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A novel method for adaptive distance protection of transmission line connected to wind farms

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ABSTRACT

Wind speed variations results in wind farm voltage, frequency and power output fluctuations. Therefore, protection of lines connecting such a farm to the grid is very important and an adaptive system for distance protection of such a line is necessary. In this paper, an adaptive unit which adjusts the relay trip characteristic using local information has been designed for distance relay using artificial neural networks. In this case, in order to prevent wrong operation of relay, changing in wind farm conditions, the set points of different zones of distance relay has to be changed simultaneously. The results obtained from proposed method are verified by computer simulation.

1. Introduction

Wind farms are increasingly integrated to the grids at different levels of voltage across the world. The share of such farms in a power system is also rising day by day. The problem that arises in integrating such farms is primarily due to variable wind speed. The speed variation results in fluctuating output power. The output power of a generating unit has a nonlinear relationship with the wind speed, and when the speed is beyond the limits, the farm cannot contribute to the grid [1]. In addition, due to under/over voltage conditions, a group of turbines may trip while others may remain in operation. Obviously, the transmission system that connects such farms will be exposed to such a continuously changing environment. In most papers, topics related to protection of wind farms have discussed about over-current relay setting in distribution systems and adaptive schemes are proposed for distribution systems connected with wind generators [2,3]. The protection of transmission line connected to wind farms is discussed in [4]. Distance relays are commonly used for line protection either as primary or backup. Their digital version has advantages of better monitoring, communication, and adaptation to system condition. Adaptive forms of distance relays are proposed to overcome associated problems in real time, which ultimately increase the overall reliability index of the protection scheme [5–13]. In distance protection, to coordinate high fault resistance with ground faults, quadrilateral characteristic is preferred. In a fixed setting approach, the boundary of the relay characteristic is predefined based on overall system study. With an adaptive feature in a distance relay, the boundary is set online in accordance with the prevailing condition. In [6], the trip boundary is set adaptively that assumes that through SCADA or PMU voltages and line flows of all parts of the system are available. The module of adaptive relay using the swiveling quadrilateral characteristics that the angle of swivel is computed using residual current where the fault area is assumed to be fixed, is proposed in [7]. The proposed scheme in [8] is based on neural network using real and reactive power at the relay location as the input vector. Such an approach provides an approximate solution and the neural network is not valid for another system.

In adaptive scheme which is proposed in this paper, the ratio of local current and voltage and instant information of wind farm has been used for adaptive protection. The proposed approach is simple to implement and provides accurate settings for such a system. Results are provided for a line-to-ground fault and the concept can be extended to other types of faults. The trip characteristic of a relay is decided from detailed off-line study of the system. In an adaptive form, the trip boundary should be changed as the system condition change. In [6], the mathematical formulation is outlined for generating trip boundary in the case of line-to-ground fault. The trip boundary considered here is of quadrilateral characteristic on an impedance plane obtained by varying fault location and fault resistance within their limits.

2. Ideal trip characteristic for distance relay

In a wind farm, a number of units are connected in parallel to harness bulk amounts of electric power for a grid. When such a

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potentially high level of generation is available at a remote place, transmission systems are hooked up for efficient power management. As the generation at a wind farm fluctuates, the connecting line will see varying degrees of transmitted power through a day. The fluctuations of voltage and frequency in the system depend on the proportionate strength of the farm. To see the effects of wind farm operating conditions on trip characteristic, a 400 kV, 60 Hz power system is studied later [6].

A schematic of a typical wind farm connection is shown in Fig. 1. In this figure, the wind farm supplies power to the grid through the transmission network that is protected by a distance relay. The line diagram of the power system for phase-A-to-ground fault in the line is shown in Fig. 2. The considered distance relay is positioned at *W* and the normal power flow direction in the system is from *W* to *P* (wind farm to grid) as marked in the figure. In this analysis, the wind farm and the grid are considered with their equivalent simplified models and shunt capacitance is not considered for the line.

The system parameters are presented in Table 1.

The pre-fault voltage relation of the equivalent sources is defined as

$$E_{AP} = \rho e^{-j\delta} E_{AW} \quad (1)$$

The pre-fault current can be written as

$$I_{WP} = (E_{AW} - E_{AP})/Z_1 \quad (2)$$

where Z_1 is the positive sequence impedance of the system and can be obtained as

$$Z_1 = Z_{1SW} + Z_{1L} + Z_{1SP} \quad (3)$$

From voltage and current relations in (1) and (2), the following can be written

$$\rho e^{-j\delta} = 1 - (I_{WP}/E_{AW})Z_1 \quad (4)$$

If system conditions ($\rho, \delta, Z_{SP}, Z_{SW}$) are fixed and R_F and fault location varied, four boundary lines, defined below, are obtained by computer simulation (Fig. 3).

