ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 6, Issue 11, November 2017

A Study of Wavelet Analysis Applications in Electrical Engineering

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ABSTRACT: In power system, identification of faulty phase, classification and the location where fault occurs are very important issues. These issues should be overcome for the reliability of the system. For the safety of electric power system, early fault detection is an important task. Power quality ideally creates a perfect power supply that is always available, has a pure noise-free sinusoidal wave shape, and is always within voltage and frequency tolerances. Poor power quality is a problem for many industries, from data centres to offshore oil rigs. Low power quality contributes to high energy cost and rising energy and production disturbances-which is especially problematic for increasingly sensitive modern production equipment. Ironically, it is often the equipment itself that generates the disturbances. This paper deals with the study of Wavelet Transform applications for various electrical problems identification. Wavelet Transform provides tool for the analysis and synthesis of signals. The advantage of Wavelet analysis is that it has the ability to perform local analysis .i.e., to analyse a localized area of a larger signal. It is capable of revealing aspects of data that other signal analysis techniques are not able to detect.

KEYWORDS: Wavelet Transform, Power System, Transmission Line, HVDC, Power Transformer, Power Quality, Electrical Machines.

I.INTRODUCTION

There is a rapid development taking place in the field of Electrical Engineering. The operation and maintenance of the interconnected power system and its protection are becoming more complex and important. Signal processing is very important as the signals contain a lot of information about the behavior of the system and the abrupt changes taking place. There are lots of modern technologies being introduced to analyze these signals.

Fourier analysis is one of the methods applied for signal processing. Fourier analysis is a method of defining periodic waveforms in terms of trigonometric functions. It breaks down the signals into sinusoids at various frequencies. It transforms the signal from time-based to frequency-based. The drawback of Fourier analysis is while transforming the data from time domain to the frequency domain, the time information is lost and it is unable to extract information about the time of occurrence of an event. To overcome this anomaly, Short Time Fourier Transform (STFT) is introduced. It is a sort of compromise between the time- and frequency-based views of a signal. The information is provided with limited precision, and that precision is determined by the size of the time window. But once a particular size is chosen for the time window, that window remains same for all frequencies.

To accurately analyze signals that have abrupt changes, we need to use a new class of functions that are well localized in time and frequency. Wavelet Analysis has the ability of revealing aspects of data that other signal analysis techniques are unable to provide. Debnath, Lokenath introduces the concept of wavelet originated from the study of time-frequency signal analysis, wave propagation, and sampling theory (2002). It analyzes the localized area of a larger signal. It affords a different view of data than those presented by traditional techniques; wavelet analysis can often compress or de-noise a signal without appreciable degradation of the original signal. The availability of a wide range of wavelet families is a key strength of wavelet analysis. The right choice of wavelet; depends on the application being considered. Wavelet analysis can also be classified as Continuous and Discrete Wavelet Transform.
The different types of wavelet transform families are listed below:

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Vol. 6, Issue 11, November 2017

- HAAR WAVELET
- DAUBECHIES WAVELET
- BIORTHOGONAL WAVELET
- COIFLETS WAVELET
- SYMLETS WAVELET
- MORLET WAVELET
- MEXICAN HAT WAVELET
- MEYER WAVELET
-

In this paper, the applications of wavelet are studied for discrepancies in the following fields:

- Power System
- Power Quality
- Machines

The problems solved in power system by wavelet analysis are categorized into transmission line, HVDC and power transformer. Some of the topics discussed in this paper are:

- Arc furnace current
- Classification of transmission system faults
- Evaluation of harmonic content
- Comprehension method for power disturbances data
- Detection, localization and discrimination of power system disturbances
- Power system transients
- Reconstruction of non-stationary
- Extraction of imperfect frequency response
- Isolation of high frequency components & distinguish the fundamental frequency components
- Analysis of voltage & current signal at relay location
- Large fluctuation of power
- Effect of fault due to neighboring DC lines
- Fault occurs during voltage zero crossing in power system
- Protection of power transformer

With the help of WT, numerous problems can be solved for power quality. Some of the topics covered in this paper are listed below:

- Classification of power disturbances
- Detection of harmonic components
- Variation in the electrical power services
- Sensitivity of the electronic equipment
- Supply voltage fluctuation problems

The problems occurring in machines can be detected by WT are over-voltages, noise, bearing element.

