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Review Article

Disturbance Modeling on Transmission Lines Using Wavelet Transform Method: A Review

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A B S T R A C T

This paper introduces a number of methods for identifying disturbances on transmission lines and provides algorithms for classifying various disturbance types. working with the discrete wavelets transform (DWT) and various embedded systems techniques using a simulator to carry out digital simulations of system trials using the controlled technique, the nature of disturbance in distinct sub-systems is determined. The analysis of transmission lines using the wavelet transform is the main topic of this study, along with techniques for transmission line protection. These factors include channel capacity, channel length, simulation software, mother wavelet type, parameters, sampling frequency, and type of disturbance analysis.

INTRODUCTION

Distributing electrical energy from generators to consumers through transmission lines frequently encounters disturbances that can affect the reliability of the distribution system itself and the quality of the end product obtained by the consumers [1]–[3]. The unreliability of the system would greatly impact the transmission system, particularly when there are disturbances that can damage the equipment [4]–[6]. In the transmission process, disturbances that often occur are caused by lightning, weather, and insulation failures [7], [8]. Moreover, disturbances also can take place in the ground line to ground, line to line, and three phases resulting in transient current and voltage disturbances [9]. Natural factors such as tree hits and birds can also trigger disruptions in the continuity of the system [10], [11]. Transmission line operations require immediate protection against all types of disturbances. These protections can be done immediately by determining protected zones, separating damaged lines from other networks, and terminating the power transmission process [4], [12]. The disturbance occurrence has become a great concern in recent years since more lightning strikes occur and it increases the number of power outages which can lead to the instability of the power grid and the unreliability of its operation [13].

Disturbances due to lightning strikes, harmonics, high impedance faults, and transmission line failures due to the use of manual equipment would lead to severe flashes that would trigger the fault in the transmission system by damaging the line conductors and line insulators [14], [15]. Therefore, detecting the fault and estimating the distance of the disturbance necessarily need to be done as fast and accurately as possible to reduce the number of interruptions. The faults in three-phase shunt and three-phase ground lines in the single line-to-line, line-to-ground, and line-to-ground frequently occur on transmission lines in natural situations [11], [16].

Currently, the most popular method used in signal processing, data compression, and image processing is the wavelet transform. The wavelet transform is a transformation function that automatically cuts data into different components and studies each component with a resolution according to the scale so that the wavelet transform can analyze signals over time and in the frequency domain. This is what distinguishes it from the short-time fourier transform (STFT). The fourier transform is limited to its use in the Fourier series, while the wavelet transform uses a flexible modulation window, which means it has adjustments to frequency and time. For this reason, the wavelet transform is widely used in power quality and power protection analysis [17], [18].

The wavelet transform consists of two parts, namely the discrete wavelet transform and the continuous wavelet transform [19], [20]. The mother wavelet used is Ψ(t) so the form of the continuous wavelet transformation equation is as follows [21]:

$$CWT(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} x(t)\varphi\left(\frac{t-b}{a}\right)dt \qquad (1)$$

where a is the scale factor and b is the translation factor, while CWT, t, a, and b are continuous systems [19], [20]. The discrete wavelet transform method can be written with the equation below

$$DWT(m,n) = \frac{1}{\sqrt[n]{ab}\sum_k x(k)}\varphi\left(\frac{k-nx}{a}\right) \qquad (2)$$

In the application of continuous wavelet transform (CWT), it produces a lot of wavelet transformation coefficients, causing the resulting data to become redundant [1], [7], [8], [22]. This problem can be overcome by using a discrete wavelet transform (DWT), where the decomposition algorithm uses MATLAB, which is the basis of the DWT system, by separating (decomposing) two input waveform signals into a low frequency (low frequency), which is called approximation, and a high frequency (high frequency), which is called detail [2], [23].

