Review on Identification of Faults of Transmission and Distribution Lines

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ABSTRACT

A comprehensive review on the methods used for fault detection, classification and location in transmission lines and distribution systems is presented in this study. Though the three topics are highly correlated, the authors try to discuss them separately, so that one may have a more logical and comprehensive understanding of the concepts without getting confused. Great significance is also attached to the feature extraction process, without which the majority of the methods may not be implemented properly. Fault detection techniques are discussed on the basis of feature extraction. After the overall concepts and general ideas are presented, representative works as well as new progress in the techniques are covered and discussed in detail. One may find the content of this study helpful as a detailed literature review or a practical technical guidance.

Keywords
Methods used for fault detection, classification and location in transmission lines and distribution systems

1. INTRODUCTION

Methods for fault detection, classification and location in transmission lines and distribution systems have been intensively studied over the years. With the concepts associated with smart grid attracting growing concern among researchers, the importance of building an intelligent fault monitoring and diagnosis system capable of classifying and locating different types of faults cannot be overstated. The past 20 years has witnessed the rapid development in various fields concerning the detection, classification and location of faults in power systems. The advances in signal processing techniques, artificial intelligence and machine learning, global positioning system (GPS) and communications have enabled more and more researchers to carry out studies with high breadth and depth in that the limits of traditional fault protection techniques can be stretched. Furthermore, two major restrictions of online fault diagnosis systems are also being solved. The first restriction is the difficulty in data acquisition. In addition to traditional measurement equipment such as potential transformer, current transformer and remote terminal unit, newly developed intelligent electronic devices (IEDs) are being deployed to obtain information at multiple nodes in the grids. Self-powered Non-intrusive sensors are also being developed with the potential to form sensor networks for smart online monitoring of smart grids. With more data available, researchers are able to develop intelligent fault diagnosis systems through mining knowledge from the data corresponding to different conditions.

2. FEATURE EXTRACTION AND FAULT DETECTION

The effect of complex and varied network configurations can also be eliminated when the current and voltage signals can be collected by interspersed sensors that are plentiful in number. The second restriction is the lack of communication and computation capability. The prospective of GPS-based synchronized sampling and high-speed broadband communications for IEDs in power grids were mentioned in. The application of phasor measurement units has also gained wide attention and a brief introduction of which is found in. These technical improvements can guarantee fast response to faulty situations and the proper functioning of online monitoring systems based on sensor networks. The computational ability of computers has also increased rapidly. High-performance computing solutions such as server clusters are able to complete distributed computing tasks within very short period of time, thus allowing methods with higher computation complexity to be implemented.

In this paper, we present a comprehensive review on the methods used in fault detection, classification and location. A simplified framework for fault detection, classification and location is illustrated. In the first step, current and voltage signals are sampled and the sampled points are passed to the feature extraction module. This module then extracts features used by the fault detector, the fault classifier and the fault locator. The outputs are the fault type and the fault location provided by the fault classifier and the fault locator, respectively. Some of the works cover all three aspects, while some others focus on one or two of the aspects.

Although the current and voltage signals contain all the information within themselves, it is extremely hard to fit the raw signals into some sets of rules and criterions capable of intelligently interpreting the underlying messages brought by the signals. This is where the feature extracting techniques come in handy, as they dig out useful information purposefully and reduce the impact of variance within the studied system. After proper feature extraction techniques are used, researchers may gain a better awareness of the nature of the fault classification or location problems and thus solve them in a more coherent and efficient manner. Moreover, a reduced dimensionality of the data can sometimes boost the performance of certain algorithms used in the classifiers or locators, providing more accurate and robust results as fast as possible.

In this section, methods used for feature extraction are presented together with detailed application examples. At the end of this section, a brief introduction to fault detection methods, which is highly dependent on the feature extraction process, is presented.
Another way to use the coefficients is to calculate the energies of detail levels. Energy within the frequency band 3840–7680 Hz was used in, while 50–100 and 1.5625–3.125 kHz frequency bands.

To make better use the information contained in the detail levels, authors in used wavelet packed transform (WPT), which not only decomposes approximation coefficients, but also decomposes detail coefficients repeatedly. Thus, the frequency resolution in higher frequency ranges could be greatly improved. In the multiwavelet packet transform, which is based on multi-WT (MWT) and WPT, was used by researchers. The MWT possesses the properties including tight support, orthogonal and symmetrical which when combined with WPT can extract features with higher information density. As a result, extremely high classification accuracy with a variety of mother wavelets adopted and coefficients in both high- and low-frequency detail levels used, the works mentioned above proved the effectiveness of DWT in facilitating the fault classification and location methods.

2.2 Modal transformation

Modal transformations such as Clarke transformation (CT) was used in to decouple three-phase quantities represented by a, b and c and transform them into components represented by α, β and 0, on the basis of which fault types were characterised by describing the relationships between phase quantities and modal component, and fault detection and location indices were calculated. Another type of modal transformation was used in to facilitate the implementation of fault characterics.

