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A morphological filtering algorithm for fault detection in transmission lines during power swings

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ABSTRACT

This paper presents a new algorithm for transmission line distance relaying, tolerant to power swings. The distinction between a short circuit and power oscillation is accomplished with the use of a morphological transform. With this feature it is possible to detect the dc short circuit component that presents a different waveshape during power swings. To show the effectiveness of the proposed technique, computer simulations have been carried out on ATP (Alternative Transient Program). Several faults including different frequency oscillations have been considered. The proposed methodology detect faults in very small times, even under the worst-case scenarios such as balanced faults during power swings.

1. Introduction

In Electrical Power System (EPS) there are some power swings in which currents and voltages waveforms behave as a fault and can result in misoperation of distance relays [1].

In power swings the rms current and voltage of power system network are not constant, but rather they swing in amplitude and phase [2]. Consequently, an impedance calculation will oscillate in amplitude and phase and may cause unwanted tripping of distance relay (ANSI 21). To prevent this mal-trips the distance relay is often combined with power swing detector relay (ANSI 68).

Conventional detectors usually measure the time which the apparent impedance takes to cross a pre-defined area. During the fault conditions the apparent impedance moves along the locus almost instantaneously. Meanwhile, under power oscillations conditions the impedance moves slowly. The time delay for discriminating fault from power swing has to be set with knowledge of the likely speed of movement of the impedance during the power swing [3]. The main problem in this method is that the distance relay may not operate correctly for faults during a power swing due to blocked status of the relay.

Fig. 1 shows the operating characteristic on impedance plane (R–X) of polygon distance relay. This relay includes one instantaneous zone ($Z1_{21}$) and two definite-time delayed zones ($Z2_{21}$, $Z3_{21}$). The power swing detector, which is based on impedance rate of change, is two concentric polygons (LI and LE). This figure also shows a power swing crossing the transmission lines C–D and a three-phase fault (CC-3ϕ) occurring during the blocked status of the distance relay. In this example the power swing relay detects the oscillation correctly but makes the distance relay unable to operate for the fault. Besides, the required settings for the power-swing blocking elements could be difficult to calculate in many applications, particularly those where fast swings can be expected. Depending of the setting the method detects slow power swings but is inadequate for very fast power swings, or vice versa. To overcome these difficulties, several techniques has been proposed. Methods based on negative and zero sequence components [4] are used to detect unbalanced faults during power swings. However, there are no such components during balanced faults, so another criterion is necessary to discriminate this type of fault from power swings.

The magnitude of the Swing-Center Voltage (SCV) is used to distinguish faults from power swings [5]. However, it is difficult to set the threshold [3]. Schemes based on neuro-fuzzy inference systems (ANFIS) [6] and wavelet-neuro-fuzzy [7] have been proposed as well. The methods demand a huge number of training patterns and need a re-training for use in different power systems.

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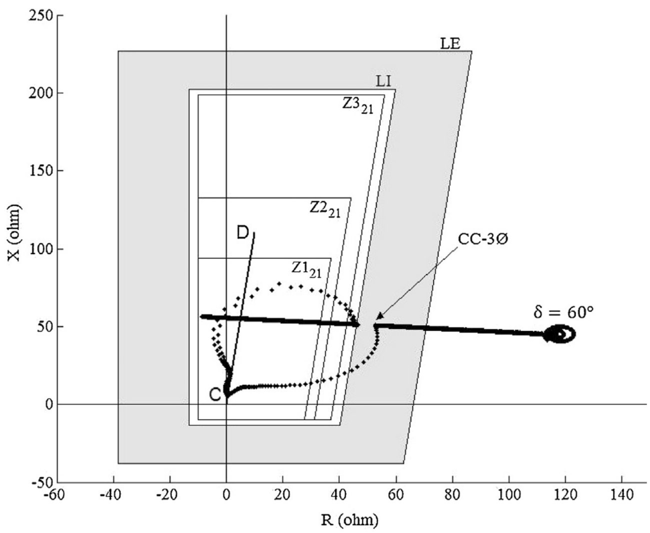

Fig. 1. Impedance seen by distance relay during a three phase fault at 5% of line length during a power swing.

Besides, techniques based on wavelet transform require high sampling rate to implement the tool. A technique based on the ratio of time of the swing locus staying in the internal circle and the time that it crosses the concentric circles was presented in [8]. The method presents good results; however, it is not tolerant to high fault resistances.