Discrete wavelet transforms can determine the location of errors; this paper will present several methodologies that are suitable for classifying errors of different kinds that occur in transmission lines, particularly in the insulator breakdown voltages [24]. This wavelet transform theory is able to process the mathematical equations using the discrete wavelet transform (DWT), which can extract the transient features from three-phase currents, and the features obtained would be used to detect short circuit faults [25], [26].

This article will analyze the types of faults studied by researchers, including LG (line-to-ground) and SLG (single-line-to-ground fault), which are short circuits of one phase-to-ground that occur due to a flashover between the phase conductor and the ground (pole) [27] and Travers or ground wire on SUTM. This disturbance is temporary, there is no permanent damage at the point of disturbance.

LL (Line to Line) is a phase-to-phase fault, and LLL (Three Phase Fault) is a three-phase short circuit fault classified as a symmetrical fault, where the current and voltage of each phase remain balanced after the disturbance occurs [1], [14]. So that a system like this can be analyzed using only positive sequences LLG (double line to ground or phase to phase to ground) is a two-phase fault that causes a break in the middle phase wire on a transmission or distribution line with a vertical configuration, which can cause damage to the insulator in two-phase transmission or distribution at the same time [1]. LLLG (Three Phases to Ground Fault) is a Three-Phase-to-Ground Short Circuit Fault, which is a disturbance that occurs when the third phase is short-circuited to the ground [28].

METHOD

In this paper, several topics related to faults in the electric power system. The literature for this study was collected from several websites, such as Google Scholar and Elsevier.

There are several methods for determining faults on a 3-phase line using an approach based on the discrete wavelet transform (DWT). The collaborative methods used have their respective advantages. Some of the methods used are the traveling wave on the transmission line, such as fuzzy logic [29]–[31], artificial neural network (ANN) [8], [32], support vector machines (SVM) [33], [34], WT, and ANN [13], [35], WT and fuzzy logic [26], [36] and combination of ANN and fuzzy logic. [13], [37], [38].

Interference and protection zones are selected based on the relationships governing radiation and reflections. Then, considering the features and relationships extracted from these waves, the interference caused by lightning strikes on the transmission line and conventional interference are classified, taking into account the mutual induction between the traveling wave and the phases of the transmission line [39]. This is important and useful for transmission lines with automatic closure. In the software, over 1100 faults of various conditions and locations were implemented on a 100-km line with a voltage level of 230 kV for fault detection, classification, and location of overhead transmission lines using the proposed discrete wavelet transform (DWT) based on the wavelet transform (WT) [15], [38].

Different system fault types, such as line-to-ground (LG), line-to-line (LL), double line-to-ground (LLG), and three-phase fault (LLLG) types, applied to different system zones on a transmission line must be detected, classified, and found quickly [37], [38]. The proposed method is based on the voltage and current signal information from the power model in MATLAB to generate transient voltage and current signals in the time and frequency domain. The majority of studies conducted in the field of power systems use simulators that represent the main generator using digital simulation models such as Matlab Simulink, ATP-EMTP, PS CAD, and GPS Timing. When the simulation is carried out, all-natural disturbances in the field are ignored, with the initial goal of this research being to provide fast, reliable analysis using uncomplicated mathematical methods, but this research has not produced the desired results because the responses obtained are not sensitive. for fault resistance and fault angle [31].

The review focuses on discussing the ability of the wavelet transform to be able to analyze transmission lines based on channel capacity, channel length, simulation software used, mother wavelet type, parameters used, sampling frequency, and type of fault analysis, as well as support methods in the signal processing operation that uses the wavelet transform.

