REVIEW: PARALLEL TRANSMISSION LINE FAULT CLASSIFICATION

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ABSTRACT

This paper presents a review of the developments in digital relays for protection of parallel transmission lines. For a modern power system, selective high speed clearance of faults on high voltage transmission lines is critical and this survey indicates the efficient and promising implementations for fault detection, classification and fault location in power transmission line protection. The work done in this area favor computerized relays, digital communication technologies and other technical developments, to avoid cascading failures and facilitate safer, secure and reliable power systems. Efforts have been made to include almost all the techniques and philosophies of transmission line protection reported in the literature up to November 2015. The focus of this article is on the most recent techniques, like artificial neural network, fuzzy logic, fuzzy-neuro, fuzzy logic, wavelet based and phasor measurement unit-based concepts as well as other conventional methods used in transmission line protection.

Keyword: - *Parallel transmission line, fault classification and detection, fuzzy logic, wavelet, ANN.*

1. INTRODUCTION

Double circuit transmission line or parallel transmission lines have been extensively utilized in modern power systems to enhance the power transfer, reliability and security for the transmission of electrical energy. The different possible configurations of parallel lines combined with the effect of mutual coupling make their protection a challenging problem.

Fundamental part of the digital distance relay is selector module which differentiates between different fault types on the transmission lines. The selector module should make an accurate decision in less than 10ms to obtain the trip signal quickly. Accurate and fast classification of transmission line faults is also needed for single pole tripping and autoreclosing. Application areas of the wavelet transform in power systems include power quality, power system protection, power system transients, partial discharge, transformer protection and condition monitoring. However, power system protection continues to be the major application areas of wavelet transform in power systems [1]. Reference [2] gives an extensive survey of the application of artificial neural network to the problems in the area of power system protection such as transmission line protection, power transformer protection, detection of high impedance faults etc.

An algorithm of fault classification and faulted phase selection for a single circuit transmission line based on the initial current traveling wave is very recently proposed in [3]. Identification of simultaneous faults on transmission system using wavelet transform was proposed in [4]. However, authors have reported that further improvement in their proposed algorithm was needed to achieve the desired accuracy. A fault classification scheme based on fuzzy logic has been presented in [5] to identify different faults on transmission line, utilizing full cycle discrete Fourier transform to compute the fundamental components of current signals. Reference [6] shows an application of artificial neural network approach to fault classification for double circuit transmission lines using superimposed sequence components of current signals. Comparison of the Fourier Transform method with Wavelet Transform method for detection and classification of faults on transmission lines was done in [7].

But the authors have reported that wavelet transform based approach gave better results only when more than one phase was involved in the fault. It may be noted that majority of the faults are ground faults that involve only one of the phase conductors and ground. Neural network based double end fed transmission line for faulty phase selection and fault distance location is presented in [8]. Application of artificial neural network for classification of only ground faults on the double circuit transmission line is discussed in [9].
A different approach is adopted here for detection and classification of all ten types of faults which might occur on the individual circuits of the double circuit transmission line. Line currents at the relay locations consist of transients of non-periodic nature significantly when the fault occurs on the transmission lines and hence were utilized for the wavelet analysis.

2. DIFFERENT APPROACH FOR PARALLEL TRANSMISSION LINE FAULT CLASSIFICATION

The work described by author [1] addresses the problems of fault diagnosis in complex multi-circuit transmission systems, in particular those arising due to mutual coupling between the two parallel circuits under different fault conditions; the problems are compounded by the fact that this mutual coupling is highly variable in nature. In this respect, artificial intelligence (AI) technique provides the ability to classify the faulted phase/phases by identifying different patterns of the associated voltages and currents. In this method, a Fuzzy ARTmap (Adaptive Resonance Theory) neural network is employed and is found to be well-suited for solving the complex fault classification problem under various system and fault conditions. Emphasis is placed on introducing the background of AI techniques as applied to the specific problem, followed by a description of the methodology adopted for training the Fuzzy ARTmap neural network, which is proving to be a very useful and powerful tool for power system engineers. Furthermore, this classification technique is compared with a Neural Network (NN) technique based on the error back-propagation (EBP) training algorithm, and it is shown that the former technique is better suited for solving the fault diagnosis problem in complex multi-circuit transmission systems.

