Electric Power Systems Research 161 (2018) 199–211

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Integrated approach based third zone protection during stressed system conditions

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ARTICLE INFO

Article history:
Received 18 December 2017
Received in revised form 7 March 2018
Accepted 14 April 2018
Available online 3 May 2018

Keywords:
Distance relay
Noise
Sampling frequency
Decaying dc
Three-phase fault
Discrete wavelet transform

ABSTRACT

Third zone of a distance relay is sensitive to system stressed conditions, such as stable and unstable power swing, voltage instability and load encroachment. Mal-operation of a distance relay under these conditions can cause power system blackout and should be prevented for power system security. An integrated approach based on two indices is introduced to improve the relay performance during system stressed conditions. The first index is based on estimated dc offset magnitude from the current signal using half cycle Discrete Fourier Transform and the second index is based on energy of first level detail coefficients obtained using discrete wavelet transform. It can be hard for a distance relay to discriminate between a three-phase fault in the third zone and stressed system events as both are balanced phenomena. Therefore, during the occurrence of a transient event if the conventional impedance calculation method detects it as a fault, it will be rightly detected as a three-phase fault only if both the indices lie above their respective thresholds. Using these two indices as a combined supervisory logic, three-phase fault in the third zone can be rapidly and reliably detected and discriminated from system stressed conditions, and thus avoid false operation of distance relay during stressed system conditions. Current based and wavelet techniques are, respectively, sensitive to noise and sampling frequency. However, with the proposition of adaptive threshold setting in the wavelet approach the robustness of this method against noise and sampling frequency is guaranteed. The proposed method is reliable during CT saturation condition as well. The proposed method is based on local end information so system condition can be rapidly scrutinized. Results for different power system events are analyzed using New England 39-bus, 10-machine test system modelled in EMTDC/PSCAD software. Comparative assessment with conventional approach confirms that this algorithm can meet the accuracy standards of the industrial relays due to better reliability.

1. Introduction

Distance relays are extensively employed for both primary protection as well as back-up protection of transmission lines. In case the primary protection fails to isolate a faulty section, the second-zone or third-zone steps in as standby for maintaining the system security. However, the longer reach of third-zone makes it more prone to creating security problems.

Transmission system can be under stress under heavy load conditions. Under stressed conditions, performance of the protective devices becomes challenging and it may happen that the device will not provide complete security to the system [1,2]. During system events, such as power swing, voltage instability and load encroachment, that cause stress, the distance relays operate close to their operating zone limits [3,4] and may be unable to discriminate system stressed events from a three-phase fault occurring in the third-zone. The apparent impedance seen by the relay can enter into the third-zone setting and get misinterpreted as a fault condition, and thereby provide an unwanted trip command.

The unbalanced faults can be differentiated due to the existence of zero or negative sequence components. However, it is difficult to correctly differentiate a three-phase fault from the stressed system conditions, as both are balanced phenomena. This is a contributing factor to the blackouts that have been a major concern for both protection engineers and consumers. In the literature, several approaches have been reported to distinguish the faulty condition from different stressed conditions [5–25].

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https://doi.org/10.1016/j.epsr.2018.04.011
0378-7796/

The initiation of a disturbance in a power system further gives rise to a critical condition of generation and load mismatch. This results in the oscillation of generator rotor angles and hence the power flowing in the system also oscillates. This is termed as power swing [5] and is usually initiated due to fault, loss of generation or switching of heavily loaded lines. During power swing the load impedance may encroach into the relay operating characteristics resulting in unsolicited tripping of transmission lines. A three-phase fault in the third operating zone and power swing are not discriminated by a distance relay. Therefore, correct discrimination of the fault from power swing is vital. In Ref. [6], a 'prony' method-based technique is proposed to discriminate between the three-phase fault and a power swing. A moving window is used in Ref. [7] for calculating the average of the current signal which is different for power swing and fault condition. Spectral energy obtained using S-transform is utilized in Ref. [8], and rate of change of active and reactive power have been used in Ref. [9] for segregation of three- phase fault from power swing. A wavelet-based approach [10], a differential power based symmetrical fault detector [11], a symmetrical fault detector based on damping frequency components of instantaneous three-phase active power [12] and an adaptive neuro-fuzzy inference system [13] based approaches are also available in the literature for the detection of fault during power swing. These techniques correctly identified fault during power swing but they were not tested for load encroachment and voltage instability situation.