RESULTS AND DISCUSSION

The wavelet transform method can be combined with several other techniques, such as the discrete wavelet transform, ANN, SVM, fuzzy logic, artificial neural networks, and pure wavelet transform methods, which give significant results for the accuracy of research results. This can be seen in figures 1 and 2 below

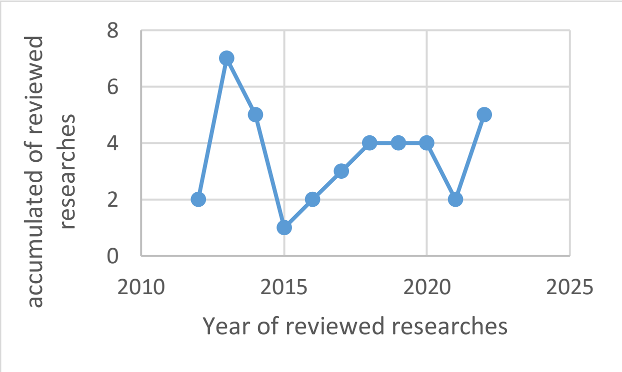

Figure 1. Accumulated of reviewed researches

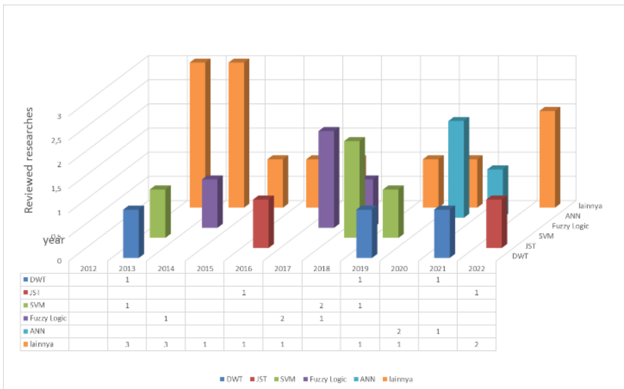

Figure 2. Used technique by researches

Wavelet Transform Using Discrete Wavelet Transform

One of the major factors to ensure the reliability, sustainability and efficiency of power delivery operations is by spotting the location of faults occurring in transmission lines [10], [40]**.** These faults may lead to a prolonged blackout. Having accurate data on where the faults take place in the transmission lines helps the maintenance crew to promptly get the faults fixed. The fault resistance, load flow, and compensated lines can affect the accuracy of applying the impedance–based fault location methods. There are 2 methods for locating the disturbance, which is Impedance – Based Method [1]. and Traveling Wave (TW) - Based Method[1], [2]. The method also can be classified by its fault location as a single-end method and a double-end method [4]. The method of the single end means that the data are derived only from one ending part of the line. On the other hand, when the data are derived from both ending parts of the line, it is called Double-End method. In the latter method, synchronizing the data from both ends will take more time than the one which doesn't. Moreover, this synchronization phase will make it less accurate and less costly than the TW-Based methods [9], [41]**.** However, if it is compared to the single-end method, the double ends still have better accuracy but more cost. Identifying the fault type and locating the fault in each of the types requires the logic of the supplement [7].

Locating the fault that occurs in the transmission line either in the single or double end was done using TW fault Method and wavelet transform by simulating it in MATLAB-SIMULINK. [4], [8], [12]**.** Attaining the resolution of the frequency time of any signal in the signal processing was done by applying the wavelet transform. Calculating the time of the TWs arrival at the line end was required due to the high TWs frequencies at 10 kHz to 600 kHz in the transmission line and 50 Hz in the system frequency. Using the Wavelet was suited well to the application. The Discrete Wavelet transform function (dwt) was used combined with Daubechies mother wavelet db2 [30], To degrade the actual signal into approximate coefficients and detail coefficients was done using DWT. The approximate coefficient was a signal convolution in the filter with the low pass and the detail coefficient was a signal convolution of the signal in the filter with a high pass.

The relay of distance error was at 1930 meters. It was found at the substation of Patnos, which similar fault of error simulation of the single-end TW method at 50 meters. Nevertheless, the method indicates significant accuracy compared to the distance relay even though the length of the transmission line of the Patnos-Ercis HV was 46587 km, considered to be a short one. 390 meters is considered to be the lowest number of error occurrences in the distance relays. The same number of errors at 50 meters also appears in the fault simulation of the Double-End TW Method. The method did work more successfully in the long line of over 250 km than that in the short one. The simulations indicate that both TW fault Location Methods show more accuracy compared to the impedance-based method.