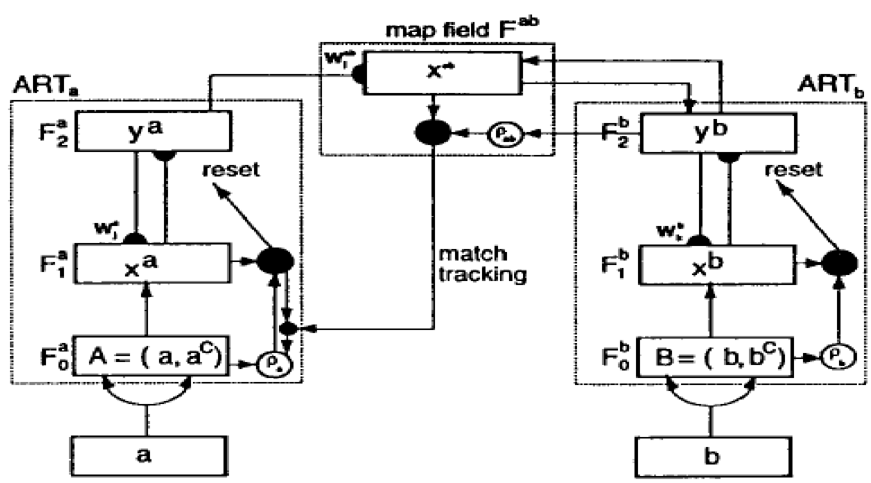

Fig 1:- A typical fuzzy ARTmap architecture [1].

The artificial neural network based on the supervised adaptive resonance theory can identify the faulted phase with a high degree of accuracy. Compared with the EBP algorithm, the classification rate is significantly higher and the training times required are much shorter for the same training sets. Furthermore, the fuzzy ARTmap network can be improved by adding more events to it, such as contingencies, without having to completely retrain the network. In particular, some experimentation in the training of such a network is given in the paper in detail. All the test results presented show that the proposed fault diagnosis technique based on fuzzy ARTmap network is well suited for the complex transmission systems than other more conventional NN-based techniques.

