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Waveform asymmetry of instantaneous current signal based symmetrical fault detection during power swing

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ABSTRACT

This paper proposes a methodology for detection of short-circuit during power swing with easy adjustment, in order to unblock the distance relay and allow its operation. If a fault occurs during power swing, it must be immediately detected and removed. One of the major challenges in these detectors is to distinguish power swing from symmetrical fault near to the electrical center ($\delta = 180^\circ$), as both are balanced phenomena. This work aims to propose a detector of fault which is reliable and capable of detecting a short-circuit occurring in the moment that apparent impedance crosses near to electrical center. The methodology proposed presents as main advantages, beside the ability to identify the three-phase faults during power swing near to the electrical center up to $\delta \leq 120^\circ$, to work in low sampling frequency and obtain the shortest response time compared to other techniques. In order to unblock the relay in the case of a short-circuit during power swing, the asymmetry coefficient of the current signal is calculated in a window of 1 cycle (60 Hz). If the asymmetry coefficient surpasses the predefined threshold, the relay is unblocked (reset of PSB function – Power Swing Blocking), allowing its operation. The methodology uses predefined thresholds through the analysis of signals of different power swing frequencies. In this work, the defined threshold is able to cover a great number of faults and to be tolerant to power swing frequencies lower than 6 Hz. The predefined threshold avoids the need for extensive studies on stability which estimate the behavior of power electrical system.

1. Introduction

In steady state, a power balance between generation and load is maintained. However, events such as short-circuits, switch of transmission lines, disconnection of the generator, and loss or application of large block of load may compromise this balance and cause the phenomenon known as power swing, in electrical systems. A power swing may cause undue operations of distance relays [1,2]; resulting in the shutdown of generators and consequent risk of insufficient supply of the generated power, causing loss of balance and blackout. The stability of Electric Power System (EPS) has become a main subject in the operation of a country's interconnected system. The North American Electric Reliability Corporation (NERC) reported an alarming statistics where an important portion of major disturbances which caused blackout involve undue tripping of distance relays [3–8]. In order to overcome this, researchers have developed a wide range of blocking techniques in recent years. Techniques for blocking against power swing have been developed (PSB – Power Swing Blocking) in order to avoid these undue tripping during stable swings and to unblock short-circuits during power swing. The detection of symmetrical fault during power swing has been a challenge, due to the fact that power swing and symmetrical fault are balanced phenomena, and therefore, block in this case.

The PSB techniques are divided into conventional and non-conventional methods [8–10]. The conventional methods work through concentric characteristics and/or through blinders plus an adjustment of time in order to measure time in which the apparent impedance goes through these characteristics. If the apparent impedance crosses in a lower time than the time set, it is interpreted that the event is a fault. Otherwise, it is interpreted that the event is a power swing, and then the PSB inhibits the tripping of the distance relay. However, this technique has two disadvantages: (i) it is incapable of detecting new events after the relay is inhibited; (ii) the measurement of the time set and values of blinders

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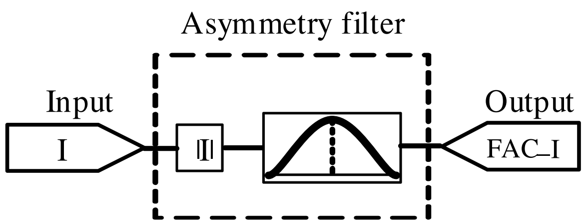

Fig. 1. Signal processing.

are obtained through complex studies of the behavior of local grid, which demand professionals in the subject [11,12].

The method based in the Swing Voltage Centre (SVC), which uses the expression $V\cos\theta$, where V is the magnitude of local voltage measured and θ is the angle between the voltage and current signals locally measured. During the power swing, the SVC changes continuously, however when a short-circuit happens the SVC remains the same. This criterium is used to distinguish between a power swing and a short-circuit [8,11,13]. Due to the fact that fault generates electromagnetic transients, the Wavelet Transform (WT) demonstrated to be efficient to the analysis of this transients in power systems. Brahma [14] studied different sampling rate used by the WT to detect power swing and symmetrical fault during the power swing. The author claimed that the sampling rate of 40.96 kHz is ideal for the detection of power swings and symmetrical fault in any place of the electrical power system. The main disadvantage of the WT is that most of the relays do not present sampling rate so elevated. Despite the fact that techniques for detection of symmetrical fault during the power swing already exist [14–19]; the reliability in the cases of power swing need improvements.

