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A new FDOST entropy based intelligent digital relaying for detection, classification and localization of faults on the hybrid transmission line

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ABSTRACT

The paper presents a new digital relaying for detection, classification and localization of faults on the hybrid transmission line consisting of an overhead line and an underground cable. The entropy principle together with fast discrete orthogonal S-transform (FDOST) represented by window dependent bases is utilized for feature extraction and the support vector machine (SVM) classifier model & support vector regression (SVR) model are employed for pattern recognitions to predict the types and locations of faults. After modelling and simulation of the transmission system in Electromagnetic Transient Program (EMTP) software, three phase fault current signals are recorded at one end of the line to extract entropy of FDOST coefficients from each of the three current signals of half cycle duration after fault initiation. The proposed relaying technique is tested on a single-junction and a multi-junction hybrid transmission lines under different fault conditions and is found fast and accurate independent of fault type, fault section, fault resistance, fault inception angle (FIA) and load angle. Another important aspect of the method is that it needs no prior identification of the faulty section for the estimation of fault location. The immunity of the proposed method to noise is also established by testing it with fault current signals impregnated with white Gaussian noise of level 30 dB signal to noise ratio (SNR).

1. Introduction

Grid connected transmission system sometime requires an underground cable line to connect the overhead transmission lines. The protection strategy for the hybrid transmission line is slightly different from that of the overhead transmission line as the travelling wave velocity is different in overhead line and underground cable. The performance of the protective relay, which detects the faulty phases and locates faults on the transmission line, determines the reliability of power supply to the consumers. If faults on the transmission line is not detected and cleared in time, the service quality will deteriorate due to interruption of power supply and costly equipments may be damaged depending on the severity of faults. Thus the relays must be fast and accurate to restore the service quickly and to ensure the system stability. With respect to the speed and accuracy, the conventional transmission line protection relays are far behind the modern digital relays designed using advanced signal processing tools and machine learning techniques, although the conventional fault analysis techniques like phasor estimation technique and travelling wave method improve a lot with the application of advanced signal processing tools. The phasor estimation technique [1–5] for fault localization estimates the phasors of fault voltages and currents using signal processing tools like discrete Fourier transform (DFT) [1–4] and fast discrete S-transform (FDST) [5]. But the phasor estimation technique has lower speed as it requires post-fault signals of long duration and necessitates filters to remove transient frequencies. The travelling wave method [6–9] determines the wave velocity and the travelling time between two consecutive reflections at the line terminals to estimate the fault location. Any reflection of travelling wave causes additional distortion in the fault transients. The wavelet transform (WT), which has better time-frequency resolution than DFT to detect even minute changes in the signals, is applied to classify transients in distribution system [10] and to improve the accuracy of travelling wave based fault localization method [6–9] by accurate calculation of travelling time between two successive reflections of fault signals. The main disadvantage of travelling wave method is that it needs high speed transducer to record fault signals at a high sampling frequency.

In recent years, the pattern recognition technique becomes popular because of its high speed and accuracy. In this technique, the fault features extracted by signal processing tools are used to train the machine learning tools for detection, classification and localization of faults. Fuzzy logic [11,12], back propagation neural network (BPNN) [13,14], radial basis function neural network (RBFNN) [15,16] and support vector machine (SVM) [9,17–20] are popular machine learning tools for fault analysis. The accuracies of

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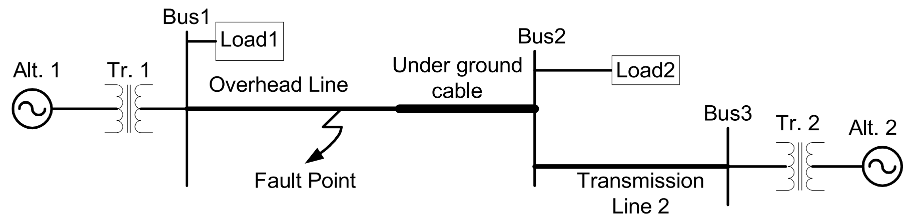

Fig. 1. Single line diagram of a single-junction hybrid transmission network.

machine learning tools depend on the quality of features extracted from fault signals. Wavelet coefficients [11,13], wavelet energy [21] and wavelet entropy [12,22–25] are very effective fault features for detection, classification and localization of faults on both distribution and transmission lines. A generalized form of wavelet transform known as wavelet packet decomposition (WPD) has better time-frequency resolution than WT as both the approximation and detail coefficients are decomposed in WPD. It is applied for high impedance fault detection and fault zone discrimination [26]. The entropy based fault features extracted using wavelet packet [27] and multi-wavelet packet [16] produce high accuracy in fault detection and classification on the transmission line.