A new fault location method based on six-sequence fault components was developed for parallel lines based on the fault analysis of a joint parallel transmission line [2]. In the six-sequence fault network, the ratio of the root-mean square value of the fault current from two terminals is the function of the line impedance, the system impedance, and the fault distance away from the buses. A fault location equation is given to relate these factors. For extremely long transmission lines, the distributed capacitance is divided by the fault point and allocated to the two terminals of the transmission line in a lumped parameter to eliminate the influence of the distributed capacitance on the location accuracy. There is no limit on fault type and synchronization of the sampling data. Simulation results show that the location accuracy is high with an average error about 2%, and it is not influenced by factors such as the load current, the operating mode of the power system, or the fault resistance.
The six-sequence fault component method was employed to locate the fault location in joint parallel lines, by resolving the mutual induction between the joint parallel lines. In the additional six-sequence fault network, the ratio of the two terminals' root-mean square currents is the function of the line impedance, the system impedance, and the fault distance. Thus, a simplified equation is deduced to obtain the distance of the fault point from the bus. For various grounded faults, the greatest fault resistance is 300 Ù. The sudden-changing six-sequence fault components are used to solve the system reactance of the two terminals of the transmission line and the fault distance away from the bus. Even if the fault resistance is very large and the fault current direction of the receiving terminal is from the transmission line to the bus, the proposed method still has a high fault location accuracy with an error of about 2%. The simulation results of various types of faults for joint parallel lines indicate that the proposed method can accurately predict fault locations, and is not influenced by factors, such as fault type, the operating mode of the power system the fault resistance at the fault point.
A new approach for protection of parallel transmission lines is presented using a time– frequency transform known as the S-transform that generates the S-matrix during fault conditions [3]. The S-transform is an extension of the wavelet transform and provides excellent time localization of voltage and current signals during fault conditions. The change in energy is calculated from the S-matrix of the current signal using signal samples for a period of one cycle. The change in energy in any of the phases of the two lines can be used to identify the faulty phase based on some threshold value. Once the faulty phase is identified the differences in magnitude and phase are utilized to identify the faulty line. For similar types of simultaneous faults on both the lines and external faults beyond the protected zone, where phasor comparison does not work, the impedance to the fault point is calculated from the estimated phasors. The computed phasors are then used to trip the circuit breakers in both lines. The proposed method for transmission-line protection includes all 11 types of shunt faults on one line and also simultaneous faults on both lines. The robustness of the proposed algorithm is tested by adding significant noise to the simulated voltage and current waveforms of a parallel transmission line. A laboratory power network simulator is used for testing the efficacy of the algorithm in a more realistic manner.
After the faulty phase detection the corresponding faulty line is identified by finding the magnitude and phase difference of the estimated current phasor. In the case of similar types of fault on both the lines simultaneously and external faults on the line, the difference in magnitude and phase cannot be used to identify the faulty line. In that case the impedance to the fault point is calculated from the estimated phasors of the faulted current and voltage signals. The relay trips the circuit breaker when impedance trajectory enters the tripping zone of the relay. Thus the proposed method provides protection of parallel lines which includes all 11 types of shunt faults on both the lines with different operating conditions. The algorithm detects the fault and identifies the line within one cycle of inception of fault and provides accurate results even in the presence of white noise of low SNR values. Further, the S-transform localizes the time of occurrence of the fault while providing an accurate calculation of amplitude and phase of fundamental voltage and current signals required for the computation of the impedance trajectory. The delayed fault clearance problem due to overloading is being studied and the sensitivity of the S-transform to this problem will be reported later.
The protection of parallel transmission lines has been a challenging task due to mutual coupling between the adjacent circuits of the line. One of the paper presents a novel scheme for detection and classification of faults on parallel transmission lines. The proposed approach uses combination of wavelet transform and neural network, to solve the problem [4]. While wavelet transform is a powerful mathematical tool which can be employed as a fast and very effective means of analyzing power system transient signals, artificial neural network has a ability to classify non-linear relationship between measured signals by identifying different patterns of the associated signals. The proposed algorithm consists of time-frequency analysis of fault generated transients using wavelet transform, followed by pattern recognition using artificial neural network to identify the type of the fault. MATLAB/Simulink is used to generate fault signals and verify the correctness of the algorithm. The adaptive discrimination scheme is tested by simulating different types of fault and varying fault resistance, fault location and fault inception time, on a

given power system model. The simulation results show that the proposed scheme for fault diagnosis is able to classify all the faults on the parallel transmission line rapidly and correctly.