The method of one end can locate the protection zone, classify faults that occurred at the back of the relay in the transmission lines and then provide an algorithm to categorize kinds of faults which includes a lightning strike hitting the phases and the wire of the shield. Therefore, the wavelet Transform (WT) and traveling wave (TW) current in level one were split up at the radiation of all bus-connected lines. These waves made it possible to extract the faulty line and its correlation. The recognition of faults caused by either lightning strikes or conventional ones was feasible considering the mutual effect in TWs on the transmission line phases [42]. It is vital for single-phase tripping and auto-reclosing mechanisms of the transmission line. Evaluating and testing the proposed method were done by PSCAD software which inserted more than 1100 faults varied in their conditions and locations on a line of 100 km in the level of the voltage level at 230 kV. This massive simulation successfully managed to confirm that the method was valid, efficient, and accurate [12].

The performance and ultra-high-speed protection algorithms of transmission lines may be disturbed only by neglecting the fault-including TW mutual inclusion. Consequently, this method is needed as it is an efficient, reliable, and simple method without using a complex mathematical calculation but only by applying the first TW current class. At last, the simulation results which are only the major data presented in this paper indicate that it is sensitive to fault resistance and inception angle and it performs well on the transmission line with recloses and a single-phase cut-off mechanism. Furthermore, the Pts limitation of the frequency bank allows the only utilize the TW current for the decision-making of the algorithm [43].

In research on the transmission line fault location discussed in the journal with a high voltage line capacity of 154 kV, 220 kV, 230 kV, and a line length of 50 KM to 177.4 KM respectively. This research is a simulation using PSCAD software, namely power system computer-aided design which is an interactive program to analyze the magnitude of the electric power system, in the form of voltage dividers, wave rectifiers, autotransformers, and converters. EMTDC (electromagnetic transient DC) software is used to monitor the output results in electrical quantities. In addition, other simulator tools used are MATLAB software, or MAtrix LABoratory, which is a complex calculation and analysis programming software that can be implemented in an easier program [12].

Furthermore, the wavelet type for signal processing uses discrete and continuous types where the discrete wavelet transform (DWT) is a function to assist the processing of discrete signals or signals that have a value when multiples of the sampling time. Meanwhile, continuous wavelet transform (CWT) is a continuous signal processing or a signal whose magnitude is in real-time and is calculated by changing the scale of the analysis window and is well localized temporally or spatially [44].

The mother wavelet or the basic function used in the wavelet transform through translation and scaling, the mother wavelet will determine the characteristics of the resulting wavelet transform. In this study the mother wavelet used is Daubechies's type, this type is a mother wavelet used to reduce the size of data to produce a dense digital representation, but can still represent the quality of the information contained in the data. In this study Daubechies (db) wavelet is considered as a mother wavelet because it has better features for protection applications [45]. There are four types of Daubechies called db1, db2, db3, and db4. The decomposition is at Level 1 for each study with the wavelet parameters used in the form of 3-phase voltage, with a frequency of 50Hz, 500KHz, 2.04 MHz. fault detection analysis is on LG, LLG, and SLG.

Wavelet Transform using Smart System

The world population growth rate has dramatically increased over time. The more population the world has the more demand for energy, particularly electrical energy. A power system must guarantee a stable and sufficient power supply to the consumers. However, this aim is unfortunately subjected to natural phenomena such as lightning, storm, and other natural disasters which unavoidably can create faults [1], [10]. Faults are any abnormal flow of current in a power system's components. There are two kinds of faults occurring in the transmission lines, which are balanced and unbalanced faults. The three-phase fault is considered to be the balanced one. Meanwhile, the single-phase-to-ground, double-phase, and double-phase-to-ground faults are naturally unbalanced faults [13].

