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Progress in research on relay protection of the power system with large-scale wind power access

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Abstract: This paper explores the relay protection of the power grid with large-scale wind power access across the globe. First, the amplitude and attenuation characteristics of short circuit current in different types of wind turbines are analyzed, as well as the contributing factors to short-circuit current in wind farms. Second, the fault characteristics and corresponding protection strategies of the collector circuit in the wind power plant are discussed. Then, in view of the adaptability of HVDC protection to the grid power with wind power access, the performance of zero-sequence protection, reclosing and distance III section and the corresponding countermeasures are analyzed. Finally, suggestions for the directions of further research are proposed: strengthening research on fault characteristics of wind turbines; performing general electromagnetic transient modeling of wind turbines for protection; developing new principles and technologies of network protection applicable to protection of wind farm collector buses and networks; and strengthening collaborations between wind farms and power grids in protection and control to solve the problems in relay protection.

1. Principle of relay protection technology

Relay protection, the most important measure of defense for the safe and stable operation of the power grid, can quickly and reliably identify and isolate faults when a fault occurs, which is of great significance to contain the further deterioration of the power system operation and ensure efficient and stable transmission and utilization of electric energy[1]. In recent years, as energy crises and environmental problems grow increasingly prominent, wind power and other forms of renewable energy draw more and more attention from the society. Widespread use of wind power is bound to result in centralized access, long-distance transmission, and networking of the internal collector bus in wind farms, thus changing the operation landscape of the power grid.

Relay protection of the power grid with large-scale wind power access is in essence a problem of compatibility with the smart grid. For the access point, large-scale wind farms have much more significant impacts on the power system operation than smaller wind farms do, because the former not only affects the overall scheduling of wind power, but causes significant changes in the fault characteristics in relay protection. Most internal units and groups of large wind farms are networked to collect electric energy at a preset voltage of 35 kV. Whether the principle and devices for protection of the traditional power distribution network can meet the requirements of the internal collector bus of wind farms is also a question that many power farm owners and power system operators must consider.

To ensure the safety of the power grid with large-scale wind power access, scholars around the world have studied the relay protection of the power grid with wind power access from varied perspectives.

1.1. Fault characteristics of wind turbines and wind farms.

The induction generator is widely used in most wind turbines, because its moment of inertia and time constant is small, and needs no special excitation devices; and its fault characteristics are significantly different from synchronous generators. Although the permanent magnet direct drive unit is a synchronous generator, its fault characteristics are closely related to the control characteristics of the converter through the grid-connected converter. In addition, the special requirements of power electronic equipment, such as protection strategies and cross-feed of low voltages, also attach additional control requirements. These will complex the electromagnetic transient process of the wind turbine, affecting the performance of the relay protection[2].

Analysis of fault characteristics of wind turbines and wind farms mainly includes transient and steady-state short-circuit current calculation, analysis of the waveform, attenuation characteristics and short-circuit impedance.

1.2. Relay protection of collector buses and networks in wind power plants.

Although 35 kV is the dominating voltage for most internal collector buses in large wind power plants, it is obviously different from the radial network architecture of traditional distribution network. For any collector bus, the power distributes on both sides of the bus, which is equivalent to a double-ended power supply element in the study of relay protection. In this case, the configuration and setting principles for relay protection in the traditional radial distribution network no longer applies.

The research on protection of the collector buses and networks in wind power plants mainly includes the protection principle, protection configuration, setting principle and the cooperative relationship with the network protection.

1.3. Relay protection of the power grid with large-scale wind power connected to the transmission network.

In most countries including China, the large-scale Implementation of wind power is inevitably accompanied by the problem of long-distance centralized transmission of electric energy. Therefore, the fault characteristics of random power sources such as wind power must be considered in the configuration and operation of high-voltage grid relay protection. The influence of randomness and volatility of wind power on protection of lines interconnected to the power grid, the adaptability and configuration of relay protection, and the new principles for excellent performance all need to be further studied[3].

The problem of connecting large-scale wind power to the grid has become a hot research topic around the world, but issues related to relay protection have not received enough attention. The author believes that one of the reasons is that relay protection serves the safe operation of power grid, and the problem of relay protection has not been shown on a large scale at present. With problems regarding the dispatch and operation mode of wind power solved, wind power is bound to see an increased proportion it takes for power supply in the grid, so the adaptability of relay protection when large-scale wind power is connected to the grid deserves more attention and further exploration.

In this study, existing works on the fault characteristics of wind turbines and wind farms, the relay protection of wind farm collector networks, and the relay protection of high-voltage grid with large-scale wind power access are reviewed, the direction for further studies is pointed out, and the author's views are put forth with a view to providing possible solutions to existing problems in relay protection and some inspiration for further research in this regard[4].

