Applied Soft Computing 36 (2015) 375–382

Contents lists available at ScienceDirect

Applied Soft Computing

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

Two novel proposed discrete wavelet transform and filter based approaches for short-circuit faults detection in power transmission lines

Hassan Fathabadi*

Engineering Department, Kharazmi University, Tehran, Iran

ARTICLE INFO

Article history:
Received 6 February 2015
Received in revised form 20 June 2015
Accepted 29 July 2015
Available online 7 August 2015

Keywords:
Discrete wavelet transform (*DWT*)
Soft computing method
Filter based technique
Power transmission lines
Short-circuit fault detection

ABSTRACT

In this study, two approaches are presented to detect short-circuit faults in power transmission lines. The two proposed methods are completely novel from both theoretical and technical aspects. The first approach is a soft computing method that uses discrete wavelet transform with Daubechies mother wavelets db1, db2, db3, and db4. The second approach is a hardware based method that utilizes a novel proposed two-stage finite impulse response filter with a sampling frequency of 32 kHz, and a very short process time about three samples time. The two approaches are analyzed by presenting theoretical results. Simulated results obtained by simulating a three-phase 230 kV, 50 Hz power transmission line are given that validate the theoretical results, and explicitly verify that the filter based approach has an accuracy of 100% in presence of 10% disturbance while the accuracy of the wavelet transform based approach is maximally 97%, but it has less complication and implementation cost. Another comparative study between this work and other works shows that the two proposed methods have higher accuracy and very shorter process time compared to the other methods, especially in presence of 10% disturbance that actually occurs in power transmission lines.

1. Introduction

A transmission line is one of the important elements of an electric power system. Since 1945, electric power systems have been extremely developed because the steep increase in population of most countries has caused a huge increase in electric energy demand [1,2]. As a result, power transmission lines have been rapidly developed both in number and length. One important factor of an electric power transmission system is to continuously deliver the electric power to consumers. A problem related to electric power systems is faults occurrence in power transmission lines which is an unfavorable and inevitable issue. Short-circuit faults are the worst types of the faults occurring in power transmission lines. Short circuit faults have many harmful effects on the electrical distribution systems and devices. Some harmful effects are: shortening the life of the electrical devices, increase in power losses, and additional heat produced by cables, wires, insulators, transformers, etc. [3]. When a short-circuit fault occurs in a transmission line, power outage is the first result which is carried out by protection relays, and consequently, there is an interrupt in delivering the electric power to consumers. Thus, utilizing some methods or using some devices having capability to determine faults location quickly and accurately are necessary. In recent years, applications of artificial neural network (ANN) in power systems such as stability and transient response analysis have attracted many attentions [4,5]. As an application, fault analysis in power transmission systems using ANN has been subject of some researches [6–9]. Based on a radial basis function (RBF) neural network with orthogonal-least-square (OLS) learning procedure, a simple fault classification method was reported in [10]. The method identifies various patterns of associated voltages and currents, but it does not have the capability of fault location, and furthermore, some faults cannot be classified because the method can not identify all possible patterns related to different faults. The RBF neural network was also compared with the back-propagation (BP) neural network, and it was shown that the RBF neural network classifies faults better than BP neural network [10]. Discrete wavelet transform (*DWT*) as a soft computing tool has been used in different applications [11–13]. In some researches, wavelet transform has been combined with other topics such as ANN and fuzzy systems to form hybrid frameworks [14–19]. A fault detection and classification method which uses

* Current address: National Technical University of Athens, Greece.
Tel.: +98 9714321; fax: +98 9714321.
E-mail addresses: h4477@hotmail.com, h.fathabadi@khu.ac.ir

http://dx.doi.org/10.1016/j.asoc.2015.07.039
1568-4946/

discrete wavelet transform in combination with ANN was reported in [20]. The technique is absolutely theoretical and fault location is impossible. A method based on S-transform (ST) and support vector machines (SVMs) for classification and identification of a faulty section in a transmission line with a fixed series capacitor placed at the middle of the line was presented in [21]. To detect faults, distinctive features of line voltages, currents, and zero sequence current are used. The relevant features of these signals are obtained using ST, and then, the obtained features are used as input for multiple SVM classifiers, and their outputs are combined to classify the fault type [21]. Using frame-based sequence classification (FBSC), the Alternative Transient Program (ATP), and a public dataset, a framework was proposed for event classification in [22]. It was shown that the method can be used for classifying short-circuit faults in transmission lines. A fault location model of a transmission line that uses Elman recurrent network (ERN) was presented in [23]. Wavelet transform was again used for selecting distinctive features of the faulty signals, and then, ERN is utilized to determine the fault location using the features obtained by wavelet transform. The model can be only used for locating balanced short-circuit faults [23]. A technique for fault detection which uses finite impulse response artificial neural network (FIRANN) was proposed in [24]. For training the FIRANN, the training patterns obtained from more than one relaying position were used in order to obtain better result. The proposed FIRANN-based method uses voltage and current samples at 2 kHz to detect faults [24]. Faults classification in transmission lines using data mining was reported in [25]. The ATP simulator was utilized to produce a comprehensive labeled dataset which is necessary to classify faults. A comparison between different processing methods and algorithms such as wavelets, decision trees, and neural networks showing better performance of neural networks was addressed in [25]. A survey in the literature shows that there are other similar researches as follows that the accuracy of each proposed algorithm in absence of any disturbance has been also reported. Particle swarm optimization (PSO) together with ANN was used to classify faults in [26]. Fuzzy logic was applied for fault classification in [27]. A method for protection of power systems using SVMs was addressed in [28]. Detection and classification of faults in power transmission lines using functional analysis and computational intelligence was reported in [29]. It is worthwhile to note that in a practical power transmission line, the disturbance is always available in the transmission line, but as mentioned, the above works have been reported the accuracy of their algorithms in absence of any disturbance.