Thus, a properly -coordinated protection system is vitally needed to detect any abnormal current flow in the power system and the type of fault more accurately and promptly. Several fault detection and classification techniques have been experimented with. They are wavelet transform [2]–[5], fuzzy logic [29], [30], artificial neural network (ANN) [8], support vector machines (SVM) [9], [10], WT, and ANN [13], WT and fuzzy logic [26] and combination of ANN and fuzzy logic [13], [37], [38].

Identifying the characteristic quantities is mostly done using the Wavelet transform; meanwhile, classifying characteristic quantities is done using ANN [13], [46]. The analysis of fault characteristic quantities in the transmission lines involves the decomposition and energy of the coefficients themselves, the maximum or minimum fault current rate, e.g. wavelet coefficients of different phase currents, the maximum and minimum detailed coefficients level rate [14], and the current wavelet coefficient energy [30], Despite its effectiveness to detect the transient signal triggered by the faults, it has a drawback, particularly in identifying the optimum mother wavelet for applications. That is to say, different results would appear if it applies a different mother wavelet although it is use the same signal.

Developing novelty in techniques for detecting and classifying the actual fault occurrence using discrete wavelet transform and artificial neural network is the main objective of this paper. The simulation of fault condition was simulated in MATLAB (8.2) on the transmission lines of 220 kV. Degrading the fault signal was done up to level five using DWT to extract the feature. The feature extraction through processing the discrete wavelet transform was in maximum and minimum detail coefficient rate of three-phase current signal at level 4 and level 5. These were considered inputs to the artificial neural network.

The Wavelet type	: one – Dimensional DWT
The chosen Family	: Daubechies
The Filter	: DB6
The level of the Resolution Level	: 5

The extraction of features derived from the discrete wavelet transform can reach the maximum and minimum detail coefficient rate at level five of the decomposition levels (d1, d2, d3, d4, d5). The maximum and minimum detail coefficient rates at level 4 and level 5 are examined in this study. They are evaluated for all different fault types, e.g. faults of single phase to ground, double phase, double phase to ground fault, and three phases using a wavelet toolbox

ANNs are a computing system inspired by a biological neural network which is first introduced in 1960. ANN consists of many computational processing elements called neurons or nodes. The nodes themselves operate in parallel [13]. The connection of the nodes is made through topologies that loosely model the biological neural system [37]. ANN can be divided into three types of layers the input layer, the hidden layer, and the output layer. Patterns are added to the network via the input layer, which passes them to one or more hidden layers where the actual processing occurs [38].

The simulation of applying fault detection and classification using the combination of DWT and ANN techniques was carried out with MATLAB 8.2. It defined the current signal of three phases in the transmission line up to level five and to obtain feature extraction, DWT was employed. The maximum and minimum detail coefficient rates in d4 and d5 from the extraction feature process of the discrete wavelet transform were also used for detecting and classifying the faults. Mother wavelet after being cautiously selected played an important part in extracting the information that was beneficial for fault detection and classification [47]. To classify the faults, a feed-forward BP-ANN structure using a scaled conjugate gradient algorithm was required. That is to say, classifying the precise fault type in the transmission line was best done by ANN as the highest accuracy rate was at approximately 90.60. It is suggested in the further experiment that the study will be focused mainly on investigating the fuzzy logic for more complicated transmission line protection. This scheme can be applied for aquatic implementation since it is easily comprehensible, deterministic, and feasible to use it [31], [48].

Based on the journal [8], [13], [14] with a 220 kV and 400 kV channel system by analyzing the transmission lines tested using MATLAB/SIMULINK and detecting errors and locations correctly and classifying all possible errors and location based on local information for source terminal to a remote terminal. The method used is a one-dimensional Discrete Wavelet Transform using an artificial neural network (ANN). An artificial neural network (ANN) consists of many computational processing elements called neurons or nodes. These nodes operate in parallel and are connected via a topology loosely modeled after the biological nervous system. ANN has three layers namely the input layer, hidden layer, and output layer. Patterns are presented to the network via input layers, which communicate with one or more hidden layers where the actual processing takes place[34], [49].