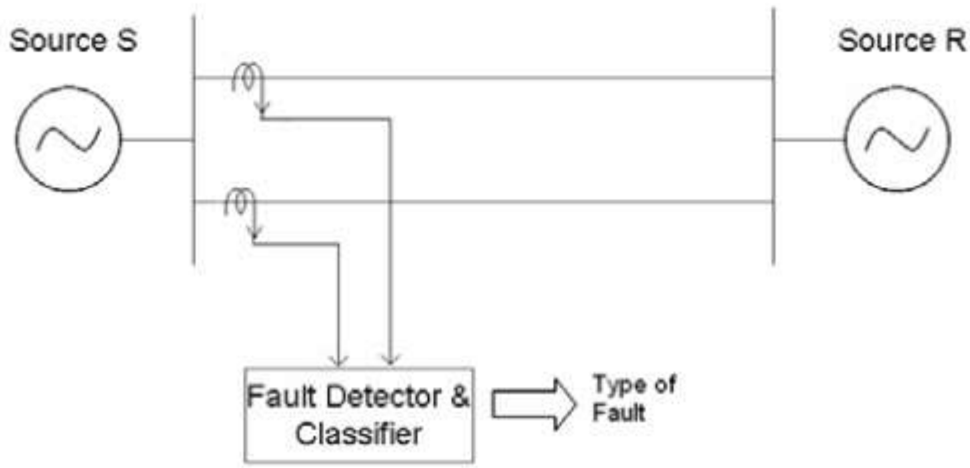

Fig 2:- Power System model under study using wavelet transform [4].

The method depends on the current signals extracted from the local relay location. Wavelet Transform was used to extract distinctive features in the input signals. This feature vector then acts as input to the neural network improving its speed and accuracy. Capabilities of neural network in pattern classification were utilized. Simulation studies were performed and the performance of the scheme with different system parameters and conditions was investigated. The proposed algorithm was found to be immune to the effect of mutual coupling, fault resistance, remote end infeed, fault location and fault inception angle.

In one of methodology, the potential application of ANN techniques for detection of single line to ground faults and fault type classification on double circuit transmission lines with remote end infeed [5]. Distance protection of double circuit transmission lines has been a very challenging task. The problems arise principally as a result of the mutual coupling between the two circuits under different fault conditions. An accurate algorithm for fault detection and classification of single line-to-ground faults (A1N, A2N, B1N, B2N, C1N & C2N) in double circuit transmission line considering the effects of mutual coupling, high fault resistance, varying fault location, fault inception angle and remote source infeed is presented using feed forward neural network (FFNN) algorithm. The algorithm employs the fundamental components of voltage and current signals. This technique neither requires communication link to retrieve the remote end data nor zero sequence current compensation for healthy phases are required. This is a major advantage of the proposed algorithm for protection of double circuit line fed from both the ends. Results of study on a 220 kV transmission line are presented as an illustration. Simulation results indicate that algorithm is immune to the effect of mutual coupling, fault type, fault inception angle, fault resistance, fault location and remote end infeed.

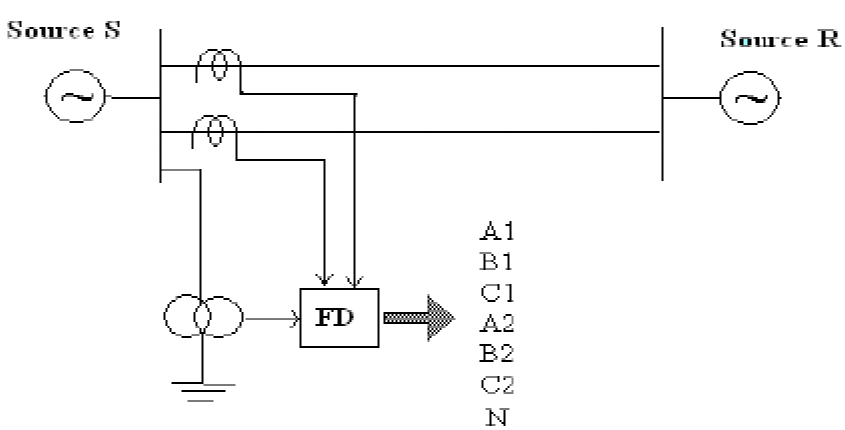

Fig 3:- Power System under study using ANN [5].