In this study, two novel approaches are presented for short-circuit faults detection in power transmission lines. The first approach is a soft computing method that uses *DWT* with Daubechies mother wavelets. The novelty of this application of *DWT* is that the detail coefficients down sampled and obtained by utilizing wavelet transform are only used to detect a short-circuit fault, and furthermore, a difference function between the detail coefficients in different times is performed to completely eliminate the effect of the usual disturbance that actually occurs in a transmission line. In fact, using detail coefficients and completely eliminating the effect of the disturbance are the two distinct differences between the *DWT* based method proposed in this work and the similar applications of *DWT* such as that reported in [30]. For example, the method presented in [30] uses approximate coefficients, and there is not any consideration for robustness of the method against the actual disturbance of the transmission line. It is worthwhile to note that using approximate coefficients for fault detection in a power transmission line cannot be practically used because approximate coefficients are actually the low-frequency components of the power signal transmitted on the line. On the other hand, the power signal itself is a low-frequency signal, so the magnitude of the power signal effectively impacts on the obtained approximate coefficients.

The second approach is an entire hardware based method that uses a proposed two-stage finite impulse response (FIR) filter. The first stage is a FIR comb filter, and the second stage consists of four FIR band-pass filters. For the first time, the center frequencies of the four FIR band-pass filters are obtained in this research. The structure of the proposed two-stage FIR filter is completely novel, and there is not any other entire hardware based method or filter with similar structure or capability reported in the literature. For example, the research addressed in [31] deals with estimating the time-instants of abrupt changes in the signal recorded in digital fault recorders (DFRs), the method does not detect any type of faults such as short-circuit faults. It only analyzes the recorded signal to determine the time-instants before fault occurrence, initiation of fault, circuit-breaker opening, and auto-reclosure of the circuit-breakers. At first, a simple first-order adaptive whitening filter with sampling frequency of 2.5 kHz is used to reduce the noise of the signal recorded in DFRs, and then, the detailed and smoothed components of the signal are extracted using *DFT*. Finally, a time-instant of abrupt changes is detected when the wavelet coefficients exceed the universal threshold of Donoho and Johnstone. Thus, the simple filter used in [31] only reduce the nose, but the two-stage FIR filter presented in this work itself alone detects a short-circuit fault in a power transmission line without any assistance, even using DFRs. Similarly, the first approach (*DWT* based method) proposed in this work is a single-handed method.

The rest of this paper is organized as follows. The wavelet transform based approach is presented in Section 2. Section 3 deals with the second approach. Simulated and comparative results are presented in Section 4 to validate theoretical results, and to verify the superior performance of the two proposed approaches. Section 5 concludes the paper.

2. Proposed wavelet transform based approach for short-circuit faults detection

Discrete wavelet transform (*DWT*) of a signal such as $x(t)$is defined as [30,31]:

$$DWT(m,n) = \frac{1}{\sqrt{a_0^m}} x(k)\psi\left(\frac{n-kb_0a_0^m}{a_0^m}\right) \qquad (1)$$

It can be summarized that *DWT* is an extended form of the discrete Fourier transform (*DFT*), so that, it can be applied to the signals such as non-stationary signals with non-iterative features that *DFT* can not be used to analyze them. When a short-circuit fault occurs in a power transmission line, some transient features appear in the magnitudes-time and phase-time characteristics of the three-phase current flowing through the power transmission line. In this section, *DWT* is used to extract the mentioned transient features of the three-phase current, and then, the obtained features are used to detect short circuit faults. In fact, the three phase currents are decomposed using *DWT* to extract the produced high frequency transient features caused by the short-circuit fault(s), so choosing mother wavelet type is very important issue. In this research, Daubechies (db) wavelet is considered as mother wavelet because it has better features for protection applications [30]. There are four different types of Daubechies wavelet which are called db1, db2, db3, and db4 [31]. All the four types with $a_0 = 2$, $b_0 = 1$, and one-level operation are used to detect short-circuit faults, but as will be shown the mother wavelet db4 has better performance and accuracy. To clarify the subject, *DWT* with the one-level mother wavelet db4 has been applied to the signal $x(t)$ shown in Fig. 1(a), the approximation coefficient (A_x) and detail coefficient (HF_x) resulted