The paper is organized as follows: Section II describes the application of wavelet used in power system. The power quality is studied in Section III and Section IV presents the analysis on machines parts. Finally, Section V concludes the paper.

II.POWER SYSTEM

Power system is the combination of all equipment with their associated control and auxiliary systems for generation, transmission, distribution and utilization of electrical power. Nagrath and Kothari (1989) have discussed power system security [1].

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A. TRANSMISSION LINE

Transmission lines are sets of wires, called conductors, which carry electric power from generating plants to the substations that deliver power to consumers. Lines are operated at relatively high voltages varying from 69kV up to 765kV, and are capable of transmitting large quantities of electricity over long distances.

Wilkinson et al. [2] presents the scheme for analysis of power system transients. It deals with wavelet analysis of the current drawn by an arc furnace and the vibration waveforms obtained from a generator turbine. Mallat's pyramid algorithm is carried out for discrete wavelet transform. In analysis of arc furnace current, 11 wavelet levels and 2048 sample points of discrete signal are considered. The transient signals are decomposed and reconstructed to get the actual current waveform. Daubechies d20 is used for wavelet analysis. For arc furnace analysis, a 5-MVA arc furnace is used. In analysis of turbine vibrations, 4-pole, 60-hz, 5MVA synchronous generator is used. The speed of the turbine is 500rpm which the gearbox converts to 1800rpm for the generator. The sampling frequency is 10,240Hz.

In [3], classification of transmission system faults based on multi criteria technique is described to define and examine faulty line. Using online wavelet transform algorithm, the line currents are refined. Time detection of fault is less than 10ms by the proposed fuzzy fault classifier. For the simulation of a sample three phase power system, Electromagnetic transients program (EMTP) software is utilized. This technique provides high speed digital relay performance, precise for different system conditions, within half cycle. For transient disturbances classification, the above method is easier and very effective as compared to the ANN based approach.

Pham et al. [4] develops an approach for the evaluation of harmonic content based on wavelet transform. The problem of images is solved by sampling of the waveform. Simultaneous identification of harmonics consists of integer, non-integer and subroutine based on wavelet algorithm. The frequency spectrum of the waveform is disintegrated into sub-bands with discrete wavelet packet transform filter banks. The continuous wavelet transform is also applied to analyze the harmonic contents of non-zero sub-bands. The harmonic frequency amplitude and phase is determined accurately. The sampling frequency, the highest identifiable frequency and the lowest frequency of interest are 400Hz, 200Hz and 25Hz. This analysis provides amplitude and phases of all components by DFT method. In the field test waveforms, the site-test phase voltages and currents are recorded at 3KV bus feeder. The waveforms are sampled at 3030 Hz and recorded for 20sec. The analyzed waveforms of maximum duration are 6s. A PENTIUM PRO 200MHz processor is used. The floating point operations required are $1.6*10^9$ in MATLAB.

Hamid et al. [5] introduces a compression method for power disturbances data via wavelet packet transform (WPT) and discrete wavelet transform (DWT). The proposed data is proved to be applicable for remote power protection and power quality monitoring. The WPT Daubechies (Db5) filters are used for the data compression of all power disturbances. Using the minimum description length criterion, the Symlets7 filter is proved to be accurate. The reconstruction of signal for the best number of wavelet retained coefficient is selected. The compression ratios obtained are less than 11% by using suitable filters. Implementation of an additional lossless coding helps to reduce the compression by more than half. The algorithm which is introduced can be utilized to compress a wide variety of one-dimensional (1-D) power system disturbance signals and also the ground fault signals. The simulation data obtained from a Power system hardware/analog simulator by the Kansai Electric Power Company (KEPCO), Japan. The DWT and WPT compression are evaluated using the Power disturbance signals, the length of one signal is N=8000 samples for 800 ms.Each sample requires 12 bytes ASCII and magnitudes are stored hence the size of 96 000 bytes.