A feed-forward neural network structure using Marquardt Levenberg algorithm is presented for fault detection, classification technique for double-circuit line protection under single line to ground fault considering the effects of mutual coupling, high fault resistance, varying fault location, fault inception angle and remote source infeed. The algorithm employs the fundamental components of three line voltages and the six line currents of the two parallel lines at one end only. Remote end data are not required. The performance of the proposed scheme has been investigated by a number of off-line tests. The complexity of the possible types of faults (A1G, A2G, B1G, B2G, C1G and C2G), fault locations (0-100%), high path fault resistances (0-100 Ohm), fault inception angles (0 & 90°), mutual coupling effects and remote end in-feed are solved. The Simulation results show that single phase-to-ground faults can be correctly detected and classified after one cycle after the inception of fault. The algorithm is immune to the effects of remote end infeed, fault locations, mutual coupling, fault inception angle and fault resistances. The proposed scheme allows the protection engineers to increase the reach setting i.e. a greater portion of line length can be protected as compared to earlier techniques. The technique does not require communication link to retrieve the remote-end data and the zero sequence current compensation for healthy phases are also not require.

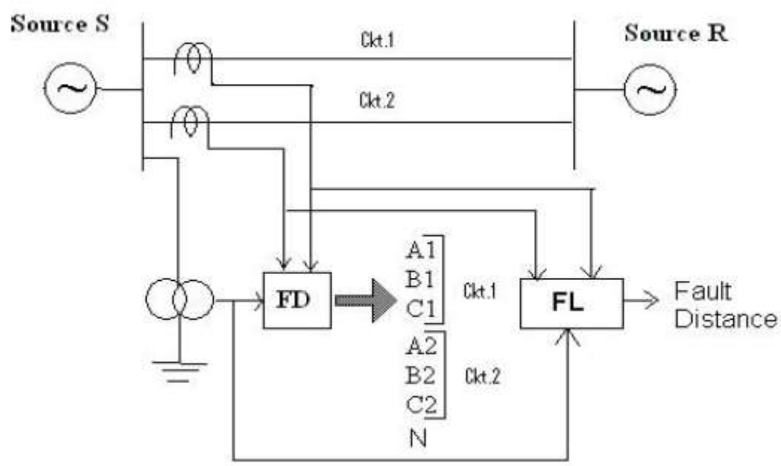

Fig 4:- Single line diagram of Power System under Study [6].

An accurate fault classification algorithm for double end fed parallel transmission lines based on application of artificial neural networks is presented [6]. The proposed method uses the voltage and current available at only the local end of line. This method is virtually independent of the effects of remote end infeed and is insensitive to the variation of fault inception angle and fault location. The Simulation results show that phase-to-phase faults can be correctly detected, classified and located within one cycle after the inception of fault. Large number of faults simulations using MATLAB®7.01 have demonstrated the accuracy and effectiveness of the proposed algorithm. The proposed scheme allows the protection engineers to increase the reach setting i.e. greater portion of line length can be protected as compared to conventional techniques. The technique neither requires a communication link to retrieve the remote end data nor zero sequence current compensation for healthy phases.

An accurate algorithm for fault detection, classification and distance location of phase-to-phase faults on double circuit transmission line fed from sources at both ends is presented. The algorithm employs the fundamental components of three line voltages and the six line currents of the two parallel lines at one end only. The algorithm provides automatic determination of faulted phases and fault distance location after one cycle from the inception of fault. The algorithm effectively eliminates the effect of varying fault location, fault inception angle and remote source infeed. The performance of the proposed scheme has been investigated by a number of offline tests. The possible types of faults (A1B1, A2B2, B1C1, B2C2, C1A1 and C2A2), fault locations (0-90%), fault inception angles (0 & 360°), variation in source strength and remote end in-feed are considered. The proposed scheme allows the protection engineers to increase the reach setting i.e. greater portion of line length can be protected as compared to earlier techniques. The technique does not require communication link to retrieve the remote end data. The conventional distance relaying the maximum zone 1 reach is limited to about 60% of line length where as modern digital relays extend it to about 70%. The proposed technique can increase the reach setting to 90% and can be used as an independent relaying tool or as back-up in the absence of communication link (failure of link).

