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An intelligent fault detection and classification scheme for distribution lines integrated with distributed generators☆

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ABSTRACT

Conventional relays fail to detect the high impedance fault (HIF) in distribution lines, as the change in the current magnitude is very negligible compared to conventional relay settings. Moreover, the incorporation of distributed generators in the distribution lines changes the fault current level, which makes the HIF-detection more complex. In this paper, a fuzzy-based intelligent fault detection and classification scheme is developed for the distribution lines integrated with DGs. Two different fuzzy inference systems (FIS) are modelled in each phase to detect the fault. The first FIS identifies the high magnitude of fault current associated with normal shunt faults; and the second FIS identifies the small magnitude of current owing to occurrence of HIF. The proposed scheme uses the features extracted from the Teager energy operator. An extensive study is conducted and the response time is found to be around ¼-1 cycle. Results validate the efficacy of the proposed scheme.

1. Introduction

The utilization of distributed generators (DGs) in the power system has increased in the recent years as they have the capability to meet the increasing power demand locally. They can also reduce the environmental problems created by the traditional fossil fuel-based sources of power generations. Inspite of the positive aspects, there are also some aspects of integrating DGs at the distribution level which would exert negative influences on conventional relays. For example, measurement of the admittance value in short distribution lines is a challenging issue for distance relays and conventional settings of overcurrent relays may fail due to changes in fault current levels [1,2]. The fault current contribution from the DGs will vary depending upon the type of the generator connected. It is high for the synchronous generator-based DG and low for the inverter-based DG. The weather conditions also affect the relay settings. The normal shunt faults (or low impedance short circuit faults) occurring in the distribution lines are identified using different available techniques in the literature, but detection of HIFs which frequently occur on the distribution lines is still a major concern. This is due to the nonlinear nature of the fault current and low magnitude of currents during the HIF which is not sufficient for the conventional protection schemes for accurate tripping. Thus, the HIF detection becomes more complex when the DGs are connected in the system.

In this paper, a fault detection and classification scheme using Teager energy operator (TEO) and fuzzy inference system (FIS) is developed for distribution lines integrated with DGs. Primarily, it aims to discriminate the HIF and normal shunt fault from the no-fault conditions and also classify the fault type. Therefore, the proposed scheme can facilitate the single pole tripping function to maintain the reliability of the power supply. The features extracted through the TEO are fed to the FIS. The measured currents at the

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respective DGs and the point of common coupling (PCC) are used to perform the protection task locally without remote end data. Once a fault is detected, the DGs go into islanding mode of operation by disconnecting from the grid and feed their local loads.

The organization of the paper is as follows. Section 2 presents the literature review. Section 3 describes the TEO-fuzzy based proposed scheme. It also explains the test system and HIF model considered for the study. Section 4 illustrates the simulation results of the proposed scheme. Section 5 compares the proposed scheme with other recently reported schemes. Section 6 presents the conclusions.

2. Literature review

Various relaying schemes are available in the literature for the protection of distribution lines. In [3], a protection scheme and a relay coordination method using sequence components have been implemented. Researchers have proposed an overcurrent differential protection scheme in [4] for each distribution line and the DGs uses a back-up voltage and frequency based protection scheme. Islanding detection based on Vector Surge (VS) relays is reported in [5]. In [6], a comparative study between the Rate of Change of Frequency (ROCOF) and VS relays for DGs protection has been made and it has been concluded that VS relay has better performance. A comparison has been made in [7] between the Under/Over Voltage (U/OV) relay and the ROCOF relay. The investigation reveals that the U/OV relay has shown results better than the other. A direct building algorithm has been implemented for the fault analysis in a micro-grid in [8]. In [9], earth fault and directional overcurrent schemes are used for the protection of biomass micro-grid in Malaysia.

Several schemes have been proposed in earlier works based on signal processing techniques. Wavelet singular entropy (WSE)-based islanding detection is proposed in [10]. In [11], an adaptive directional overcurrent relay setting is proposed for micro-grid protection using the superimposed sequence currents. In [12], an S-transform-based protection scheme using differential energy is proposed for micro-grid but has the drawback of increased computation time. In [13], another protection scheme has been proposed using the Hilbert–Huang transform, which uses the differential currents of two buses to issue the trip decision. The TEO is used in transmission lines to extract the travelling waves in [14]. The TEO has also been reported to detect the fault during power swing in [15]. But, the TEO is not yet reported for protection of distribution line with penetration of DGs.

Intelligent techniques which use effective features for the fault detection are also available. A fault classification scheme using adaptive neural fuzzy inference system (ANFIS) in the distribution system is reported in [16]. A Data-mining-based protection scheme for the micro-grid has been presented in [17]. It requires more number of features to train two classifiers includes the support vector machine (SVM) and decision tree (DT). A combined protection scheme is proposed in [18], which uses a number of wavelet-based features as input to the DT and random forest (RF) classifiers. A review on hybrid computing techniques for fault analysis has been reported in [19]. A fault detection and classification scheme using fuzzy and WSE has been reported in [20] which does not consider the effect of HIF. Many earlier solutions for fault detection in distribution lines deal with short circuit faults, but limited solutions are available in literature to detect the HIF situation in distribution lines in presence of DGs.

3. Proposed protection scheme

The proposed scheme concentrates on solving the HIF detection issue in distribution lines integrated with DGs using simple fuzzy rules. The flowchart of proposed scheme is presented in Fig. 1. The scheme begins with sampling the three-phase current signal and then, effective features are extracted from the signal using TEO method. Finally, fuzzy rule base is framed using the features to identify the HIF and type of fault.

3.1. Test system

A single line diagram of distribution lines integrated with DGs is shown in Fig. 2. The details of the system are considered as in [20]. It consists of a utility grid of rating 1000 MVA, 66 kV and two diesel generators as DG units. The system operating frequency is 60 Hz. Pi-section lines have been used for the interconnections and loads have been connected at the respective buses as shown in Fig. 2. The input signal is measured in-terms of per unit (p.u) at each bus. For any fault initiated in the utility grid, bus-1 or PCC should be disconnected by isolating the utility grid from the distribution lines and the utility grid operates in islanded mode. If any fault occurs on the distribution lines (DL-1 or DL-2); bus-1 should be disconnected from the distribution lines. Moreover, the tripping of bus-2 and bus-3 should take place to separate the DGs into individual islands simultaneously and the DGs supply their local loads [20].

3.2. HIF model

Identifying a low impedance fault is an easy task using many earlier reported algorithms but, identifying the HIF which is characterised by the low magnitude of fault current is a challenging one. The change in current magnitude is not adequate for the conventional relays during the HIF condition compared to other fault conditions. To verify this issue, a realistic HIF model [12,13,21–24] is simulated using anti-parallel diodes, DC sources, and non-linear resistances for each phase as shown in Fig. 3.