Line I: solid faults at different points of line.
Line II: faults at relay-reach end (90% of line length) with different fault resistance up to 50 Ω.
Line III: faults at different points with a 50 Ω fault resistance.
Line IV: faults at the relaying point with different fault resistance up to 50 Ω.

These four lines and included area define ideal trip region of relay under the prevailing system conditions.

In [14], it is shown that variation of two parameters as wind farm local information affects on seen impedance by the distance relay and ideal trip characteristic. These parameters are equivalent impedance of the wind farm (Z_{1SW}) and the ratio of current and voltage in relay point (I_{WP}/E_{AW}).

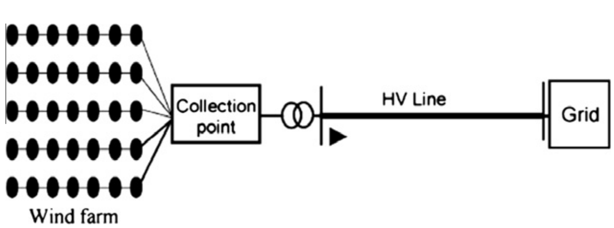

Fig. 1. Interconnection of wind farm to the grid [14].

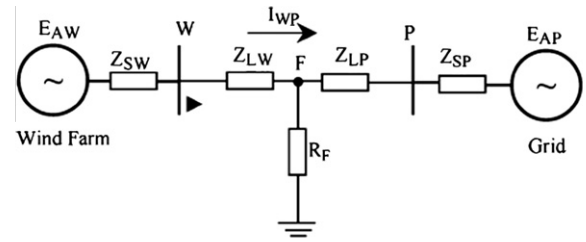

Fig. 2. Line diagram for phase A-to-ground fault [14].

Table 1
Values of different parameters of studied system.

	Z_{SW} (Ω)	Z_{SP} (Ω)	Z_L (Ω)
Zero sequence	30∠85°	1.5∠85°	87.35∠83°
Positive sequence	20∠85°	1∠85°	28.75∠86°

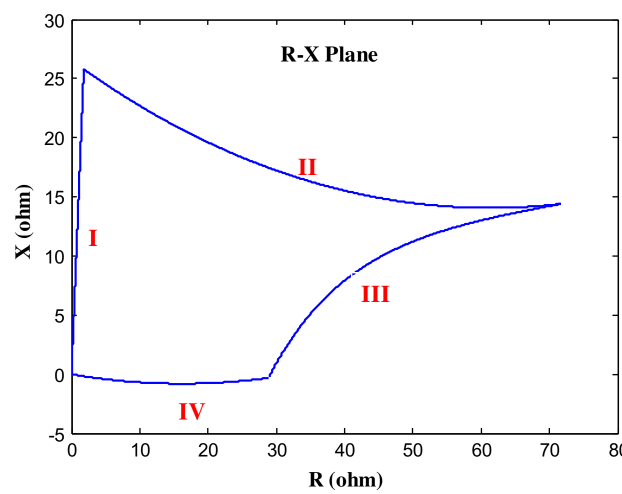

Fig. 3. Ideal trip characteristic for $Z_{1SW} = 20\angle 85°$, $Z_{0SW} = 30\angle 85°$, $\rho = 0.95$, $\delta = 20$.

3. Proposed adaptive protection scheme

To prevent mal-operation of distance relay, it is necessary that relay trip decision can change by variations of wind farm conditions. In fact, for a point in firs zone of relay (90% of line length), impedance value seen by relay must be included inside of trip characteristic. Thus, the four lines which determines relay trip boundaries must be varied with wind farm conditions (the amount of I_{WP}/E_{AW} and equivalent impedance of the wind farm). Therefore, how to make a distance relay operate sensitively as these conditions vary is the main problem that must be solved. To solve this problem, two different approaches can be proposed:

(1) Firstly, setting patterns under all possible system conditions can be calculated off-line and stored in a data table for using during fault. Alternatively, only one set of setting parameters are calculated on-line and they are renewed from time to time as the system conditions change. When a fault occurs the relay will operate with the latest setting parameters, an optimal trip boundary [6].

This method is faster in on-line processing due to less computation. However, a large amount of computer memory would be needed to cover all the possible conditions. Also, the nonlinear boundaries will make it more complex.