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A novel adaptive distance protection scheme for DFIG wind farm collector lines

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ABSTRACT

In view of the sensitivity and selectivity problems in DFIG (doubly-fed induction generator) wind farm collector line protection, a new adaptive distance protection scheme is proposed. First, according to the geometric distribution characteristics of the collector line voltage and current, the equation of voltage drop from the relaying point to the fault point is established and the adaptive setting coefficient is calculated. On this basis, a new adaptive distance protection criterion is formed according to the phase relationship between the fault current and the measured current. Wind farm simulation tests on RTDS verify that, the proposed method is well adaptable to different operation modes, strongly immune to the fault resistance and unaffected by the weak feed characteristics of the wind generator collector system.

1. Introduction

With the large-scale access of wind power into the grid, wind farm relay protection has received more and more attention. Currently, study is mainly focused on the protection of wind farm high-voltage sending lines [1–14], and research on the protection of wind farm low-voltage collector lines is relatively rare [15–20]. In fact, the probability of fault occurrence on the collector lines is higher than the probability of fault occurrence on the high-voltage sending lines. And without proper treatment, collector line fault will probably cause multiple wind farms to trip off the grid. Therefore, it is of great importance to study in depth the protection of wind farm collector lines and propose a feasible protection scheme, so that the safety and stability of the power grid can be guaranteed. The traditional relay protection is always equipped with single-ended protection component at the bus-side of the collector line, mostly two-stage current protection. But the two-stage current protection installed on the collector line generally does not have selectivity [21]. When a fault occurs on the high-voltage side of one box transformer, the two-stage current protection will override trip and enlarge the fault range, because the step one of the two-stage current protection cannot judge whether the fault occurs on the collector line or the high-voltage side of the box transformer.

In recent years, there are excellent propositions for adaptive distance relaying available in literature without wind farm. Ref. [22] establishes the protection scheme from the perspective of eliminating the effect of fault resistance on the measured impedance. By compensating for the fault supplementary impedance caused by fault resistance, the measured impedance could accurately reflect the impedance from the fault point to the relaying point. In Ref. [23], the actual fault location is calculated first, and then it is determined whether the fault location falls in the protection setting range, so that in-zone faults could be identified. Ref. [24] calculates the line fault impedance by constructing an artificial neural network. Ref. [25] establishes a digital distance protection scheme by comparing the measured impedances of different phases. Ref. [26] presents an extreme learning machine based fast and accurate adaptive distance relaying scheme for transmission lines in the presence of a static synchronous series compensator. An algorithm by combining resistance magnitude and volt-ampere characteristics of fault resistances for fault cause identification has been proposed in Refs. [27]. A new digital distance relaying algorithm is presented for the compensation of errors produced by the conventional digital distance relay during a high-resistance single line-to-ground fault in Ref. [28]. And only a few literatures have conducted research on the protection of wind farm collector lines. Ref. [15] studied the internal faults of multi-terminal dc wind farm collection grid in detail, and put forward a new protection scheme that use the dc-link voltage change to separate ac fault from dc faults and fault over-current for fault-type identification and detection, in which the radial wind

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farm topology with star or string connection is considered. Ref. [16] proposed a protection relay scheme for wind farms, which provides short-circuit protection for a medium-voltage collection circuit and the medium-voltage (MV) and low-voltage (LV) windings of the generator-transformers connected to it. Ref. [17] provides a new approach of capturing adaptively the dominant transient frequency band based on amplitude-frequency analysis to judge the state of lines. In Refs. [18,19], a new current-voltage protection scheme and an adaptive current quick protection scheme for wind farm collector lines are proposed respectively, both of which consider the polymorphism of wind generator short circuit current, and could meet the requirement of LVRT operation. However, in the above protection schemes, some simplify the wind generator collector system as load or synchronous generator, some require real-time synchronous data, some do not consider the influence of wind generator crowbar protection, others do not install protection on the collector system side, thus when fault occurs on collector lines, the wind farm side will not be able to isolate the fault lines effectively.

In view of the above problems, a new adaptive distance protection scheme for DFIG (doubly-fed induction generator) wind farm collector lines is proposed in this paper. First, according to the geometric distribution characteristics of wind farm collector line voltage and current, the equation of voltage drop from the relaying point to the fault point is established and the adaptive setting coefficient is calculated. And then, the adaptive distance protection criterion is formed according to the phase relationship between the fault current and the measured current. Since the voltage drop equation is not related with the fault resistance, the influence of fault resistance on adaptive distance protection criterion can be totally eliminated. Wind farm simulation tests on RTDS verify the correctness and effectiveness of the proposed method.

