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High impedance fault detection in power distribution systems using wavelet transform and evolving neural network

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ABSTRACT

This paper concerns how to apply an incremental learning algorithm based on data streams to detect high impedance faults in power distribution systems. A feature extraction method, based on a discrete wavelet transform that is combined with an evolving neural network, is used to recognize spatial–temporal patterns of electrical current data. Different wavelet families, such as Haar, Symlet, Daubechie, Coiflet and Biorthogonal, and different decomposition levels, were investigated in order to provide the most discriminative features for fault detection. The use of an evolving neural network was shown to be a quite appropriate approach to fault detection since high impedance faults is a time-varying problem. The performance of the proposed evolving system for detecting and classifying faults was compared with those of well-established computational intelligence methods: multilayer perceptron neural network, probabilistic neural network, and support vector machine. The results showed that the proposed system is efficient and robust to changes. A classification performance in the order of 99% is exhibited by all classifiers in situations where the fault patterns do not significantly change during tests. However, a performance drop of about 13–24% is exhibited by non-evolving classifiers when fault patterns suffer from gradual or abrupt change in their behavior. The evolving system is capable, after incremental learning, of maintaining its detection and classification performance even in such situations.

1. Introduction

High impedance faults (HIFs) are common events in multi-grounded distribution networks. HIFs generally occur when an energized conductor comes into contact with an insulating or very poorly conductive surface such as concrete, asphalt, sand or tree branches. The resulting fault current may be equivalent in absolute value with the typical load current of a system, thus preventing overcurrent protection devices from operating correctly [1,2].

Several methods have emerged in recent decades that seek to obtain an effective HIF detection system. A survey of such detection methods is given by Ghaderi et al. [1]. Among the most successful methods are those based on combining a feature extraction algorithm and a pattern recognition technique. Feature extraction is desirable mainly because the electrical currents associated with HIFs are nonlinear, asymmetric, and time-varying [1]. Extracted features usually facilitate HIF detection by means of pattern recognition tools, which are specially designed for the purpose.

Among these research studies, we highlight [3] whose main contribution is to show that a pure simulation based procedure, using HIF models, can be used to investigate new schemes for detecting HIFs. The paper by Samantaray et al. [4] introduces the use of a probabilistic neural network as a pattern recognition tool for HIF detection. The paper is also a pure simulation-based study. Reference [5] is a research study based on Discrete Wavelet Transforms and on an Artificial Neural Network (DWT-ANN) arrangement. It introduces a detection method based on an ensemble of decision trees. An extended Kalman filter is used to analyze the magnitude and phase of the harmonics in the HIF current. In [6], a complete WT-ANN detection scheme is presented. A HIF model is also proposed by the authors in order to simulate the dynamic characteristics of electric arcs. The paper also highlights the importance of the robustness of the method against typical transients in power systems. Use of a neural-fuzzy inference system (ANFIS) in a HIF detection method is proposed by Etemadi and Sanaye-Pasand [7]. The authors also investigated the best wavelet family to be used for feature extraction. This analysis is usually ignored by other HIF

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detection studies. The detection scheme proposed by Michalik et al. [8] is an example of using of the DWT as feature extraction method; however, the authors did not use a pattern recognition tool for classification. The detection process can be distinguished from others due to its simplicity and effectiveness. The article by Santos et al. [9] is a recent simulation-based research study, in which the most important contribution is the way to identify the location of HIFs with good overall precision, which results in a 70% reduction of the location time in some cases.

Ideally, fault detection systems should be: (i) highly efficient, meaning that the detection rate should be high; and (ii) robust, meaning that the system should not give false positives when typical transitory events occur on a power system, e.g. due to capacitor switching or transformer energization. In particular, some detection schemes have been proposed using wavelet transform as a feature extraction method and different types of artificial neural networks as tools for pattern recognition. In some studies, neural-wavelet systems were subject to typical transitory events and showed significant robustness [4,8,10].

All research studies discussed above use intelligent classifiers with fixed topology. This means that their structures (rule base or connections and neurons of a neural network) are rigid and pre-constructed. A fixed number of neurons in the hidden layers of a neural network must be defined by the user based on tests or previous experience. Occasionally, a learning algorithm is used to create the network hidden layer based on training data. In Support Vector Machines, the number of support vectors is defined during the training process. For each case mentioned, a unique learning approach is applied to set the parameters of the classifier. Once trained, the resulting topology is static, i.e., the neural structure or support vectors cannot be changed. This means that the classifiers cannot learn during their online operation. If new information needs to be added to the classifier, a new offline training process from scratch must be performed, thus adding the new samples to the training dataset. Undertaking pattern recognition tasks that deal with non-stationary data is a typical situation in which the ability to add new information to the system is of great value [11,4]. That is the case of the HIF detection problem since fault patterns can change due to a series of factors. A classifier that is able to learn continuously from its environment, thereby adapting its structure and parameters, can maintain its performance. On the other hand, a typical intelligent system can lose its ability to detect patterns.

