.1. International

For improvement of the power system operational safety, grid operators have formulated renewable energy grid-connected technical regulations based on the control requirements and stable operation.

- The renewable power plant should not disconnect from the power system within the voltage boundary.
- Within this voltage boundary, the renewable power plant should not adversely affect the maintenance capability of system voltage.
- The voltage ride-through is aimed at the step-up transformer high-voltage side of the renewable power plant. The voltage ride-through requirement is determined by the ride-through performance of the generator or the installation of additional voltage control devices (such as STATCOM, SVC, etc.) and dynamic reactive power by the power generation company.

Foreign grid guidelines and standards mainly come from mainstream power alliances or grid operators in Europe and America. Including AESO in Canada, AEMC in Australia, Energinet.dk, Eltra&Elkraft in Denmark, and EIRGRID in Ireland. They have detailed technical requirements and standard specifications in terms of HVRT and LVRT. The structure and characteristics of power systems in different regions and countries are very different, and there are also certain differences in the degree of overvoltages that occur on the lines. If we using the New Zealand National Grid as a reference, in the light of its investigation report of generators fault ride-through released in February
2009, the voltage of its 110kV and 220kV lines might rise to 1.3pu after a fault, and could recover to 1.2pu within 0.5s. It might recover to 1.1pu within 1s, and it could reach 1.43pu near the HVDC terminal voltage. WECC in the United States, Energinet.dk in Denmark, Scottish Power in Scotland require HVRT capability in 1.2pu for wind power. And also, Energinet.dk requires the wind farm to have the capability of ride-through is 0.2s when the grid connection point voltage is 1.2pu. Scottish Power requires the wind farm to have a continuous 1.2pu capability of HVRT when connected to a 132kV line, and a continuous 1.15pu capability of HVRT when connected to a 275kV line.

For HVRT detection devices, there are four main types proposed in the existing literature, namely synchronous generator type, inductance capacitor voltage divider type, transformer type and simulated grid type. Literature [1] selects a 15k diesel-powered synchronous generator as the fault ride-through detection device. Due to the size and weight of the high hardware and the diesel engine cost of the synchronous generators, and only symmetrical voltage faults can be simulated. Literature [2] selects a HVRT detection device composed of thyristors, inductors, and capacitors to test the HVRT of wind turbines. Literature [3] considers the design of switching actions during overvoltage and overcurrent, selects the topology of a transformer-type fault ride-through detection device, designs and tests a 30KW transformer-type fault ride-through detection device, and obtains good dynamic and static performance. Literature [4, 5] uses four-quadrant power electronic devices to form a simulated power grid, and simulated low-voltage and high-voltage faults occur.

### 2.2. National

At present, study on high-voltage ride-through mainly focuses on wind energy control strategies in China. Unlike the relatively mature technology of low-voltage ride-through, voltage swells are actually a common grid abnormality. This phenomenon usually occurs when there is excess reactive power in the grid [6], especially in wind farms equipped with reactive power compensation devices. Under normal circumstances, reactive power is in dynamic equilibrium, but when the grid voltage drops, it will often cause some wind turbines with no LVRT capability are disconnected from the grid. In that time, if the compensation device of reactive power is not adjusted in time, it will cause excess reactive power in the grid, that will increase the grid-connected point voltage. For ensure the stable and safe of the power system operation, the State Grid Corporation of China has gradually put forward relevant requirements for the wind turbines HVRT capability. Among them, the State Grid Adjustment (2011) No. 974 "Key Points on Anti-accident Measures for Initiating Wind Power Grid Operation" clearly put forward the requirement that "wind turbines should have the necessary capability of HVRT ", and proposed " The response speed of wind farm reactive power dynamic adjustment should match the wind turbine HVRT capability to ensure that the wind turbine will not be disconnected from the power grid due to high voltage during the adjustment process". The newly revised " The State Grid Corporation of China Eighteen Major Grid Anti-accident Measures " also pointed out that " as prescribed by regulations, that wind turbines should have LVRT capability and necessary high voltage withstand capability. "NB T 31099 " Technical Regulations for Reactive Power Configuration and Voltage Control of Wind Power Plants" puts forward requirements for the HVRT technical indicators of wind turbines [7-8]. Literature [9-11] analyzed the two mainstream wind turbines characteristics of transient. When the grid voltage swells, and whether the wind turbines have HVRT capability has a direct big impact on the stability of the grid. Literature [12] initially studied the doubly-fed wind turbine transient process s and their improved control schemes when the grid voltage surges. Aiming at the insufficient control bandwidth and dynamic response performance of traditional PI regulators, rotor excitation control strategies based on virtual impedance and variable damping are respectively proposed. It shortens the rotor oscillation process when the grid voltage changed, and improves the system HVRT performance of to a certain extent.