Transmission and distribution lines are vital links between generating units and consumers [7]. They are exposed to atmosphere, hence chances of occurrence of fault in transmission line is very high, which has to be immediately taken care of in order to minimize damage caused by it. In this paper discrete wavelet transform of voltage signals at the two ends of the transmission lines have been analyzed. Transient energies of detail information for two consecutive data windows at fault are used for analysis. Four layer feed forward back propagation neural networks are designed to classify and locate the fault at different single line to ground fault conditions.

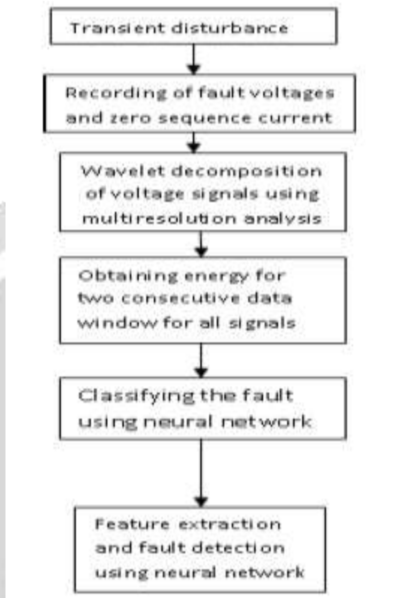

Fig 5:- Procedure for fault analysis [7].

One of the paper, presents the application of wavelet multi resolution analysis in combination with artificial neural network for accurate classification and location of single line to ground fault [7]. The method uses energy of spectrum D1 and D5 for two consecutive data windows for classification and location of faults. Wavelet transform is used to get details D1 and D5 of the voltage signals. Capabilities of neural network in pattern classification were utilized to classify the faults. After successful classification, details of fault signals are used to locate the fault. Simulation studies were performed for different fault conditions with faults at different phases, at different locations and at different fault inception angles and performance of the proposed scheme was investigated. The classification of faults was exact and the location of the faults was identified with above 95% accuracy. This work deals with fault classification and detection for single line to ground faults, but the proposed algorithm and scheme can be extended to other faults also with same effectiveness.
A fuzzy logic-based fault classification of transmission lines is proposed [8]. The classification procedure is carried out by only current phasors of three phases. The proposed technique is able to classify all the possible faults including single-phase to ground, two-phases, two-phases to ground and three-phases faults with high accuracy in a wide variety of system pre-fault loading conditions. In addition, this method can identify the faulted phase(s) from non-faulted phase(s). The mutual effect of parallel transmission lines has been investigated in this study, too. The proposed method has a good performance in high fault resistances, high system loading level and high fault distances from relaying point. Large numbers of test cases are generated to verify the performance of proposed technique. The simulation studies have been carried out by using PSCAD/EMTDC and MATLAB fuzzy-logic toolbox.

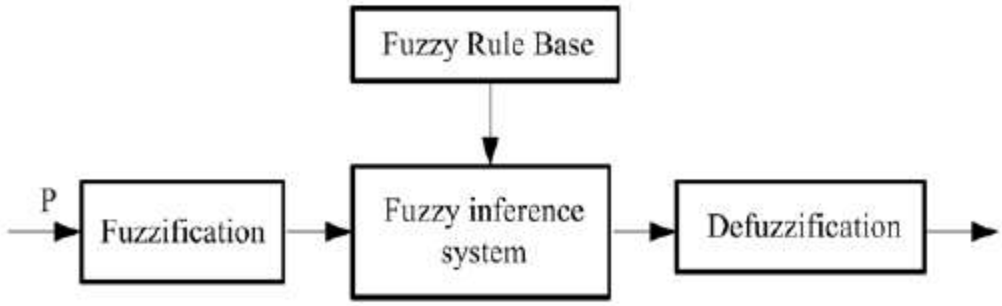

Fig 6:- Fuzzy-Logic based fault classifier [8].

