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A blocking scheme for enhancement of distance relay security under stressed system conditions

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ABSTRACT

Mal-operation of zone-3 of distance relays has been one of the main causes of widespread disturbances and blackouts in power systems throughout the world. Under some non-faulty conditions, the measured impedance may enter zone-3 and cause spurious trip of transmission lines. This can happen during stressed system conditions such as power swing, extreme loading and voltage decline. In this respect, there is an essential need to improve security of zone-3. Introducing a new two-dimensional decision plane, this paper presents a new technique based on superimposed components of voltages magnitude to discriminate non-faulty conditions from fault events. This way, not only the rate of change of the voltage magnitude but also its pattern of change is included into the decision logic. The proposed method is able to provide high security and sensitivity in detecting non-faulty cases and prevents relay from undesired trip in such conditions. The 39-bus New-England test system is used to demonstrate the effectiveness of this method. The obtained results show that the proposed method is able to reliably distinguish stressed conditions from fault events for different power system disturbances and considerably improves security of distance relay.

1. Introduction

Distance protection schemes are conventionally designed so as to provide remote backup for all transmission lines (TLs) connected to the remote end to enhance reliability of the power network protection system. For this purpose, it is desirable to cover longest following line at the next substation by zone-3 of distance relays. Accordingly, reach of zone-3 of a distance relay might be extended close to the TL load limit. In such cases, it is likely that the impedance seen by the relay enters its operating characteristics under stressed system conditions, e.g. power swing, extreme loading condition, and voltage decline. This could lead to distance relay undesired operation and might result in cascading trips in the power system [1–4].

One of the main reasons of mal-operation of distance relays is load encroachment [5]. Under normal conditions, the distance relay mal-operation due to load encroachment can be prevented by reducing the reach of zone-3 [6]. Rather, numerical distance relays mostly provide a load encroachment element by which the relay trip is blocked if while the positive-sequence voltage is nearby the nominal value, the measured impedance is located inside a predefined load area. This way, the relay tripping characteristic is modified by excluding an load area corresponding to the maximum load with the highest power factor in the impedance plane [7–10]. Under extreme operating conditions of power system, however, the load impedance might enter the relay tripping zone and activate it, since such conditions are not commonly anticipated in the setting calculations. In [11], an adaptive anti-encroachment zone is proposed based on steady-state security analysis. The proper performance of this technique is highly dependent on communication system as it requires signals from the remote end to make a proper decision.

Dynamic encroachment of the measured impedance into the relay operating characteristics due to power swings subsequent to a disturbance can also cause spurious trip by distance relays. The conventional criterion used for identifying the power swing condition is based on the rate of change of apparent impedance seen by the relay [12–14]. Most of industrial relays use this criterion in some manner to differentiate between fault and power swing. In the GE D60 distance relay, the power swing condition is identified if the impedance locus spends more than a certain time between the outer and inner characteristics of the power swing blocking (PSB) function [8]. The ABB REL670 relay uses almost the same approach but since the initial swings are usually not as fast as the later swings, it employs a different timer for

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the consecutive swings [9]. In SIEMENS 7SA612 relay, the impedance vector calculated in 1/4 cycle intervals is monitored. If the change from one sample to the next is smaller than a predetermined value, and also not more than one of the two resistance and reactance components of the impedance vector (R, X) has changed its direction within one measuring window, the power swing is recognized [10]. However, finding appropriate settings for these algorithms need detailed stability studies for all possible power swing scenarios on the system which is not an easy task on a large power system [15].

In [16], it is shown that the resistance seen by the relay varies persistently during power swing condition whereas it is almost constant during fault events. However, recognizing power swings based on this feature requires long time to make an appropriate decision [17]. Jafari et al. [18] reported a scheme independent of the rate of change of power system parameters which is based on the locus of center of the admittance trajectory. Nonetheless, this scheme is not verified for zone-3 faults in which the center of admittance trajectory could be beyond the transmission line admittance characteristic. Using mathematical morphology (MM), a power swing detection method is proposed in [19] which detects swings by analyzing current waveforms and detects faults by analyzing voltage waveforms. But, the process of design and selection of structuring element in MM is very complex for application in a real power system. In [20], an algorithm based on the support vector machine (SVM) is proposed for discrimination between fault and power swing. Three phase current samples for half cycle duration of post-fault/power swing are given as an input to the SVM. However, the SVM classifier needs off-line training using a large data set to become capable of recognizing similar patterns under different conditions. Using both ends measurements, a data-mining based intelligent differential relaying scheme is proposed in [21] to provide supervisory control to the distance relays operation. This scheme is able to recognize power swing conditions within an acceptable time, but it is not a local technique. In [15] a method based on relative speed of a fictitious equivalent machine representing the entire system by its single machine infinite bus (SMIB) equivalent from the relay location has been proposed to discriminate stable power swings from unstable ones. If the relative speed goes through a zero crossing, the swing is classified as a stable power swing, otherwise it is classified as an unstable swing. But, this method requires a long time to make decision and also it does not block the distance relay during unstable power swings.

