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Fault diagnosis system for series compensated transmission line based on wavelet transform and adaptive neuro-fuzzy inference system

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ABSTRACT

This paper proposes a new fault diagnosis approach based on combined wavelet transform and adaptive neuro-fuzzy inference system for fault section identification, classification and location in a series compensated transmission line. It performs an effective feature extraction approach based on norm entropy in order to obtain the features represented main frequency, harmonic and transient characteristics of the fault signals. The proposed method uses the samples of fault voltages and currents for one cycle duration from the inception of fault. The feasibility of the proposed method has been tested on a 400 kV, 300 km series compensated transmission line for all the ten types of faults using MATLAB/Simulink for a large data set of 23,436 fault cases comprising of all the 10 types of faults. Fault signals varying with fault resistance, fault inception angle, fault distance, load angle, percentage compensation level and source impedance are applied to the proposed algorithm. The results also indicate that the proposed method is robust to wide variation in system conditions and has higher fault diagnosis accuracy with regard to the other approaches in the literature for this problem.

1. Introduction

A fault event happening in power systems both causes damages in the devices of the system and leads to significant power quality problems. Accurate fault diagnosis which includes fault classification and fault location estimation is a very important task in power transmission systems in order to both restore power supply as soon as possible with minimum interruption and determine which phase was affected considerably. Therefore, classification and location of faults on power transmission systems can save time and resources for the electric utility industry.

Nowadays, series compensated transmission lines are commonly used in the power systems in order to achieve an improved enhancement of transmittable power, improvement in the system stability, reduction in transmission losses and more flexibility in power flow control. However, a transmission line equipped series capacitors with overvoltage protection devices, typically metal–oxide varistors (MOVs), has certain problems in terms of the protective system of the line. In the series compensated transmission lines, fault diagnosis is a very challenging task compared to that of an uncompensated transmission line because of the nonlinear behavior of a series capacitor arrangement, the rapidly changing characteristics of circuit impedance, and the high-frequency noise generated from the nonlinear protective devices of the compensation capacitors [1–5]. In the literature, various methods based on conventional techniques have been put forward to solve this problem for series compensated lines [6–8]. In [6], an algorithm based on traveling waves is proposed for the protection of series compensated lines. In [7], authors present a new one-end fundamental frequency based fault location technique. In [8], an elegant voltage compensation method based on calculating of fault impedance has been developed for protection of series compensated transmission lines. Recently, the various methods using artificial intelligence techniques have been reported for fault

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diagnosis in series compensated transmission system [9–16]. Some of the recent papers have used artificial neural network (ANN) [9], support vector machine (SVM) [10–12], fuzzy logic [13,14], probabilistic neural network (PNN) [15] and extreme learning machine [16]. In the proposed artificial intelligence based techniques, in addition to the usage of raw fault data [10,11], various signal processing methods such as wavelet transform (WT) [12,13,16,17], higher order statistics [14], S-transform (ST) [15] have been applied to the fault signals for obtaining distinctive features to the input classifiers or regressor algorithm. In [9], fault classification techniques using artificial neural network (ANN) have been used. Although the ANN based approaches have been quite successful in determining the correct fault type, ANNs have several important disadvantages such as determining a proper architecture problem, local optimum problem, bad convergence property, over-fit or under-fit problem. In [10], a SVM-based method for fault classification and section identification has been proposed. However, the authors have tested the performance of the proposed method using only 200 cases. In [11], authors present a fault classification technique using SVM. In [12], a SVM method based on the WT has been presented for only fault section identification. In [13,14], authors have proposed only fault classification algorithm. In [15], a PNN based method has been presented for both fault section identification and fault classification using S-transform. In [16], authors have presented a fault diagnosis approach which includes fault section identification, classification and location. In this approach, only high frequency coefficients of WT have been used. In [17], authors have suggested a WT based technique for protection of series compensated transmission lines. However, the sampling frequency is high (200 kHz), which may prove to be a little inconvenient for practical implementation.

In this paper, an attempt is made to identify the fault section, classify and locate the fault in a series compensated transmission line using a combined WT and adaptive neuro-fuzzy inference system (ANFIS). The proposed methodology relies on the fact that, in a series-compensated line, the signal features in the fault voltages and currents are generally different for faults occurring before and after the capacitor. Therefore, the main idea in this paper is to capture the features of the fault voltages and currents and utilize these features in an ANFIS algorithm to determine the fault section, type and location. For this purpose, after multiresolution analysis (MRA) with 6-level has been applied to each phase of fault signals, three efficient features representing the main frequency characteristic, harmonic characteristic and transient characteristic of signal are obtained. Thus, an effective feature vector representing fault signal is applied to the input of ANFIS algorithms. The proposed scheme has been tested on a 400 kV, 320 km series compensated transmission line under a variety of fault conditions. This proposed technique uses the one-cycle data measured at one end of the transmission line. A total of 23,436 training and test data are generated with different combinations of fault types and system parameters. In addition, experimental results indicate that the proposed methodology has a high identification accuracy compared to the other approaches in the literature for series compensated transmission line.

The novelty presented in this paper in comparison to other similar literature papers can be summarized as follows.

A norm entropy-based effective feature extraction method, by means of which fewer features than the number of selected MRA levels are obtained, is proposed. Using this method,

- The memory space and the computing time at both the training and testing processes of classifier can be decreased.
- The fault diagnosis accuracy percentage rate can be increased.

Another advantage of this paper is that proposed fault diagnosis approach based on ANFIS and WT is robust to wide variation in system conditions and has higher fault diagnosis accuracy, taking account of the fault diagnosis accuracies which have been both obtained in testing process using a large data set of fault cases and presented in other similar literature papers.

2. Preliminaries

2.1. Wavelet transform

WT discussed in [18] is a relatively new signal and image processing tool and has been applied recently by many researchers in power systems due to its strong capability of time and frequency domain analysis. In the studies containing of analyses the transient waveform, WT is an effective method since it examines different frequency components separately. Mathematically, the WT of a given signal with respect to a mother wavelet is defined in the continuous domain. However, for practical applications, a discretized version of the WT, called DWT is used. The DWT is normally implemented by Mallat's algorithm [19]. DWT uses the low-pass filter $h(k)$ (LPF) and the high-pass filter $g(k)$ (HPF) to divide the frequency-band of the input signal $f(k)$ in respective low-frequency and high-frequency components into octave bands. The LPF is determined from the scaling function. The HPF is determined from both the wavelet and scaling functions. The wavelet and scaling functions are respectively given as:

$$\psi(k) = \sqrt{2}\sum_n g(n)\phi(2k-n) \tag{1}$$

$$\phi(k) = \sqrt{2}\sum_n h(n)\phi(2k-n) \tag{2}$$

where n is integers and represents the number of samples. While the LPF produces the approximations A_j, the HPF produces the details D_j of the decomposition. The relationship of the approximation coefficients and detail coefficients between two adjacent levels are given as:

$$A_{j+1}(k) = \sum_n h(n-2k)A_j(n) \tag{3}$$