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Directional relaying using support vector machine for double circuit transmission lines including cross-country and inter-circuit faults

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ABSTRACT

The conventional distance relaying algorithms are unable to detect the inter-circuit faults, cross-country faults, high resistance faults which may occur in a double circuit line. This paper presents combined Discrete Wavelet Transform (DWT) and Support Vector Machine (SVM) based directional relaying and fault classification scheme including inter-circuit faults, cross-country faults and high resistance faults. SVM modules are designed for forward or reverse fault identification and fault classification using single terminal data. The 3rd level approximate discrete wavelet transform coefficients of three phase current signals only have been used. Proposed method is tested with variations in fault type, fault location, fault inception angle, fault resistance, inter-circuit faults, and cross-country faults. The proposed method based on SVM does not need any threshold to operate which is an exceptional attribute for a protective function. As SVMs are not based on comparing with some threshold, rather initially the SVMs are trained with the wide variety of fault patterns which is an offline process and then the trained SVMs are tested online to detect and classify the fault within short time. The test results show that all types of shunt faults can be identified within half cycle time. The proposed scheme offers both primary protection to 95% of the line section and also backup protection to 95% of the adjacent reverse and forward line section also.

Introduction

An electric power grid is spatially and temporally complex, non-linear and non-stationary system with uncertainties at many levels. Transmission lines carries and transfer power from generating station to load centre's and possibility of occurring faults is much more as compared to other components of electric power grid. The greater number of possible faults in double circuit transmission line like LG, LL, LLG, LLL, LLLG, inter-circuit faults [1,2], cross-country faults [1,2], high resistance faults, etc. demands the use of a relative more complex and reliable protection scheme. The protection of dual-circuit lines has various difficulties which arise from fault resistance, pre-fault power flow conditions; mutual coupling that exists between the circuits, and variety of faults that can occur on such lines. Mutual coupling is often considered to be the main concern when protecting dual-circuit lines. The conventional distance relaying algorithms are unable to detect the inter-circuit faults, cross-country faults, high resistance faults. This makes the task of developing an efficient protection system very challenging which is required for converting the conventional grid into a smart grid.

High speed directional relaying and fault classification are the prime objectives of any protection system of transmission lines in a highly interconnected network to increase the reliability. Various directional relaying algorithms have been developed in past employing phase angle difference of sequence components of voltage and current voltage [3,4], Mathematical Morphology [5], Travelling wave [6,7] and Intelligent techniques based on fuzzy logic [8], Artificial neural network [9]. However these techniques [3–9] does not identify the faulty phase.

Faults in power transmission lines are classified using different techniques during the past two decades. Fault classification technique [10] for double-circuit lines have been proposed based on a combined unsupervised/supervised neural network. A modified digital distance relaying scheme for inter-circuit faults only has been proposed in [11]. Furthermore, ANN based intelligent scheme [12] have been developed for providing different functions of protective relaying i.e. fault detection (both forward and reverse), classification, zone/section estimation to offers primary protection to 95% of the line length. But the drawback of ANN based schemes is that it requires large number of fault cases (patterns) for training. Another paradigm of artificial intelligent techniques known as SVM has been used for fault analysis [13–24] in electric power

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Nomenclature

Φ_i	fault inception angle	LG	line to ground fault
δ	power flow angle	LL	line to line fault
A1	phase A of circuit 1	LLG	double line to ground fault
A2	phase A of circuit 2	LLL	triple line fault
ANN	artificial neural network	LLLG	triple line to ground fault
B1	phase B of circuit 1	R_f	fault resistance
B2	phase B of circuit 2	S1	section 1
C1	phase C of circuit 1	S2	section 2
C2	phase C of circuit 2	S3	section 3
DB	Daubechies wavelet	SVM	Support Vector Machine
DWT	Discrete Wavelet Transform	t_i	fault inception time
G	ground		

system. The main advantage of SVM is that it requires less number of training patterns and less training time. Authors of [13] proposed the fault classification and section identification of an advanced series-compensated transmission line using support vector machine. Further SVM along with radial basis function neural network [14] has been used for distance relaying of transmission line. In [15] SVM has been used for fault detection in power transmission lines. Besides SVMs have been also used in conjunction with wavelet for fault zone identification and classification in [16,17] respectively and for fault classification in series compensated transmission line in [18]. SVMs have been used for fault classification/location in [19,20] and fault diagnosis in [21]. Another fault classification scheme for self-excited induction generator system have been proposed using Hilbert–Huang transform and least square support vector machine in [22]. Support vector machines have also been used for fault location estimation in distribution system in [23,24]. But all of these methods [16–24] don't identify the direction of fault.