2. Adaptive distance protection scheme for wind farm collector lines

2.1. Problems in protection configuration of wind farm collector lines

In the wind farm, the wind generator collector system will parallel the high-voltage sides of the step-up transformers of 5–10 adjacent generators with a cable, and then transmit them via a 10 kV or 35 kV collector line to the wind farm step-up substation. The problems in current wind farm collector line protection are listed below.

(1) Poor selectivity. Due to the weak feed characteristics of wind generator, the proportion of positive and negative sequence components is much smaller than the proportion of zero sequence component in the collector system side short circuit current. Thus traditional distance protection may operate incorrectly. Meanwhile, since the lengths of the collector lines differ from one another, it is not easy for the setting values of line distance protection to cooperate with each other, thus poor selectivity may result.

(2) Low sensitivity. The wind farm collector lines are grounded via resistance or arc suppression coil [29,30]. When fault occurs, the fault resistance will greatly affect the operation performance of distance protection.

Based on the above analysis, it is difficult for wind farm collector line protection to clear the fault fast and accurately. Therefore, it is necessary to study new protection schemes to guarantee the safe operation of wind farm and power grid.

2.2. Adaptive distance protection configuration of wind farm collector lines

The main wiring and relay protection configuration diagram of wind farm is shown in Fig. 1. As can be seen, the high-voltage sides of the box transformers of 3–8 wind generators are paralleled (according to the principle of proximity), and then via a 35 kV collector line they are transmitted to the step-up substation. In the step-up substation, the collected power is boosted to 110 kV (or 220 kV), and then connected to power system.

When fault occurs on the collector line of the wind farm shown in Fig. 1, the distance protection analysis model as shown in Fig. 2 can be established. In Fig. 2, M is the collector system side, the equivalent system voltage being $\dot{E}_S$; N is the grid side, the equivalent system voltage being $\dot{E}_R$. The equivalent system impedance of each side is Z_S and Z_R respectively. Take the protection on the collector system side for example, the protection setting range is MP, setting value is Z_{set}. F is the fault point, and Z is the positive sequence impedance of the line length from fault point to the relaying point.

In Fig. 1, the left side of the collector line is the wind generator, and the right side is the schematic diagram of its integration to the high-voltage power system via electrical devices such as the step-up transformer and out-going lines. To facilitate analysis, Fig. 2 replaces the wind generators on the left side of the collector line in Fig. 1 with an equivalent voltage source in series connection with an equivalent impedance, and the right side of the collector line in Fig. 2 is the power system which consists of the 330 kV power system in Fig. 1 and transmission line and boost transformer and 35 kV bus.

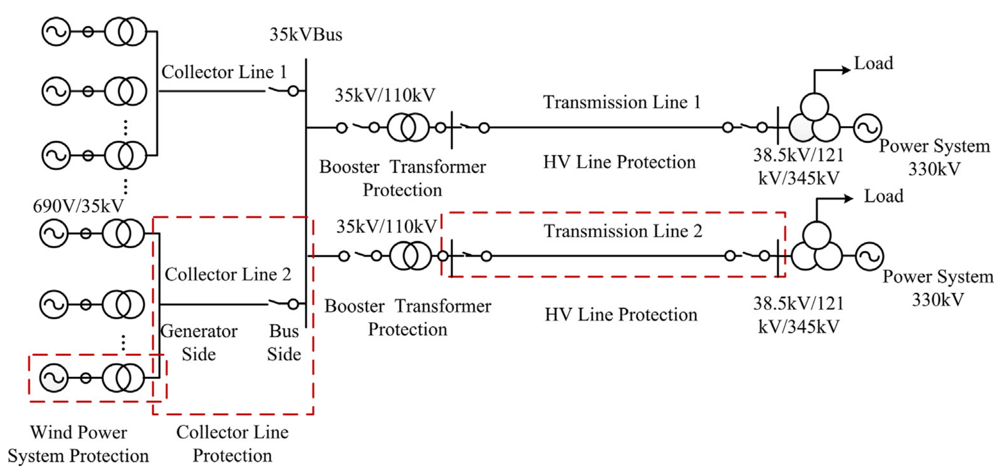

Fig. 1. Wind farm main wiring diagram and relay protection configuration.