For HVRT detection device, literature [13] currently has a wind turbine HVRT test device. The device uses a converter constructed with power electronic devices. The converter is composed of a DC link, a rectifier and an inverter. The converter was connected in series between the power grid and the wind turbine under test. Finally, the output voltage of the inverter side of the converter is changed by
controlling the on and off of the power electronic devices, so as to realize the simulation test of the different voltage level faults of the tested wind turbine. Literature [14] proposes a scheme based on current-limiting impedance and fast control capacitors to more realistically simulate high-voltage faults in the power grid.

3. Requirement Analysis and Implementation Plan

3.1. Requirement Analysis
Through the development of related research, it is urgent to establish a semi-physical simulation test platform for the wind turbines HVRT capability to conduct pre-test and simulation analysis on the wind turbines HVRT capability. By studying the implementation of HVRT device, the detection method is finally proposed to optimize the detection process. The requirement analysis is shown in figure 1.

- Study the mechanism and typical fault characteristics of high voltage generation in the power grid, and study the typical electrical topology and high voltage implementation methods of wind turbine HVRT detection devices.
- Establish a model of a HVRT detection device. And compare and analyze the impact of various detection devices on the HVRT test.
- Establish a multi-time scale simulation model for the primary loop of HVRT including wind turbines, typical topology models of wind turbine inverters, HVRT detection device models, and grid models.
- Realize the physical docking of the wind turbine HVRT simulation model and the inverter controller through the simulation physical interface of hardware-in-the-loop. And carry out the HVR simulation test of hardware-in-the-loop on the real wind turbine inverter controller.
- Change the inverter control algorithm of wind turbines. And study the interaction between different wind turbines grid-connected control characteristics and the grid under high-voltage conditions.
- Research the high voltage ride-through detection method and detection process, and use the half-physical simulation method to carry out the closed-loop test of the wind turbines high-voltage ride-through capability.

3.2. Implementation Plan
For wind turbines to carry out capability of high-voltage ride-through tests and simulations, power electronic grid-connected power generation devices are required to simulate the grid-connected conditions of real units, mainly including simulation test source models, inverter power loop models, and high voltage ride-through detection devices Models and other models. The hardware connection of the simulation platform with hardware-in-the-loop mainly includes the physical connection between the emulator and the device under test and the selection of the linear transformation unit. On this basis, it is possible to carry out the joint debugging work of the HVRT capability semi-physical simulation platform, and improve the model based on the joint debugging results, and finally propose a HVRT detection method, and carry out the HVRT semi-physical simulation test, which is the follow-up test procedure. Formulated to provide strong support.

The HVRT hardware-in-the-loop platform in figure 2, which mainly includes the determination of the overall construction plan, the establishment of simulation model of hardware-in-the-loop, the connection of the simulation hardware platform of hardware-in-the-loop, the study of HVRT detection methods, and the development simulation tests of HVRT hardware-in-the-loop.

![Hardware-in-the-loop simulation platform](image)

**Figure 2.** The implementation plan of the hardware-in-the-loop simulation platform.

4. Conclusion
When carrying out research on HV Ride-through capability semi-physical simulation test technology, how to construct HVRT detection device semi-physical simulation model requires full consideration of the manifestations of high voltage faults, so that the HVRT detection device model can fully reflect the fault characteristics of the power grid. Constructing a hardware-in-the-loop simulation model of the detection device by HVRT and the power grid, realizing the simulation test of the real wind turbine inverter controller through the simulation physical interface, and establishing a high-voltage ride-through simulation detection platform is a hot spot in future research.

Acknowledgments
The work is supported by the National Key R&D Program of China: (2018YFB1501305) and China Huaneng Group Science and Technology Fund: (HNKJ19-H16)
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