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Arcing fault identification using combined Gabor Transform-neural network for transmission lines

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ABSTRACT

This paper presents an intelligent identification scheme for transient faults in transmission systems using Gabor Transform (GT) and Artificial Neural Network (ANN). The successful discrimination between arcing and permanent faults can be then utilized for realize a reliable operation of autoreclosure systems. The proposed algorithm employs the GT as a signal processing technique and the ANN for pattern recognition and classification processes. The use of GT is motivated by the fact that the Gabor elementary functions have distinctive an optimal localization property in the joint time and frequency domains, which leads to an optimal feature extraction. The extracted GT coefficients are used as the inputs to a three layer feed-forward ANN. The generalization capabilities of neural networks together with the GT are expected to discriminate between arcing and permanent fault cases successfully. The fault behavior is simulated by ATP/EMTP where the arc model is realized using universal arc representation. Finally, the possibility of hardware implementation of the proposed scheme is visualized in order to verify its practicality and suitability for real field operation. The results show that combining of GT along with ANNs achieves an excellent performance to discriminate between arcing and permanent faults with eliminating the impacts of fault resistance, fault location and fault inception angle as compared with conventional discriminators.

Introduction

Most transmission line faults are single phase to ground faults and the most of them are transient ones. Transient faults can be cleared by momentary de-energizing the transmission line until the fault clears naturally. Then, the service can be re-stored by reclosing the circuit breaker. Therefore, autoreclosure scheme plays an important role in achieving reliable power systems. It consequently plays a major role for a sustainable improvement in the continuity of power system supply [1]. The autoreclosure schemes in transmission systems employed a fixed prescribed dead time in which it re-closes the circuit breakers after a fixed time delay following a protection trip. This scheme may cause a greater shock to the power system especially if the fault is permanent. In transient faults, arc restriking can threaten system stability and reliability because of insufficient time for fully de-ionization. In such circumstances, it has been recommended to forcedly extinguish the secondary arcs in order to reduce the dead time [2]. This can be correctly forced when the arcing fault is successfully identified. Therefore a reliable, dependable and secure protection system should be able to distinguish between transient and permanent faults in order to achieve high speed response to a sympathy trip, minimize unsuccessful reclosing and improve the system stability. During the past years, several techniques have been developed to address the arcing fault identification. An earlier system was proposed on late 1980s [3]. Some proposed techniques were developed using the restoring voltage of the tripped phases [3–5]. Other techniques were based on the high frequency content of the voltage signals [6,7]. Unfortunately, methods based on the tripped phase voltage suffer from inaccuracy as a result of the low levels of the measured voltages which burden high accurate estimation especially in case of transmission lines with shunt reactors. Moreover, the requirement of voltage transducers definitely limits the application of such techniques. In [8,9], other techniques based on transient arc-voltage characteristics have been proposed. However, such techniques were introduced to declare the instant of reclosing when the fault is transient fault. It is more reliable to give information for such techniques about the fault nature; arcing or permanent.

To overcome the problems associated with voltage signals, another technique has been presented using the high frequency contents of the current transients [10]. The technique depended on a dedicated signal processing algorithm to identify permanent

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faults. The algorithm computed the spectral energy and compared it with a predefined level. The choice of the optimal threshold value is a challenge as the sources of the high frequency components are unlimited. Moreover, this algorithm did not evaluate the effects of fault location and fault resistance well.

A scheme based on parameter identification was presented in [11] where the fault current signal was utilized. The key of this scheme was based on the inductance difference between the solved values and the actual ones to detect the fault nature and compare it with margin coefficients for identification. However, the choice of these margins was based on observation which may not be justified.

The aforementioned schemes may be highly affected with some factors such as transmission line construction, fault location, preloading source parameters and atmospheric conditions which in turns need introducing of artificial intelligence tools as proposed in [12]. A dedicated ANN was trained using extended delta bar delta algorithm in which speed of convergence was improved. The feature extraction was based only on some specific frequency components. Choice of these features or frequency bands was unfortunately implemented by observation.

Moreover, these techniques employed Fast Fourier Transform as a signal processing algorithm. In spite of the efficient computation of Fourier Transform (FT), it does not provide any relevant information pertaining to the non-stationary signals or when translation in time changes the properties of the signal. Therefore for analyzing such signals more advanced platforms than FT is needed. The non-stationary behavior of the transients associated with the fault signals may lead to inaccurate results when using the FT. In order to overcome the problems associated with the FT, Wavelet Transform (WT) was recently utilized where it is an advanced signal processing technique. However, it does not give information on specific frequency harmonics; instead it gives information on frequency bands. Furthermore in all WT-based applications, the signal processing is made in general using wavelet transform, in this sense there is no consensus among the authors about the wavelet mother useful in each case, or a guide for specific ones in transients [13].