In this paper, support vector machines have been employed for detecting the fault (both forward and reverse), identifying its section, classifying the fault type and identifying the faulty phase in transmission lines. The proposed scheme uses 3rd level approximate DWT coefficients of three phase current signals only measured at one end. Effect of variation in different fault parameters such as fault type (all shunt faults, inter-circuit-faults, cross-country faults), fault location, fault resistance, fault inception angle, close-in faults, and boundary faults have been considered in this study. Unlike ANN or radial basis function neural networks, the proposed SVM based scheme doesn't require large training data set. Further as compared with other techniques based on phase comparison [3,4], fuzzy logic [8], the proposed method based on SVM does not need any threshold to operate. The reason behind this is that, working of SVMs is not based on comparing with some threshold, rather initially the SVMs are trained with the wide variety of fault patterns which is an offline process and then the trained SVMs are tested online to detect and classify the fault within short time (usually less than one cycle). The method does not require any threshold because the SVM based method is based on supervised learning algorithm. It learns from the training data which involves both input and target patterns of faulted condition and normal operating condition. During training, SVM creates an imaginary decision boundary in form of hyper-plane with margin in both sides. The training data is separated into different classes (either two classes or multiclass) by SVM by constructing a hyper-plane using support vectors. Hyper-plane is not a single value like threshold; it is an imaginary decision boundary that separates different classes of the defined problem. So it can be called as an exceptional attribute for the protective function. SVM hyper plane is advantageous over threshold because it provides a margin which helps in accurately classifying the patterns unlike threshold which depends on a single value. Threshold is decided by user, while the hyperplane is constructed by SVM during training process in which only training patterns (inputs and targets) are given by user. As SVM is a learning based algorithm, it has the capability of adapt to change. Therefore it can accurately classify the faults and no-fault condition not only in normal operating conditions but in extreme operating condition faults like cross-country faults also.

Further the paper is organised as follows. In Section 'Cross-country faults and inter-circuit faults', the brief overview of DWT and SVM is given. In Section 'Feature extraction and pattern classification techniques', the SVM based fault direction estimation method is described. In Section 'Proposed wavelet and SVM based directional relaying', test results are given. Section 'Test results under different fault conditions' presents the comparison of the proposed scheme with earlier reported techniques. Conclusions are exemplified in Section 'Comparison with earlier reported techniques'.

Cross-country faults and inter-circuit faults

Two types of faults other than normal shunt faults (LG, LLG, LL and LLL) that have been considered in this work are cross-country faults and inter-circuit faults. The word "Cross-country faults" is used in this paper for those faults which occurs in different phases of one circuit at different location. The word "Inter-circuit faults" is used for those faults which occur between two different phases of the two circuits at same location. Inter-circuit faults are generally seen in multi-circuit transmission lines. Fig. 1 shows the diagrammatic representation of the cross-country and inter-circuit faults. Fig. 1a illustrate the cross-country fault, A1G fault at 20 km and B1G fault at 60 km occurring at 0.08 s time, while Fig. 1b shows the A1B2G inter-circuit fault at 60 km in 0.08 s time.

Feature extraction and pattern classification techniques

In this section, a brief introduction of the techniques used for feature extraction and pattern recognition and classification is described. In this study, DWT has been used to process the currents signals of the test system. These DWT processed signals are applied as input to SVM modules which determines the presence of fault and its direction whether forward or reverse, identify its section and identify the fault phase.

Discrete wavelet transform

The disturbances in power systems are non-periodic, non-stationary and of short duration. Discrete Wavelet Transform