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Distance-differential protection of transmission lines connected to wind farms

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ABSTRACT

Distance relays are often used in the protection of the transmission lines connected to the wind farms. The distance relay using the transmission line impedance measurement identifies the type and location of the fault. However any other factors that cause the failure of the measured impedance, makes the relay detect the fault in incorrect location or do not detect the fault at all. One of these factors is the fault resistance which directly increases the measured impedance by the relay. One of the methods to eliminate relay under-reach effect is using of the trip boundaries. Trip boundaries are changing with wind variation and following with output power of the wind farms. Therefore, trip boundaries should continuously change proportional by the wind speed. In this paper, a method is provided based on the combination of distance and differential protection. In this method, using active power calculation in both ends of the transmission line, fault resistance is calculated and its effects are directly deducted from the calculated impedance by the relay. Therefore, variable trip boundaries are not needed anymore. Also in this method, unlike the technique that the trip boundaries are used, the exact location of fault and its distance from the relay also is calculated. Detailed model of a doubly-fed induction generator (DFIG) driven by a wind turbine is used in the modelling. Results of studies show that the presented method eliminates properly the mal-operation of relays under all different fault resistance conditions.

1. Introduction

Wind farms are one of the cheapest sources of large-scale renewable energies and due to its sustainability, their use is recently increasing. In the most transmission lines connected to the wind farms, the distance relays are used. The performance of these relays is based on the calculated impedance of the transmission line. Therefore, any factor that change the calculated impedance will affect relay performance. Fault resistance is one of the most important of these factors. Fault resistance increases directly the calculated impedance by the relay and therefore calculated impedance will not be located in the operation zone of the relay. In the *mho* relays, these zones are designed as circle or quadrilateral. Numerous papers are published in this area and presented different techniques to eliminate impacts of fault resistance in the relay performance. In [1], a method is presented based on solving the related linear differential equations. This method utilizes the lumped transmission–line model and its results shows that it can properly eliminate the negative effects of the fault resistance on the superficial impedance when the transmission line is short enough. The proposed method in [2] is based on the phase coordination and a fault resistance estimation is developed for the trip decision procedure. Results of their studies show that this method increases the accuracy of the relays. In [3], local–end data is used to compensate the fault resistance negative effects on the relays. This method reduces the errors in conventional relays. In [4], negative, zero and comprehensive negative and zero–sequences of current signals used for fault impedance estimation. In [5] authors investigated a type of adaptive distance relay with composite polarizing voltage and a new additional blocking component is also presented.

Recently, research has been performed to study the distance protection of transmission lines connected to the wind farms. In [6], the tree-included fuzzy rule-based differential relay is used for protection of the transmission lines in the presence of wind farms and unified power-flow controller (UPFC). In this paper, communication channels are used to transmit data across the both ends of the transmission line to the relay. In [7], distance protection in transmission lines connected to the wind farms is studied. In [7], only balanced faults with resistance of 1 Ω is considered. In [8,9] trip boundaries are used to eliminate the effect of fault

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resistance. In this method, two factors including fault resistance and fault location are considered. The trip boundaries are designed in the way that all faults with high resistance in all points of the transmission line are placed inside the trip boundaries. In [9], impacts of inverter-based distributed generations on fuse-recloser coordination in the fuse-saving protection scheme are thoroughly studied. In [10], impact of wind farms and its variations in trip boundaries are presented. It has been shown that factors such as the internal impedance, output voltage, and frequency are related to variations in wind speed and cause essentially variation in trip boundaries. In other words, for using trip boundaries in the existence relays in the connected transmission lines to the wind farms, trip boundaries should continuously change and be coordinated by the wind speed.

The presented technique in this paper is directly eliminating fault resistance effect from the calculated impedance by the relay. Then, trip boundaries are not needed anymore. This technique uses data in both ends of the transmission line and it acts similarly to the differential protection.

On the other hand, presented method is capable to detect the fault location similar to distance relay. Using voltage and current in both ends of the transmission line, active power in the both end of transmission line under high resistance faults are calculated. This method is not dependent on the impedance of the transmission line. Then, changing parameters of the transmission line does not affect the obtained results. The different operation types and conditions of wind farm and also different ground faults are investigated in this paper.

2. Analytical study

The power system under study is shown in Fig. 1. In this system, A-G fault is considered in transmission line connected to the wind farms. As system is unbalanced, positive, negative and zero sequence components are used to study the system.