The GT is also an advanced signal processing tool for accurate phasor estimation purposes. Because the GT possesses the time-frequency localization characteristics, the time and frequency information of a waveform can be jointly presented. Therefore, this approach is suitable for estimating such phasors as opposed to FT-based methods. In spite of GT difficulty in calculating the transform coefficients, GT has been applied in power system applications as a measurement technique for detection and analysis of power system short time transient phenomena. In [14], the potential of this promising transform as an advanced signal processing techniques for power system application has been investigated. It was used for detection and analysis of power system short time transient phenomena as presented in [15]. It was used in [16] to observe power system harmonics for investigating power quality issues as seen in [17]. In [18], GT was applied for accurate fault location as well.

In this paper, an arcing fault identifier is proposed utilizing all frequency components of the current signal of the faulted phase. The scheme utilizes the GT as an advanced signal processing technique for optimal features extraction. GT has superior characteristics including time localization and frequency resolution which make it suitable for such applications. The scheme also uses the ANN to discriminate between the transient and permanent faults. Unlike the previous work in which features extraction were based on either low order harmonics or high frequency components, the proposed ANN classifier utilizes both high and low frequencies associated features for precise fault identification. As seen in the literatures, the ANNs (when combined with signal analysis or pattern recognition mechanisms) are capable of analyzing complex fault transients and incipient arcing conditions. This was in spite of using simple ANN structures such as the feedforward one [19–22]. The proposed scheme does not depend on measuring voltage in the network along with its associated burden. Also, the proposed scheme does not depend on adjusting threshold or discrimination coefficients. Moreover, the nature of the ANN allows it to compensate for any errors or noise associated with measuring instrumentation and will have a low impact on network correct decision. The test results clearly demonstrate the technical feasibility of the proposed technique.

Proposed technique principles

The application of GT and ANN in order to implement the arcing fault identifier is described in Fig. 1. Phase current signals at the relaying location are extracted, sampled, and then fed to the ANN-based Gabor coefficients extractor. These coefficients represent the extracted features of current signals. As shown in Fig. 1, there are two ANNs. The first one is a network that is used for GT coefficients extraction through online training. The second one is used for pattern recognition to classify the fault nature. The extracted Gabor coefficients are fed to the adopted feedforward ANN-based classifier that will identify whether it is permanent or transient fault. The classifier network is a three layer back propagation type network that is pre-trained with different fault cases using supervised training. If the fault is classified as a transient one, adaptive autoreclosure algorithm can be initiated. For the case of transient faults it is recommended to store fault occurrence information for further analysis. The Gabor coefficients can be stored in that case taking the advantage of energy packing capability of the GT.

1-D Gabor Transform coefficients extraction

Basically, the 1-D Gabor Transform is a special case of the Short Time Fourier Transform (STFT), where the window function is of Gaussian shape. Unlike the STFT, the basis functions of the GT are formed from the resultant product of a harmonic oscillation of any frequency (basis functions of the FT) with a window function of a Gaussian form as follows:

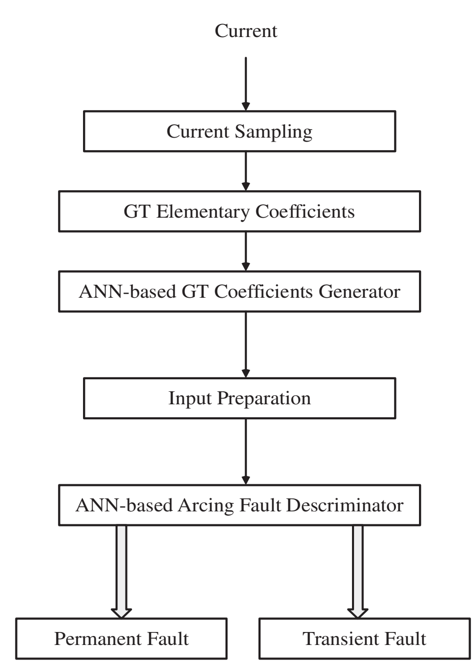

Fig. 1. Gabor Transform based arcing fault identification block diagram.