This work presents a method based on the identification of short-circuit during the power swing through the monitoring of asymmetry coefficient of current signal seen by the relay. The advantages of the proposed method in relation to the mentioned are: (i) it does not require to be set, avoiding the need for intensive analysis on the electrical power system; (ii) it is able to distinguish fault during stable power swing through a threshold (iii) it does not need elevated sampling rate.

Section 2 presents a review of the concepts approached in this work and explains the working of methodology proposed. Section 3 shows studies of case and results and, in Section 4 the conclusion is presented.

2. Proposed methodology

This work is based on the assumption that the occurrence of a short-circuit on a transmission line results in sudden change of frequency components of current waveform. Here, a filter which measures the asymmetry of data distribution in a window with fixed length is used in order to detect a short-circuit and unblock the relay during power swing condition. Fig. 1. shows the diagram of signal processing through this filter, which has as input the current instantaneous signal, then, the absolute value is determined and the asymmetry coefficient is calculated to the data group inside the window (1 cycle of 60 Hz). Thus, through this filter of asymmetry, the value of Fisher Asymmetry Coefficient (FAC) is obtained and used for the detection of a short-circuit during power swing. The filter of asymmetry proposed has the function of detecting a short-circuit through a one threshold, based on the value of the asymmetry coefficient of the current waveform.

2.1. Coefficient of asymmetry

The asymmetry coefficient is a measurement that indicates symmetry of a distribution in relation to the mean data without

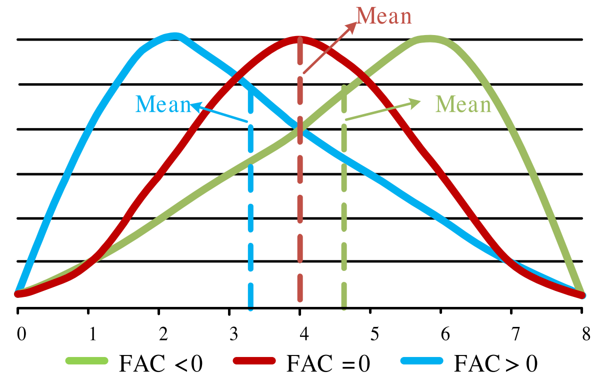

Fig. 2. Types of asymmetry for a distribution of data.

requiring a graphic representation. In this work, Fisher Asymmetry Coefficient (FAC) is used, which indicates the change in the amount of elements to the right and to the left in relation to the mean data. There are three types of distribution curve according to its asymmetry: Negative asymmetry, symmetry and positive asymmetry. Fig. 2 shows distribution behavior for each type. Among the conditions to classify the type of asymmetry are: If FAC < 0, distribution has negative asymmetry and flattens to higher values in relation to the mean. If FAC = 0, distribution is symmetrical, in other words, data distribution fulfills the condition of normal distribution. If FAC > 0, distribution has positive asymmetry and flattens to lower values in relation to the mean. FAC evaluates proximity of data to its mean.

When higher the sum $\sum_{i=1}^{N}(x_i-\bar{x})^3$, greater the asymmetry will be. Considering the distribution $x=(x_1, x_2, \ldots, x_N)$, Fisher Asymmetry equation is:

$$FAC = \frac{\sum_{i=1}^{N}(x_i-\bar{x})^3}{N\sigma^3} \quad (1)$$

where

FAC: fisher asymmetry coefficient;
$\bar{x}$: mean of data distribution;
σ: standard deviation of data distribution;
N: length of data distribution.

In this work, the asymmetry coefficient is employed applied to a data window of 1 cycle (60 Hz) sampled to 64 samples per cycle (spc); this variable is represented in this work by the abbreviation FAC. This sampling rate is subject to characteristics of the protection relay analyzed.

2.2. Decision criterion

The voltage and current signals measured for each phase and the output of the asymmetry filter are shown in Fig. 3(a)–(c), respectively. A differentiated increase in the amplitude value is evidenced in the output of the asymmetry filter when short-circuit is applied in 3 s, as shown in Fig. 3(c). The filter is able to provide a response with a differentiated value in the occurrence of short-circuit compared to a power swing. As for faults during low and/or high power swing frequencies, the distinction of short-circuit through the filter is evident, providing well-established decision making and posterior reset of blocking against power swing in protection relays. The proposed methodology aims to help the protection relay to reset PSB function, in the occurrence of fault during power swing. For the output signal is applied a 2nd order low-pass filter with cutoff frequency of 35 Hz in order to obtain a cleaner response. This value was also moved to 0.5 in vertical axis considering as reference the FAC value in normal operation.