A fault classification scheme based on fuzzy-logic is presented to identify all ten types of faults that may occur in power transmission lines. Only three line currents measurement are sufficient to implement this technique. The Full Cycle Discrete Fourier Transform (FCDFT) is used to compute the positive, negative and zero sequence components of fundamental frequency of currents. The time taken by this method is about 20 ms for a 50 Hz system. To improve the performance of the fault classification scheme, membership functions have been preferred to have overlap with each other and the phase angle difference of positive sequence of fundamental currents between pre-fault and fault conditions for each phase. The proposed fuzzy logic-based fault classification scheme identified all of the test cases correctly. The performance of the proposed method is not affected by a wide variety of pre-fault system loading level, fault resistance and fault distances from the relaying point. In addition, the mutual effect of double-circuit transmission line has been investigated. The performance of proposed fuzzy fault classifier in double-circuit lines 3000 test cases are generated and examined. Then, a modified method has been performed to increase the accuracy of proposed fuzzy fault classification system. The results show that the accuracy of the proposed method is extremely high.

One methodology presents a new approach to classify fault types and predict the fault location in the high-voltage power transmission lines [9], by using Support Vector Machines (SVM) and Wavelet Transform (WT) of the measured one-terminal voltage and current transient signals. Wavelet entropy criterion is applied to wavelet detail coefficients to reduce the size of feature vector before classification and prediction stages. The experiments performed for different kinds of faults occurred on the transmission line have proved very good accuracy of the proposed fault location algorithm. The fault classification error is below 1% for all tested fault conditions. The average error of fault location in a 380 kV–360-km transmission line is below 0.26% and the maximum error did not exceed 0.95 km.

The proposed digital distance relay approach uses the high frequency information measured in the relay point (sending end of the line). DWT is employed to extract the distinctive high-frequency components of the current and voltage signals. To reduce the learning data, wavelet entropy criterion is applied to wavelet detail coefficients. SVM are used for classifying the fault types and locating the ground faults. The results of numerical experiments performed for the location of faults in different type of power system configurations have proved very good performance of the proposed algorithm. The mean of all average errors of fault classification is about 1% for all fault types and the overall accuracy of fault locator is 0.26484% for SLG, 0.20516% for LL, 0.74856% for LLG and 0.39816% for LLLG faults respectively in the 360-km transmission line. Simulation studies have demonstrated that the proposed method is highly accurate and very encouraging for fault location applications.

One of the methodology, presents a pattern recognition approach for current differential relaying of power transmission lines [10]. The current differential method uses spectral energy information provided through a new Fast Discrete S-Transform (FDST). Unlike the conventional S-Transform (ST) technique the new one uses different types of frequency scaling, band pass filtering, and interpolation techniques to reduce the computational cost and remove redundant information. Further due to its low computational complexity, the new algorithm is suitable for real-time implementation. The proposed scheme is evaluated for current differential protection of a transmission line fed from both ends for a variety of faults, fault resistance, inception angles, and significant noise in the signal using computer simulation studies. Also the fundamental amplitude and phase angle of the two end currents and one end voltage are computed with the help of the new formulation to provide fault location with significant accuracy. The results obtained from the exhaustive computation show the feasibility of the new approach.

4. CONCLUSION

A survey of parallel transmission line protection is done through this article. Since the implementation of digital relaying, a lot of work has been done to improve the performance of digital protective relays, but in the context of reformation in the power industry and operation of transmission lines close to the stability limits, new tools and algorithms are needed to maintain system reliability and security within an acceptable level. The ANN, fuzzy logic, genetic algorithm, SVM and wavelet based techniques have been quite successful but are not adequate for the present time varying network configurations, power system operating conditions and events. Therefore, it seems that there is a significant scope of research in AI techniques which can simplify the complex nonlinear systems, realize the cost effective hardware with proper modification in the learning methodology and preprocessing of input data and which are computationally much simpler. Also development of reliable software and communication system will pave the way for better relaying and fault location performance using multi terminal synchronized phasor measurement based on GPS. This article is an effort to present the most comprehensive set of references on the subject of recent techniques in transmission line protection.

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