Discrete wavelet transform and multi-layer percepton (MLP) neural network with Bayes and baive Bayes classifying methods where the multi-layer perceptron network (MLP) is a model of artificial neural network (ANN) which has random weights from backpropagation training (BP) [50], [51]. Meanwhile, Naive Bayes is a machine learning algorithm for classification problems. It is based on Bayes' probability theorem [52]. It is used for data classification involving high-dimensional training data sets. Auto regreeive (AR) wavelet transform and minimum entropy Decononlution technique (MED). The wavelet transform uses an entropy calculation system, whereas Autoregressive is a forecasting method that uses past data series. Continue Wavelet Transform CWT fault analysis is fast, reliable, accurate, and also easier to implement and provides less computation time and resources required compared to continuous wavelet transform.

Wavelet Transform using GPS Timing

The main focus of fault research in the last few decades is mostly to find the location of faults in transmission lines accurately since it helps greatly both the consumers and network provider [53]. A transient or permanent fault frequently occurs in transmission lines. These incidents have led to the invention of the varied model of power network models in laboratories. It is done by simulating it under the circumstances that there will be noise, distortion, and attenuation [1], [54], [55].

Bewley first introduced the analysis techniques of traveling waves (TW) in the 1930s [2]. Meanwhile, in the 1960s Barthold and carter came along with their digital solutions [3]. The increased number of applying traveling wave-based techniques in power systems is due to the innovation in accurate time synchronization based on GPS and the availability of digital data communications. TWs can reach almost a speed of light in overhead transmission lines, circa 3x108 and the application of GNSS shows a nearly precise number (less than 1 microsecond) in data acquisition [8], [51].

Several subsequent studies, namely Fault location techniques in power systems based on traveling wavelet analysis and GPS timing, Wavelet-based method for transmission line fault detection during power swing with a channel similarity classification of 400 kV, with a channel length of 200 KM, provide a solution by combining the wavelet transform with Global Position System / GPS Timing where this system provides easy and accurate analysis time as well as the ability to synchronize over a wide area such as that covered by the power system network. The simulation uses ATP – EMTP software, namely the Electromagnetic Transients Program, which is software used in the analysis of electromagnetic transients and isolation problems in power systems. By still using the Discrete Wavelet Transformation method and traveling waves, with Daubechies's mother wavelet. the wavelet parameters used are three phases with a sampling frequency of 1 MHZ and the failures analyzed are at LG, LL, and LLG [35], [56].

Wavelet Transform using Other Methods

Wavelet-based fault location on power transmission lines using real-world traveling wave data. With a channel length of 50 KM and a sampling frequency of 250 HZ, the analysis uses simulations from ATP – EMTP software, Mother Bhyorthogonal wavelet where the interactive process of applying the Biorthogonal wavelet transform provides a developed and flexible multi-resolution of the recorded data which provides the most accurate results compared to other methods available. used in this article [57]. The application of this method is based on the commonly known fault location model of the double traveling wave fault location technique using two fault finders, at the two ends of the transmission line, and requires data synchronization [36], [58]. The method that can be used for this error is the discrete time domain wavelet transform, using 2 parameters, namely scaling and shifting [33]. Where Scaling and shifting are two important parameters for this analysis, the application of a discrete wavelet transform that uses wavelet transform mothers with different scaling levels helps to find the best results for estimating fault locations. Then the analysis was carried out on LL and SLG [18], [32].

CONCLUSIONS

After conducting a description of several experiments in the many studies above, it can be concluded that the use of MATLAB software is more widely used because simulations using MATLAB make complicated calculations and analyses that can be implemented in programs more easily and can be modeled according to the level of error and level of decomposition. For wavelet types in signal processing systems used in many of these studies, the use of the discrete wavelet transform (DWT) is easier to implement than the continuous wavelet transform (CWT). Furthermore, Doubechies's type of wavelet mother is more effective because it has various features that are better for protection applications. If seen from the analysis, the most dominant type of fault is the LLG fault, or line-to-ground fault, with the wavelet transform method.

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