Voltage instability has been identified as one of the main reasons for most of the recent power systems blackouts worldwide. Under stressed voltage conditions, the voltage magnitude reduces in most of the buses and consequently, the impedance seen by the relay decreases. As a result, the measured impedance might enter zone-3 of distance relays and cause undesired TL tripping. In [22], an adaptive algorithm based on the rate of change of voltages magnitude is proposed to distinguish voltage instability from fault events and prevent zone-3 mal-operation. In [23], it is proposed to use the rate of change of currents magnitude as well, to make the algorithm more secure. But, this could make the algorithm more susceptible to mal-operation during switching large loads in which line current increases suddenly. Also, it cannot detect power swing condition and an additional algorithm is required to provide power swing blocking. In [24], a voltage stability index is proposed to detect stressed voltage condition and block the relay operation. Nikolaidis [25] proposed to modifies the zone-3 characteristic if some predefined conditions are fulfilled, indicating that a severe system situation is evolving. This method detects the voltage stressed condition based on the rate of change of apparent impedance during the transition between two supervisory zones. But, finding proper setting for the supervisory zones of all distance relays in a bulk power system needs detailed dynamic studies and is extremely tedious.

In [26], a method based on wide area measurement system (WAMS) is proposed in which critical relays that are prone to undesired operation are identified using state estimation, and then wide area control is used to block these relays. In [27], a synchrophasor-based wide area backup protection is presented which detects faults by comparing the calculated voltage of each bus from more than one path. In [28], a fuzzy logic based method combining different indices including angle, frequency, voltage and damping information derived from WAMS data is used to prevent mal-operation of relay during power swing condition. The intelligent scheme proposed in [29], called online sequential extreme learning machine (OSELM), blocks zone-3 during voltage instability and also power swing conditions. This method needs data from different PMUs installed in the transmission network to work properly. Although WAMS based approaches can help to achieve a secure backup protection, their reliable performance is highly dependent on reliability of the communication system. Therefore, depending on placement of measurement units, they may fail to operate correctly if some of the measurement units are disconnected from the control center.

This paper introduces a new simple and powerful technique for enhancing security of distance relay zone-3 using local measurements. In order to distinguish fault events from stressed system conditions, a two-dimensional decision plane is proposed which uses the superimposed voltages magnitudes. The fault occurrence is identified based on the trajectory of samples of defined indices in this plane. This way, the change in the voltage during two subsequent cycles is observed simultaneously. Accordingly, not only the rate of change of the voltage magnitude but also its pattern of change is incorporated into the decision making logic, which helps to provide higher sensitivity and reliability in discrimination of fault events. The proposed technique is evaluated using the 39-bus New-England test system for different power system events. The obtained promising results show that the proposed technique is well capable to discriminate between faulty and non-faulty conditions and can enhance security of distance relay zone-3 operation during stressed system conditions.

2. The proposed technique

2.1. Proposed discrimination feature

For a given signal $x(t)$ sampled at the frequency of $f_s = N \cdot f$, the superimposed component can be defined as follows [30–32]:

$$\Delta x(n) = x(n) - x(n-N) - [x(n-N) - x(n-2N)] \quad (1)$$

where $x(n)$ is the measured signal sampled at instant n, N is the number of samples per cycle, and f is the power frequency. Therefore, $x(n-N)$ and $x(n-2N)$ are the signal samples measured one cycle and two cycles earlier than the instant n, respectively.

The proposed algorithm is based on the superimposed voltages magnitudes which are obtained using discrete Fourier transform (DFT) algorithm. The above equation can be rewritten as follows:

$$\Delta|v(n)| = |v(n)| - |v(n-N)| - [|v(n-N)| - |v(n-2N)|] \quad (2)$$

$$\Delta|v(n)| = -k_1 + k_2 \quad (3)$$

where k_1 and k_2 are defined as

$$k_1 = |v(n-N)| - |v(n)| \quad (4)$$

$$k_2 = |v(n-2N)| - |v(n-N)| \quad (5)$$