2. Fault characteristics of wind turbines and wind farms

2.1. Overview

Fault analysis is the basis of relay protection as it underlies the determination of new principles for the design, configuration and calculation of relay protection. The traditional theoretical system of relay protection is based on synchronous generator power supply and the three-phase symmetrical system. In other words, it is assumed that the synchronous generator can act as an ideal power source without any changes in the parameters and the running state in the electromagnetic transient process after the fault occurs. Based on it, the short-circuit current and its attenuation characteristics can be calculated, which can be used as the basis for the design and setting of relay protection principle and the selection of circuit breakers.

Asynchronous generators are widely used in wind turbines, and even permanent magnet synchronous generators are grid-connected with power electronic equipment. Obviously, the magnitude of short-circuit current and fault characteristics have changed significantly[5].

Table 1: High voltage DC relay market statistics

	Shanghai Aishi	Panasonic	BYD	Hongfa Stock	other
proportion	20%	31%	13%	23%	12%

In table 1, in terms of the current market share of high-voltage DC relay, Shanghai Asahi Co., Ltd. accounts for 20%, Panasonic Co., Ltd. accounts for 31%, BYD Co., Ltd. accounts for 13% and Hongfa Co., Ltd. accounts for 23%.

2.2 Calculation of short-circuit current in wind turbines

2.2.1. Induction generator

Calculation of short-circuit current of induction generators is not a new problem. Morren and de Haan [2] deduced the analytical expression of short circuit current when stator three-phase short circuit occurs in an off-load induction wind generator. Based on the assumption that winding resistance can be ignored and slip is small during normal operation of the induction generator, it is concluded that the difference between the stator flux and the rotor flux is 180 ° after half a cycle of short circuit. On this basis, the analytical expression and attenuation rule of the maximum short-circuit current are derived. The error of the maximum short-circuit current obtained in this paper can reach 10% ~ 20%. On the basis of the same assumption, the analytical expression of the short-circuit current for the squirrel-cage induction generator is derived by using the space vector analysis method proposed in literature [3]. It is worth noting that the short-circuit current of the induction generator under the asymmetric short circuit is analyzed by using the sequence component theory in [3]. The results have positive significance for the analysis of the relay protection performance and the sensitivity verification.

Samaan et al. [4] simulated and analyzed the short circuit current of induction generators by the Power Factory software package, and their conclusion was the same as those reached in [2-3], that is, the induction generator injects considerable fault current into the power grid when a fault occurs, and the current gradually decreases as the fault lasts, and the decay time is related to the fault type. For three-phase faults, the attenuation is the most rapid.

Ouhrouche [5] took into account the role of prime motor and its control system when analyzing the short-circuit current of induction generators by the RT-LAB software package of a real-time simulation platform of power systems. His conclusion is not specifically aimed at relay protection, but the simulation results can still verify the correctness of the analysis in [3], that is, in the case of short circuit between phases, the short-circuit current of the non-fault phase increases slowly to the steady-state value, while the short-circuit current in the fault phase gradually attenuates.

2.2.2. Doubly-fed asynchronous generator

The short-circuit current analysis of the doubly-fed induction generator is a research hotspot in recent years. The slip of the doubly-fed induction generator can no longer be considered as a small value due to the rotor current control. The resistance of the rotor circuit cannot be ignored because of the crowbar resistance in the external short circuit. Morren and de Haan [2] considered the abovementioned factors and the phase relationship between the stator and rotor fluxes after the occurrence of short circuit, and deduced the factors of circuit fault characteristics. The research results in show that the fault current in three-phase short-circuit is most 8 times of the rated current, and the fault current curves of two-phase short-circuit and single-phase short-circuit are drawn, and it is concluded that the fault current amplitude cannot be used as a method to judge the fault type.

3. Summary and recommendations

For connection of large-scale wind power to the power grid, there are problems in varied aspects to be solved. For relay protection, the concern is not only the amplitude of the fault current, but also the waveform characteristics of the fault current, as well as factors of the power system such as positive and negative sequence impedance that affect the existing protection principle.

The waveform and transient harmonic content of short circuit current will affect power frequency protection based on the Fourier algorithm, and then cause protection rejection or maloperation, which poses a threat to the safety of the power grid.

The control strategy of doubly-fed and direct-driven wind turbines will directly affect the fault characteristics such as amplitude and attenuation of the fault current. So far, crowbar protection has been fully considered in fault current calculation and fault analysis. Due to the specific control strategy involved, the short-circuit current characteristics of permanent magnet direct drive wind turbines have not been fully studied. The control system is regarded as a technical secret by most manufacturing enterprises. It can be predicted that if permanent magnet direct drive wind turbines become the main models of large-scale wind farms, the relay protection will be faced with a more difficult situation than before due to the inability to fully grasp the fault characteristics.

Utilizing electromagnetic transient simulation to study fault current and fault characteristics provides a feasible solution to this problem, but there are still obstacles in the control strategy.

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