This paper introduces an adaptive HIF detection method to deal with power systems in changing situations. The primary goal is to outperform the existing detection and classification methods by exploring online incremental learning procedures to find new fault patterns in streams of data [12,13]. The proposed method is based on using a discrete wavelet transform approach for feature extraction and an evolving artificial neural network for HIF recognition. Evolving neural networks differ from classical neural networks mainly because they do not have a fixed topology. References [11,14–17] are examples of evolving fuzzy neural networks. These systems are very flexible to the data and able to adapt their structure online, thus allowing the system to learn in non-stationary environment. References [11,17] are examples of evolving granular neural networks (eGNN) for classification. eGNN classifiers are able to undertake structural and parametric adaptation to handle abrupt and gradual changes that are typical in non-stationary environment. Another class of evolving networks is proposed by Rubio [16]. The paper describes an algorithm that has the ability to reorganize the network model to a changing environment, where structure and parameters are adapted simultaneously. Several classes of evolving intelligent systems discussed in [18,19] may be useful for further reference.

The existence of an evolving layer of neurons allows neural networks to change their connectionist structure to fit new information dynamically. Evolving neural networks have the following advantages: (i) fast learning due to one-pass incremental training; (ii) great resistance to catastrophic forgetting; and (iii) good generalization ability. These characteristics are advantageous especially because HIF current waveforms suffer from different types of changes. In other words, because signals and patterns are time-varying, the performance of ‘non-evolving’ classification models may drop substantially [18,19,11].

In order to compare the performance of the proposed evolving wavelet-neural system with the performance of other methods and systems, several families of wavelets are used for feature extraction and four types of classification models are considered for fault detection. They are the well-known Multilayer Perceptron Network (MLP), Probabilistic Neural Network (PNN), Support Vector Machine (SVM), and the evolving neural network, namely, Simple Evolving Connectionist System (SECoS). Non-evolving classifiers, such as MLP, PNN and SVM, exhibit the usual features of intelligent systems: (i) fixed topology during operation; (ii) all data samples are required to be available for offline training; (iii) they require multiple passes over the training samples; and (iv) they are subject to catastrophic forgetting if new patterns need to be learned [20]. SECoS addresses these weaknesses by adding and deleting neurons and/or adapting neural connections online [18]. SECoS is able to engage on online one-pass-through-the-data training, thus offering prevention from catastrophic forgetting. This paper shows the advantages of using wavelet decomposition combined with an evolving neural network considering the HIF detection problem.

The remaining of this paper is organized as follows. Section 2 introduces the HIF detection problem. Section 3 addresses the evolving neural network model and discusses its topology and learning algorithm. Sections 4 and 5 present the experimental results. Different classification models are compared and the advantages and disadvantages of the proposed wavelet-SECoS method for HIF detection are presented. Section 6 provides conclusions and suggestions for further investigations.

2. HIF detection

This section describes the HIF detection method used in this work and its main characteristics. A general flowchart of the proposed detection scheme is shown in Fig. 1. Fundamentally, the flowchart consists of three elements: (i) a medium voltage network HIF algorithm; (ii) a feature extraction method performed over current signals; and (iii) an evolving intelligent method for recognition of patterns in data streams. Medium voltage network HIF simulation is carried out by using ATP (Alternative Transients Program) and its graphical processor ATPDraw. Feature extraction and pattern recognition algorithms are implemented in Matlab.

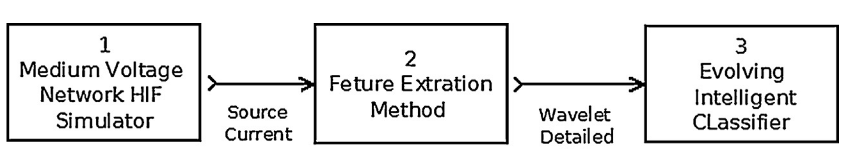

Fig. 1. Flowchart of the proposed HIF detection scheme.