Electrical Power and Energy Systems 64 (2015) 24–34

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

An effective combined method for symmetrical faults identification during power swing

Zahra Moravej *, Jamal Dehghani Ashkezari, Mohammad Pazoki

Electrical and Computer Engineering Faculty, Semnan University, Semnan, Iran

A R T I C L E I N F O

Article history:
Received 29 May 2013
Received in revised form 5 June 2014
Accepted 6 July 2014

Keywords:
Power swing
Symmetrical faults identification
S-Transform
Feature extraction
Probabilistic Neural Network

A B S T R A C T

This paper presents a new protection scheme based on combination of S-Transform (ST) and Probabilistic Neural Network (PNN) methods to identify symmetrical faults during power swing conditions. The ST, an effective time–frequency decomposition transform, is used for extraction of beneficial features from a half cycle of the current signal. The constructed features vector is fed to a PNN classifier as an input pattern. No need to set the initial weights is the key attribute of PNN. The discrimination capability of extracted features which is the main contribution of the proposed method is investigated under different circumstances. The simulation results show that the protection scheme identifies a symmetrical fault during power swing correctly. Moreover, the proposed intelligent scheme has a fast performance due to the low computational burden of the combined methodology. The efficacy of the proposed scheme is confirmed by comparing with some of existent algorithms.

Introduction

One of the main aspects of the power system is safe operation of its protection unit. In order to prevent widespread outage in the power network, system disturbances and their influxes on the protection unit performance must be assessed. Transmission lines are vital arteries to provide electrical power for consumers and have a significant role in the power system stability. However, incorrect operation of distance relay under different conditions, such as power swing, is the most important reason in large disturbances in the United States. For instance, the largest blackout which occurred in the North of the United States and the South of Canada on 14th August 2003 caused the loss of 50 GW for 50 million consumers. The reason of this blackout was improper operation of zone 3 of distance relay under overload and power swing, which eventually led to the collapse of the power system [1–3]. Thus, studies of system disturbances and their impacts on the performance of distance relay for increasing of power system security and reliability are inevitable.

Power system under steady state conditions has a balance between product and consumption active/reactive power. Also, the sending and receiving end voltages are in the range of 5% deviation from their nominal values. The interval deviation of system frequency is ±0. 2 from the nominal frequency [2]. Generally, events such as faults of transmission line, loss of generation units, switching of lines with heavy loading, and sudden change in large loads cause power swing occurrence in the system. Power swing leads to fluctuate the transmitted power, voltage and current at distance relay location, and apparent impedance seen by the relay may arrive at one or more protection characteristics. In order to avoid undesirable operation of distance relay during power swing, it must be blocked. Some of the researches focus on distinguishing power swing from fault. Concentric circles and blinders schemes are two main traditional methods for above-mentioned purpose [2]. But distance relays should be able to detect faults during power swing immediately. The most common technique for detection of faults during power swing is based on the presence of zero and/or negative sequence component(s). Since power swing is talented to make mal-operation of distance relay, but lacks such component(s) [4–7]. Therefore, this criterion is efficient for detection of all faults except symmetrical one, because both symmetrical fault and power swing are symmetric events. Consequently, the major challenge is symmetrical fault identification during power swing conditions.

A number of papers in the literature deal with identification of symmetrical faults during power swing [8–13]. In [8], a method based on changes in the active/reactive power is introduced for detection of symmetrical faults during power swing. It needs to continuous zero crossing detection of dP/dt and dQ/dt. In addition, effect of fault impedance on the threshold value is not considered. Digital signal processing techniques such as Wavelet Transform

* Corresponding author.
E-mail address: moravej.zahra@gmail.com (Z. Moravej).

http://dx.doi.org/10.1016/j.ijepes.2014.07.039
0142-0615/

(WT) [9], S-Transform (ST) [10], and Fast Fourier Transform (FFT) [11] beside learning machines such as Support Vector Machine (SVM) [14] and PNN [15] are used to analyze the power protection system. In [9], a fast WT-based technique for extraction of the energy from high frequency components of voltage and current travelling waves is presented. In [12], a scheme for symmetrical faults detection during power swing is suggested according to dc component of the fault current signal. In [13], differential power using auto-regression is proposed. This method is sensitive to the presence of harmonics and noise, and effects of both are not considered. In [16], a fault detection technique for the series-compensated line during power swing is introduced. Advantages and disadvantages of [8–13] are discussed at the end of this paper.