Wavelet based feature extraction techniques have very good accuracy but they suffer from the drawbacks of poor noise immunity and the dilemma of the mother wavelet selection. Recently, S-transform (ST) is applied for detection, classification and localization of faults on the transmission lines [14,28,29]. But due to high redundancy, ST has more computational and memory burden as it generates N^2 numbers of coefficients for a signal of length N. A non-redundant fast discrete S-transform (FDST) with N numbers of coefficients is applied to obtain the spectral energy for differential protection of compensated lines [30,31]. Other faster versions of ST like hyperbolic S-transform (HST) [18], discrete orthogonal S-transform (DOST) [19] and fast discrete orthogonal S-transform (FDOST) [20] are also very efficient to extract features for fault classification and localization on both compensated [18,20] and uncompensated [19] lines. The main advantage of ST and its modified versions is their better immunity to noise and they are also free from mother wavelet selection unlike WT.

The nature of fault transients in the hybrid transmission line consisting of an overhead line and an underground cable is quite different from that of the overhead transmission line because the travelling wave velocity and characteristic impedance are different in overhead section and cable. Additional reflection of travelling waves at the junctions on the transmission line contributes to the change of fault transients. Hence, the pattern of fault features may deteriorate if the features and feature extraction tools are not properly considered. The phasor estimation technique [4] and travelling wave method [7–9] are demonstrated for fault localization on the hybrid transmission line although these methods do not discuss about fault classification. An adaptive network fuzzy inference system (ANFIS) is applied for detection, classification and localization of faults on a hybrid transmission line [32]. In these articles [4,7–9,32], faults are localized after identifying the faulty section (overhead line or underground cable) which increases the computational burden because of the requirement of an additional algorithm for faulty section identification. Electromagnetic time reversal (EMTR) method [33,34] locates faults accurately without section identification on the hybrid power system networks. In this method, the signal energy of back-injected time reversed fault transients for each guessed fault location is calculated and its value will be the highest when the guessed fault location is close to the real one. This method has high accuracy but it requires high sampling frequency like travelling wave method and the accuracy decreases with the decrease in sampling frequency [34].

From the literature, it is found that the application of entropy principle in DWT and WPD is very popular for feature extraction from fault signals because of its ability to consider uncertainty and complexity of the signals. But the application of entropy principle in ST and its modified versions (FDST, DOST and FDOST) is not yet popular for feature extraction. The present article demonstrates the application of Shannon's entropy in FDOST represented by window dependent bases for feature extraction and SVM based pattern recognition for detection, classification and localization of faults on the hybrid transmission line consisting of an overhead line and an underground cable. The fault analysis on the hybrid transmission line under noisy environment which always exists in real-time fault signals is a challenging task because of deterioration of fault features for noisy fault signals. The proposed method is designed to detect, classify and locate faults quickly and accurately for both noise free and noise impregnated fault current signals without faulty section identification to reduce the computational burden. The robustness of this method against fault type, fault section, fault inception angle (FIA), fault resistance and load angle is also established.

2. Initial test network

A 400 kV, three phase, both ends fed hybrid transmission network consisting of an overhead line and an underground cable is modelled and simulated in ATP/EMTP environment to investigate the performance of the proposed method at different fault conditions. The single line diagram of a single-junction hybrid transmission network is shown in Fig. 1. The synchronous machine model (SM-59) of alternators and BCTRAN model of transformers are used for modelling the transmission system in EMTP. Both the alternators (Alt. 1 & Alt. 2) are rated 588 MVA each with voltage ratings of $V_1 = 21\angle 0^\circ$ kV and $V_2 = 21\angle(-\delta^\circ)$ kV, where δ is known as the loading angle of the alternator. The transformers (Tr. 1 & Tr. 2) used in the power system model are step up transformers with a voltage ratio of 21 kV/400 kV each. Transmission line 2 in Fig. 1 is an overhead transmission line, while the combined transmission line of an overhead line and an underground cable between Bus 1 and Bus 2 is the hybrid transmission line which is considered for testing the proposed relaying for detection, classification and localization of faults. Two three-phase balanced loads of rating of 400 MVA, 0.85 lagging power factor (load1) and 700 MVA, 0.92 lagging power factor (load 2) are connected at the two ends (Bus 1 and Bus 2) of the hybrid transmission line which is 140 km long with 100 km overhead section and 40 km underground cable. The transmission lines are modelled in EMTP using positive, negative and zero sequence components of resistance, inductance and capacitance. The details of the transmission line parameters are tabulated in Appendix A. Ten types of faults including three line to ground (LG) faults, three line to line (LL) faults, three double line to ground (LLG) faults and one three phase fault (LLLG) are simulated in EMTP for different parameters presented in Table 1.

The recording of fault signals is very important for speed and accuracy of fault detection, classification and localization. Synchronised measurement technique requires costly remote telemetry