These sequence networks are presented in Fig. 2. Regarding the positive network we will have [11,12]:

$$V_{1A} = xZ_{1L}I_{1A} + R_f I_{1f} + V_{1f} \quad (1)$$

The negative (V_{2A}) and zero (V_{0A}) sequence voltages are obtained from Fig. 2 in the same way:

$$V_{2A} = xZ_{1L}I_{2A} + R_f I_{2f} + V_{2f} \quad (2)$$

and

$$V_{0A} = xZ_{0L}I_{0A} + R_f I_{0f} + V_{0f} \quad (3)$$

For a single-phase-to-ground fault, the following equations can be used:

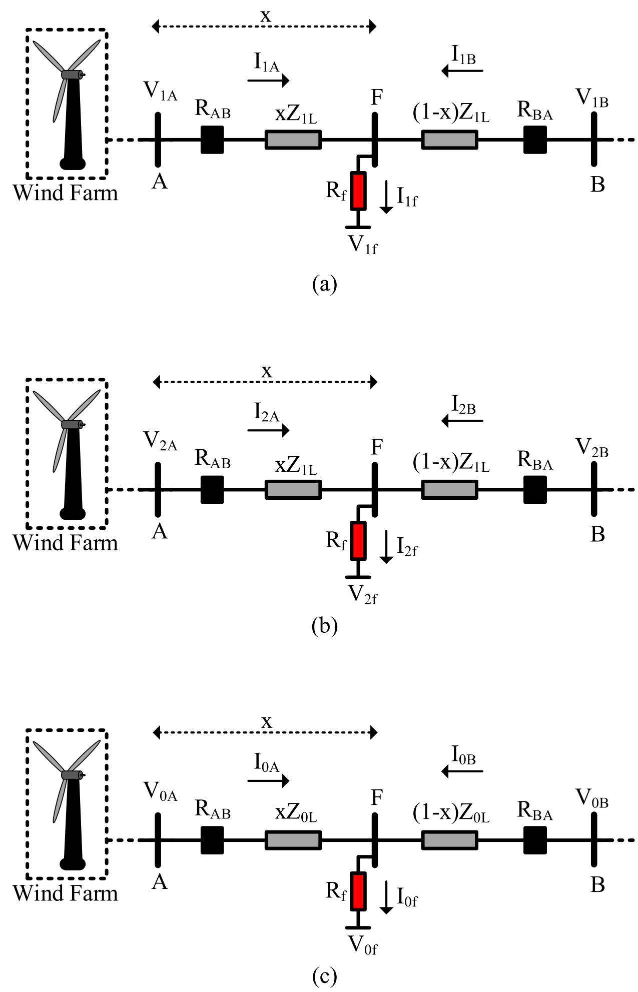

Fig. 2. Positive (a), negative (b) and zero-sequence (c) networks of the power system from the viewpoint of the R_{AB} relay for an A-G fault.

$$I_A = I_{1A} + I_{2A} + I_{0A} \quad (4)$$

$$I_f = I_{1f} + I_{2f} + I_{0f} \quad (5)$$

and

$$V_A = V_{1A} + V_{2A} + V_{0A} \quad (6)$$

Introducing the calculated V_{1A}, V_{2A} and V_{0A} into Eq. (6) and using the fact that $V_{1f} + V_{2f} + V_{0f} = 0$ is valid for single-phase-to-ground fault, following equation can be derived:

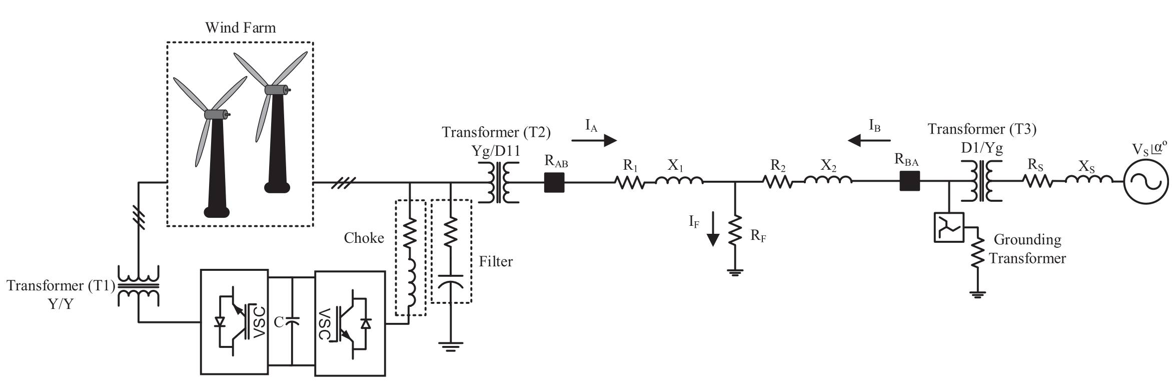

Fig. 1. Single-line diagram of power system with the wind farms.