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A review on hybrid wavelet regrouping particle swarm optimization neural networks for characterization of partial discharge acoustic signals

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ABSTRACT

Partial discharges (PD) emit energy in several ways and in the process, electro-magnetic emissions in the form of radio waves, light and heat, audible and ultra-sonic acoustic emissions are produced. These emissions enable the detection, location, measurement and analysis of the PD activity. PD activity is a precursor to failure thus it is construed as fault activity that must be addressed to prevent unplanned power losses. To prevent these unplanned failures that could result in power and revenue losses, an intelligent model that can detect, identify and characterize acoustic signals due to partial discharge activity has been proposed. The model is capable of differentiating abnormal operating conditions from normal ones. This paper highlights some smart techniques which have recently been used to identify the partial discharges on electrical overhead network that will guarantee sustainable and reliable energy savings. Furthermore, the main focus of this review is on a hybrid algorithm combining particle swarm optimization (PSO) with a neural network, referred to as PSO-NN.

Contents

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1. Introduction

In power systems, high voltage (HV) equipment can be monitored by using partial discharge (PD) technique, PD technique has been instrumental in condition monitoring of HV equipment due to its effectiveness during service. HV equipment experience thermal, electrical and mechanical stresses thereby becoming vulnerable to ageing which can ultimately lead to insulation failure [1]. Flashover phenomena on high voltage outdoor insulators are a serious threat to safe operation of transmission systems. In polluted areas, airborne particles are deposited on insulator surface, gradually building up pollution deposits. Under dry conditions, these deposits do not pose a threat to the insulation electric strength. However, when the deposits are moist a conductive layer is formed promoting the flow of large leakage current. The leakage current density is non-uniform and in some areas sufficient heat is developed leading to the formation of dry bands, which can be bridged by one or more partial arcs; these arcs are generally precursors to transmission line contamination flashover. Preventive maintenance by insulator washing is fundamental to reduce flashover risk, but it is very costly [2]. Thus, to systematically manage scheduled washing of these insulators, a warning system should be employed which will only trigger when PD occurs on the surface of the insulator. Therefore, an additional intelligent system capable of detecting and characterizing the various types of PDs that normally occur on HV lines is required. In order to design such a system, it is crucial to know what causes PDs and what methods are currently in use to locate PDs [3].

PD activity generates both physical phenomena and chemical changes within the dielectric material, causing the transmission of acoustic, electrical and optical energy that can be detected and analysed using appropriate sensors. The acoustic technology for target detection has developed very rapidly in the past few years [4] and therefore strong tools such as signal processing and feature extraction for the detection of such a PD condition are required [5]. Several researchers have successfully used acoustic detection methods for studying the characteristics of electrical discharges on insulators [6]. Many signal analysis techniques have been used, such as Fourier transform [7], wavelet transform (WT) [8], as well as neural networks in order to characterize and classify the electrical discharge signals [9,10].

Wavelet transform (WT) has been successfully employed in various fields for signal processing as well as shape optimization to improve the quality characterization of partial discharges (PD).

Artificial neural network (ANN) is a computing system whose fundamental concept is taken from analogy of biological neural networks [11]. The artificial neural network is a network of interconnected elements. In general the function of neural network is to produce an output pattern with an input pattern. ANN is made up of many computational processing elements called neurons or nodes. These nodes operate in parallel and are connected together in topologies that are loosely modeled after biological neural systems. The training of ANN is carried out to associate correct output responses to particular input patterns [12]. Neural networks can learn from experience and provide an output of at least a best guess under any circumstances [13]. Among the different structures of artificial neural networks (ANNs), the multilayer perceptron with the error-back-propagation training algorithm, called the back-propagation network (BPN), is the most popular [14]. However, due to its multi-layered structure and the greedy nature of the back-propagation algorithm, the training process often settles in an undesirable local minima of error surface or converges slowly. Recently, radial basis function neural networks (RBF-NNs) have been found to be very attractive for many problems [15].

Radial Basis Function Network emerged as a variant of artificial neural network in late 1980s. However, their roots are entrenched in much older pattern recognition techniques such as potential functions, clustering, functional approximation, spline interpolation and mixture models. The construction of a RBF network in its most basic form involves three entirely different layers. The input layer is made up of source nodes (sensory units). The second layer is a hidden layer realizing radial basis functions with high enough dimensions, which serves a different purpose similar to the multilayer perceptron. The output layer supplies the response of the network to the activation patterns applied to the input layer. The transformation from the input space to the hidden-unit space is nonlinear, whereas the transformation from the hidden-unit space to the output space is linear [16]. The RBF neural network is a forward network model with good performance, global approximation, and is free from the local minima problems. It is a multi-input, multi-output system consisting of an input layer, a hidden layer, and an output layer. During data processing, the hidden layer performs nonlinear transforms for the feature extraction and the output layer gives a linear combination of output weights [17]. An important property of the RBF-NNs is that they form a unifying link among many different research fields such as function approximation, regularization, noise interpolation, pattern recognition, and medicine. The increasing popularity of the RBF-NNs is partly due to their simple topological structure, their locally tuned neurons, and their ability to have a faster learning algorithm than other multilayer feed forward neural networks.

In researches, determining the structure and parameters of RBF-based neural networks promptly and efficiently has always been an issue. These parameters include the position of RBF centres, the width of RBFs, and the weights [18]. The main disadvantage of this method is that it is very difficult to quantify how many centres are required to cover the input vector space. Furthermore, the training algorithm is prone to getting stuck in local minima. The selection of these optimal parameters plays an important role in various training algorithms [19]. A single parameter choice has a tremendous effect on the rate of convergence. In this study, the optimal parameters are determined by the PSO algorithm, to calculate the number of centres and all other parameters of the WRBF-NN and also to overcome the premature convergence so as to help the swarm escape from the state of stagnation by using the idea of a regrouping technique [20].

This work describes and portrays the great capabilities of WT to extract unique features from the signal of the PD, which, when combined with a Radial Basis Function Neural Network (RBF-NN) and optimized using a Particle Swarm algorithm, produce very high classification accuracy.

Partial discharges (PDs) have been described as small electrical discharges which are caused by high and inhomogeneous electrical fields that are generated in insulators [21]. The life of a HV power equipment is highly dependent on the quality of its insulation [22]. Acoustic technology has been used to detect PDs.