2.3 Dimensionality reduction

Principal component analysis (PCA) is useful to reduce the dimensionality of data by mapping the data from the original high-dimensional space onto a low-dimensional subspace in which the variance of the data can be best accounted for. In researchers applied PCA to the wavelet coefficients and used the principal components for fault classification and location tasks. Cheng et al., proposed a feature extraction method based on random dimensionality reduction projection (RDRP). The measurement matrix used in RDRP to reduce the dimensionality of original input vector is a Gaussian random matrix, making this method independent of the training data. In addition, this method requires small memory space, as the feature extraction process is done with matrix multiplication.

3. FAULT-TYPE CLASSIFICATIONS

Fault-type classification plays a significant role in protection relay for transmission lines and power distribution systems, thus researchers have had constant interest in developing new, robust and accurate fault classification algorithms and models for decades. The majority of the classification methods adopt classifier models based on statistical learning theory while some other works used logic flows based on experience and observation of collected data. It is noteworthy that the development of studies in this particular field has been highly relevant to the development of pattern recognition and machine learning (more specifically supervised leaning algorithms for classification). In this section, a detailed review of methods for fault-type classification is provided in a developmental and comprehensive point of view.

3.1 Fault classification based on logic flow
If no machine learning or artificial intelligence based algorithms are implemented, usually a tree-like logic flow with multiple criterions is used. If any one of the values exceeds its threshold, the corresponding phase (or ground) is involved in the fault. Researchers in extracted the features using WMA and generated logic flows based on observations of the characteristics of the features. At each node in the logic flow, certain comparisons were made between feature values or between a feature value and a threshold adopted modal transformation for feature extraction. CT was used in to produce fault detection indexes for each phase. Thresholds were then added to complete the classification task. In Karrenbauer transformation and WT were used. Modulus maxima of the WT were then fed to the logic flow to decide the fault type. WT and Shannon entropy were used in to produce features. In where the authors used the WSE method, logic flows were implemented after the features related to the entropies were calculated.

3.2 Neural network
A neural network is a parallel system, capable of resolving paradigms that linear computing cannot. They are used for applications where formal analysis is difficult or impossible such as pattern recognition and non linear system identification and control.

Neural networks are composed of simple elements which operate in parallel with interconnection between them. The weights of connection determine the network function. It is considered as the simplest kind of feed forward network. A neural network when created, has to be configured which is done using training function. The elements of the network are adjusted automatically to get a particular target output for specific input. A network can have several layers. Each layer has a weight matrix, a bias vector and an output vector. Each neuron in one layer has direct connections to the neurons of the subsequent layer. The second class of feed forward neural network distinguishes itself by the presence of one or more hidden layers, whose computation nodes are called hidden neurons or hidden units. By increasing the number of layers and neurons the network is enabled to extract higher order statistics which is advantageous when number of inputs is large and highly nonlinear. A neural network learns from its environment. In this process parameters of a neural network are adapted through a continuing process of simulation by the environment in which the network is embedded. A popular model for ANN is multilayered feed forward back propagation.

The multi-layer perceptron has the ability of handling complex and non-linear input-output relationship with hidden layer. In this back propagation algorithm in the process of supervised learning, the errors are propagated backwards. The idea of back propagation algorithm is to reduce error until the ANN learns the training data. The training begins with random weights and the goal is to adjust them so that the error will be minimal. In this work multilayer feed forward network has been chosen to process the prepared input data which were obtained from wavelet transform.

3.3 Support vector machine
SVM was invented by Cortes and Vapnik in 1995 [the theoretical foundation of which can be found in. The main idea of SVM classifiers is to find an optimal hyper plane that maximizes the margin between two groups of examples. By using non-linear kernel functions which map the examples into higher dimensional spaces, one can obtain non-linear SVM classifiers.
7. FAULT LOCATIONS

A considerable number of studies have focused on fault location in that accurate location of faults in transmission lines and distribution systems can greatly reduce the time to recovery. A comprehensive review of fault location in power systems is provided. In where a smart fault location method was proposed, the background knowledge for fault location was also provided.

Thus, in this paper, on the basis of existing review studies, we present the fundamentals and some new progress in fault location techniques. For transmission lines, conventional fault location methods can be divided into impedance focused methods (phasor or time-domain based) and travelling wave based methods. For distribution systems, methods using superimposed components and power quality data may also be considered. Depending on the source of data, fault location methods may be further categorized as single-end methods, double-end methods, multi-end methods and wide-area methods. In this paper, however, we present fault location methods in a different manner as we only focus on some special portions of them.