In this paper, a protection scheme based on combined PNN and ST is provided. Employment of two extracted features from a half cycle of current signal by a PNN result in fast response time. Moreover, low dimension of extracted features lead to the low computation burden and memory space requirement. Then, extracted features are fed to a PNN. Prominent characteristics of PNN are inherent simple structure and fast training process. Consequently, by symmetrical fault detection during power swing, the distance relay can make proper decision (send trip or keep on block command). To obtain realistic data for training and testing of classifier, behavior of the generator is controlled by the exciter and governor. Simulation results during various conditions are carried out in the MATLAB/SIMULINK environment. The article makes a comparison between proposed scheme and dc component-based method in more details. Finally, the proposed scheme performance is compared with some of previous similar works. The structure of this paper is organized as follows:

In next section case study is introduced. Section 'Distance relay behavior during power swing and fault' describes behavior of distance relay during power swing and fault. In Section 'Preliminaries', ST and PNN are described. Structure of the proposed method and feature selection are discussed in Section 'Proposed protection scheme'. Performance of the proposed method with simulation results are discussed in Section 'Simulation results'. In Section 'Performance comparison with previous methods', the proposed method is compared with previous methods. Finally, the conclusion is given in Section 'Conclusions'.

Case study

To generate training and testing data, simulation of power swing and faults carry out on a Single Machine to Infinite Bus (SMIB) system [10,12,13], as shown in Fig. 1. In sample system, Generator 2100 MVA, 13.8 kV by step up transformer 2100 MVA, 13.8 kV/250 kV is connected to transmission lines with 300 km length. The nominal frequency of the system is 60 Hz. Details component of generator, exciter system and the turbine – governor is modeled in the MATLAB/SIMULINK environment. The sample system data are given in [17]. The relay performance located in point *R* is evaluated. To this end, a three-phase fault occurs at line B. The fault duration varies from 3 to 12 cycles. It causes power swings occurrence with different slip frequency (f_s) in line A. Now, the symmetrical faults are simulated under different conditions in line A.

Distance relay behavior during power swing and fault

As mentioned in Section 'Introduction', voltages and currents will be fluctuated during power swing. Fig. 2 shows voltage and current waveform during a typical power swing. According to Fig. 2, when the amplitude of the voltage is in its maximum value, amplitude of current is in its minimum value and vice versa. Therefore, the apparent impedance seen by the relay seems to impedance trajectory corresponding to a fault. Fig. 3a depicts entrance of measured impedance trajectory to the MHO circles due to power swing occurrence. In this particular case, the impedance trajectory enters to the protection zone 2 after 11.5 cycles from starting of power swing. It must be said that in this especial case, slip frequency of power swing and line loading are slow ($f_s = 1$ Hz) and normal, respectively. In heavy loading and fast power swing conditions ($f_s = 7$ Hz), the number of cycle can be much smaller. Anyhow, distance relay should detect power swing before entering of impedance trajectory to protection zones rapidly, and it must be blocked to prevent unwanted operation.

In Fig. 3b, entrance of measured impedance trajectory at relay location during fault is shown. In this case, less than 1 cycle (0.0067 s) is taken for entrance of impedance trajectory to zone 2. Here, it can be deduced that quantities such as current, voltage, and impedance during the fault change faster than those of power swing [2]. Fig. 3c represents an impedance trajectory of a symmetrical fault during power swing conditions. The blocked relay (due to power swing conditions) must be unblocked and clears the fault. The detection of these symmetrical faults during power swing is a challenging task for the distance relay. In [18], more detailed study of power swing characteristic and distance relay behavior is presented.

Preliminaries

S-Transform

ST is a linear operator and it is known as a time–frequency representation [19]. The key feature of ST which distinct from those of other tools, is its accuracy in demonstration of amplitude and phase of both time and frequency domain simultaneously. One drawback of FFT is that only gives frequency spectral and provide no information in relation to time domain. Consequently, FFT is proper for processing of stationary signals that their characteristic of time series is time-invariant. In order to solve this problem, Short-Time Fourier Transform (STFT) was suggested. In STFT, the function to be transformed is multiplied by a window function

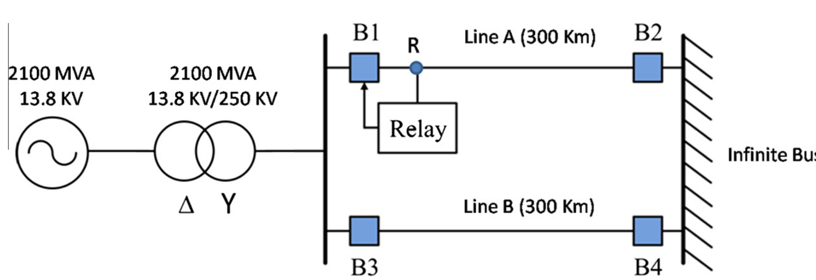

Fig. 1. Single line diagram of sample system.