When the system is unable to meet the reactive power demand, the voltage magnitude decreases resulting in a voltage stressed condition which increases the chance of third-zone mal-operation. Rate of change of voltage and mathematical logic blocks have been utilized in Ref. [14] to prevent relay mal-operation during voltage instability. A voltage stability index has been developed in Ref. [15] for preventing relay mal-operation. Rate of change of current and voltage magnitudes are proposed in Ref. [16] as the fault recognition criteria. A new approach based on modification of third-zone characteristics during voltage collapse situation, where the normalized rate of change of apparent impedance is used to modify the third-zone characteristics, is proposed in Ref. [17]. An online approach is used in Ref. [18] to classify power swing, voltage instability and fault using one classifier and a second classifier to detect symmetrical faults during power swing. A new index called relay ranking index has been proposed in Ref. [19] for identifying the critical relays and it differentiates the power system events into power swing, voltage instability and fault using SVM based protection scheme.

The load impedance is sufficiently high under normal conditions that it does not enter into the relay characteristic. In certain situations when the load increases, it can cause the apparent impedance measured by the relay to encroach into the third-zone element thereby resulting in undesired tripping. Load encroachment is one of the major causes behind power system blackout. Similar situation took place in India on 30th and 31st July, 2012. Due to the overloading of Bina-Agra-Gwalior line, relay operation was under stress and mal-operated as load impedance encroached into the third-zone [20]. For improving system security, a novel load blinder scheme has been developed in Ref. [21] which is based on artificial neural network. A new adaptive load encroachment prevention scheme based on steady-state security analysis and adaptive anti-encroachment zone is proposed in Ref. [22]. Combined steady-state and transient state characteristics of current, using state diagram, are exploited in Ref. [23], and a protection algorithm for third-zone is put forward to detect three-phase fault during voltage instability and load encroachment.

Research articles on third-zone considering all the different system stressed events are reported in Refs. [24,25]. In Ref. [24], an integrated approach based on least square technique and phase angle of positive sequence impedance has been used to make a clear discrimination between the system stressed events and three-phase fault in the third-zone. A synchro-phasor based approach is utilized in Ref. [25] for distinguishing fault from stressed system conditions. To prevent blackout conditions, that can be initiated due to overload, a dynamic line rating supported overcurrent line protection, which can increase the line transfer capacity by online monitoring of the overload temperature and weather conditions, is proposed in Ref. [26]. A complete survey report of problems and solutions related to third zone mal-operation is provided in Ref. [27].

A single logic is not suitable enough for different critical conditions of power system to provide a secure decision. Thus, an integrated approach based on half cycle DFT and Discrete wavelet transform (DWT) is proposed here to enhance the protection functionality during system stressed conditions. Using half cycle DFT, the magnitude of dc offset is computed and works as a first detector for the proposed logic. Next, DWT is used to compute the energy of level-1 detail coefficients that functions as a second detector. In this work, the db8 wavelet is considered for analysis.

In recent years, use of DWT technique in power system analysis has been reported. For example, a wavelet-based approach for the classification of transients resulting from the changes in circuit topology in a radial distribution system is reported in Ref. [28]. However, main limitations of the DWT technique are the chance of mal-operation in the presence of noise and its high computational burden. These limitations are overcome in the proposed approach, thereby increasing to a great extent the robustness of the DWT technique for fault detection. The techniques available in the literature utilize detail level coefficients, i.e. the high frequency components for fault-swing discrimination. In Ref. [10], such an approach is demonstrated. The main drawback of this approach is that it relies on fixed threshold setting and, therefore, is not always suitable for secure operation of protective relaying in the power system. Considering the impact of noise and transient events, an adaptive threshold setting based DWT logic is proposed in this work. The computational burden and memory requirement by the proposed technique are reduced to a great extent, compared to other conventional DWT based techniques, as the sampling frequency used is low i.e. 1 kHz. With the proposed method, relay ensures correct detection of fault only when the preset conditions are satisfied. The New England 39-bus, 10-machine system is considered for study and developed in EMTDC/PSCAD software. Efficacy of the proposed scheme is confirmed through test cases.

2. Proposed technique

Control and protection of power system subjected to fault under normal operating range is possible. System stressed conditions being non-fault events could be seen as fault event by the distance relay as the measured parameters are very close to the operating zone. To correctly differentiate three-phase fault from stressed conditions, the following two criteria are proposed.

2.1. Magnitude of decaying dc component using half cycle DFT technique

During fault, the current magnitude changes abruptly. However, the inductive nature of the system impedance being dominant does not allow sudden change in current and the current lags the voltage by its natural power factor. This nature of current is being satisfied during fault event with the inclusion of dc offset. Therefore, the presence of dc offset is a clear indication of system disturbance, such as switching of lines, initiation of fault, and it is represented as a decaying exponential function [24]. Its initial magnitude will