Due to the fast development of wide-area methods and the need of building reliable large-scale smart grids, we take wide-area methods into account. Similarly, we take fault location methods of series-compensated transmission lines and hybrid transmission lines into consideration because of their special properties that distinguish them from normal transmission lines. At the same time, we take modern artificial intelligent methods into account because of their good performance on fault location and broad application prospects. Consequently, the following fault location algorithms to be discussed mainly concentrate on wide-area fault location algorithms, series-compensated transmission lines fault location algorithms, hybrid transmission lines fault location algorithms and artificial intelligence based fault location algorithms.

7.1 Wide-area fault location algorithms

Traditional fault location methods fail to locate faults when either of the monitor devices at the terminals of the faulty line fails to record the fault waveform. Wide-area fault location methods are applications of the wide-area monitoring system and they can overcome the adverse situation by providing a viable solution to the fault location problem. In other words, wide-area fault location methods can precisely locate the fault point within the entire large-scale transmission network by using the information provided by a small amount of monitor devices that are dispersed in the network. It proposed a non-linear optimization-based synchronized algorithm. By acquiring the arrival time of voltage travelling waves at different sensor nodes in the network and splitting all the transmission line at virtual bus nodes, a closed-form expression solution was obtained. In multiple synchronized voltage measurements were utilized to model the fault location problem as a non-linear estimation problem, which was solved by applying a novel transform based on pre-fault bus impedance matrix to convert the non-linear problem to a linear weighted least-squares problem.

Azizi and Sanaye-Pasand proposed as synchronized voltage-based non-iterative method by taking advantage of the substitution theorem. By replacing the faulted line with a suitably adjusted current source injecting the same amount of transmission line current, an equivalent network was established. The positive-sequence and negative-sequence
network impedance matrix constructed based on the pre-fault network topology was utilized to calculate the location of fault using the linear least-squares method. Through building a positive-sequence network, a matching degree factor, which is a function of fault distance and is equal to zero only at the exact fault point, was defined. Concretely, calculating the matching degree factor at every bus that is temporarily assumed to be the faulty bus can point out the fault region. Fault location is then determined by calculating the factor at all the lines included in the fault region by a small step. Similarly, the impedance-based method proposed in locates the fault in a hierarchical manner, by which the faulted zone, faulted line and fault point are located in turn.

7.2 Fault location algorithms for series-compensated Lines

Series-compensated lines are installed with series capacitors (SCs) and metal oxide varistors (MOVs) to accomplish series compensation. In spite of the favourable performance of series compensation, the presence of SC and MOV causes some difficulties to faulty segment detection for fault location because of their non-linear behavior. Thus, traditional approaches need improvement so as to fit the fault location task on series-compensated lines impedance-based algorithm utilizing double-end voltage and current signals was proposed. Impedance between the capacitor and the fault point was calculated to obtain the entire fault current. As the angle difference of fault voltage and fault current at the real fault point is minimized, the real fault point can be found by searching the potential fault point along the entire line with small steps. Swetapadma and Yadav used artificial intelligent method to locate the multi-location faults and normal single fault.

DWT was used to extract the third level (62.5–125 Hz). Approximate wavelet coefficients from one pre-fault cycle and two post-fault cycles of voltage and current signals. The features of standard deviation of approximate coefficients of voltage and current signals were then calculated as inputs for an ANN. In a time-domain model of thyristor-controlled SC (TCSC) and distributed transmission line model was built. The method requires synchronized information from two ends of the line, and the transient resistance of the TCSC measured during the first cycle of fault inception can be acquired as a fault section indicator.

7.3 Fault location algorithms for hybrid transmission lines

Similar to series-compensated lines, hybrid transmission lines consisting of overhead transmission lines and underground cables have discontinuous points named joint-nodes where reflections of fault signal are generated. Another important property of hybrid transmission line is the difference of travelling wave velocities in line and cable. Therefore, conventional approaches need improvement to be suitable for hybrid transmission lines. A travelling wave based algorithm was proposed in which the authors used transients caused by opening of circuit breaker instead of using fault-induced transients. The arrival time of modal components of voltage travelling wave was detected by WT, and the fault zone was then judged by the polarity of the reflections.

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It gives us on immense pleasure to submit this project report entitled, “FAULT DETECTION/CLASSIFICATION AND LOCATION FOR TRANSMISSION AND DISTRIBUTION LINES: A REVIEW ON THE METHODS”. It is our attempt to represent this topic into compact and to the point framework to the best of our efforts. We wish to express our sincere thanks with profound gratitude to our guide Prof.S.S.Kamble and H.O.D. Prof B.N.CHAUDHARI for their valuable guidance and constant encouragement without which it would have been impossible for us to present and complete this seminar successfully. We would like to extend our sincere thanks to our principal Dr. A.P. WADEKAR and all the staff member for inspiring us and guidance. Last but not least, we thank all our friends for their assistant and their help.

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