Recently, an algorithm for transmission line protection has been proposed [9]. The methodology uses mathematical morphology [10] to detect and classify the fault, and least-square curve fitting to estimate fault location. The paper [9] shows good results; however, does not deal with the power swings effects. To overcome this drawback, this paper proposes a numerical distance relaying tolerant to power oscillations, based on [9] and include another criterion based on unidirectional component (DC component) using mathematical morphology also. Unlike Fourier transform or wavelet transform, which extract frequency information in signals, mathematical morphology works exclusively in time domain and is useful in de-noising signals and images. Distance estimation is realized by a real-time fault location algorithm, which is developed using an instantaneous circuit model [11]. For reliable operation, the innovative algorithm estimates the exponentially decaying component (DC component) to detect phase faults during power swings. Single phase-to-ground faults are detected based on zero sequence components. The distance relaying uses a counting strategy in the R–X plane to trip [12].

The major advantages of proposed distance relay algorithm, when compared with other techniques, is that it is not influenced by power swing frequency, slow or fast power swing are detected without any threshold. Although, all fault types are detected even during a power swings. Another important issue is that the fault resistance does not affect its performance.

The tests conducted with the novel algorithm are concerned with different fault types, ground-fault resistances, locations and load angles. Detailed results are presents for events that involve power oscillations.

2. Power swing concepts

The dynamic operation of power systems is characterized by the equilibrium between generation and load. A sudden change in power system network caused by a fault, a disconnection of loaded lines or an automatic reclosing of circuit breakers forces the generators to adjust to this new operational condition. The adjustment will not happen in a jump step due to the inertia of the generators, but rather as an oscillation [2]. These system disturbances cause oscillations in machine rotor angles and can result in severe power flow swings.

Large power swings, stable or unstable, can cause unwanted relay operations at different network locations, which can further aggravate the power-system disturbance and possibly lead to a cascading outages and power blackouts [13].

The frequency of voltage and current depends on the rate of change of the power angle between two systems and is characterized by slip frequency. The slip frequency can be as low as 1–3 Hz (slow swing) and as high as 4–7 Hz (fast swing) [7]. During a power swing in a two-machine system, the current in transmission line is composed of two sinusoidal components that can be written as follows:

$$i(t) = 2I\ \cos\left[2\pi t\frac{(f_1 - f_2)}{2} + \frac{(\varphi_1 - \varphi_2)}{2}\right]\cdot \sin\left[2\pi t\frac{(f_1 + f_2)}{2} + \frac{(\varphi_1 + \varphi_2)}{2}\right] \quad (1)$$

where I is the amplitude of the two sinusoidal components; f_1, f_2 are the two unknown slip frequencies; φ_1, φ_2 are the initial phase angles.

Fig. 2 shows a typical current waveform during a power swing for two slip frequencies. Fig. 2(a) has been used $I_m = 40$ A ; $f_1 = 60$ Hz ; $f_2 = 61$ Hz ; $\varphi_1 = 88.1^\circ$; $\varphi_2 = 1.9^\circ$ and Fig. 2(b) has been used $I_m = 40$ A ; $f_1 = 60$ Hz ; $f_2 = 65$ Hz ; $\varphi_1 = 88.1^\circ$; $\varphi_2 = 1.9^\circ$. Fig. 3 shows the typical shape of apparent impedance seen by a distance relay for a stable and unstable power swing.

Mathematical Morphology (MM) was introduced in 1964 by Matheron and Serra and its first applications were in the area of image processing [10]. Nowadays, it has been applied to wide range areas, including power systems.

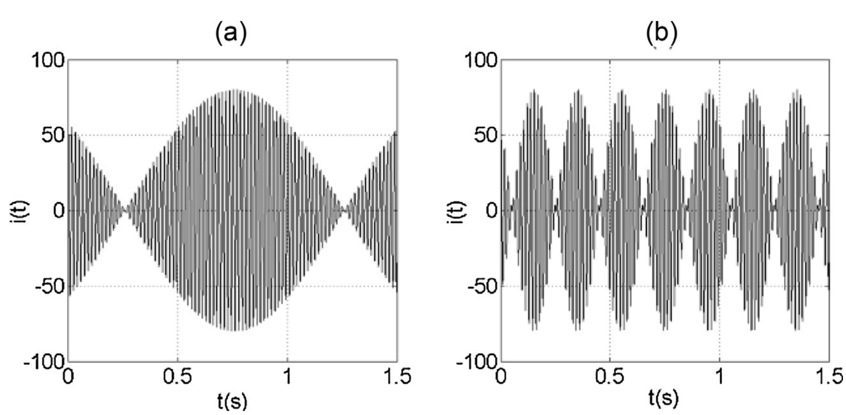

Fig. 2. Typical behavior of current during power swing for (a) frequency oscillation = 1 Hz; (b) frequency oscillation = 5 Hz.