In [6], new method for the study of power system disturbances with wavelet analysis and neural systems is explained. In the detection, localization and discrimination of power system disturbances, discrete wavelet transform (DWT) (Daubechies Db4) is chosen for accurate analysis. The introduction of neural system with wavelet analysis together works as an advanced tool. It is used for the extraction of 8 typical disturbances. In power quality problems, the proposed method has a good capability for the diagnosis. Eight typical disturbances are distinguished using wavelet analysis and neural classification system. The calculation of two digitized signals with DWT using MATLAB program contains 16384 sample points each.

Zheng et al. [7] illustrates the application of wavelet transform of power system transient and harmonic analysis. Transient model and steady state model are classified for transient analysis, harmonic analysis and time frequency response of the power system. For arc furnace voltage and current waveforms, the harmonic voltage is considered as a source and the sampling frequency is 7.68 KHz. The Daubechies 10 wavelet is used as mother wavelet. An actual arc furnace is used to prove the influence of the analysis scheme and system model which examines the switching operation, harmonic and time frequency response. The system frequency is 60 Hz and the supply system voltage is **394V.** The current waveform is scaled to 200.

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In [8], the analysis of electromagnetic power system transient based on wavelet transform is introduced. The aim of the visual analysis is to reduce the large volume transient signals into smaller and productive quality information to the power system. Wavelet transform provides information about the frequency composition and is more accurate for non-periodic signals. Though the two buses are distanced 100miles apart, the EMTP system has the ability to determine the location of disturbances and to distinguish accurately between the two types of transients (capacitor switching and single-phase fault). With manual inspection or automated transient signature recognition system, the detection scheme is analyzed.

In [9], the reconstruction of non-stationary power system disturbances is shown. The use of wavelet coefficients is introduced to differentiate the types of faults. For reconstruction, the Daubechies wavelet having N=2 is used. The result shows that the 100% of the coefficients are utilized. The application of wavelet is applied to model several short term events like an auto-reclosure, voltage dip and capacitor switching transients. The different power systems are considered for study in which the reconstruction is for 2% of the coefficient.

Pham et al. [10] describes the extraction of the imperfect frequency response of filters in wavelet transform filter banks. Using arc furnace waveforms and field test waveforms, the analysis is done with the non-stationary waveforms algorithm of wavelet probabilistic network (WPN). It is illustrated in the diagnosis of a motor-starting problem. Disturbing Events Detection System (DEDs) with WPN can be used to detect power quality disturbances .The high order Daubechies wavelets are normally very effective for the determination of harmonic power system waveforms. The Daubechies Db10 and Db5 are used for simulation. The modified DWPT filter banks consist of decomposition of waveform to recognize the harmonic trends. It provides a robust WPN algorithm for the analysis of harmonic non-stationary power signal waveform. The diagnosis of motor-starting problem occurred in Western Australia power system has been described by the power and practicality of algorithm with its application.

In [11], new approach by the Dyadic-Orthonormal wavelet transform (DOWT) using multi-resolution analysis of voltage and current signals is presented. The relatively smaller rise of the harmonic current is examined at scales 7 and 8. Comparing the classical FFT based algorithm, the DOWT is more effective in electric power quality assessment and the analysis of waveform. Some other wavelet can be used in voltage and current signals with time varying power system harmonics like Meyer-Wavelet. The proposed technique provides better results as compared to FFT. The lamp of 20W is used for current drawn by a small energy device. Over 10 periods of current (fundamental frequency 50Hz) i.e., 4096 samples are plotted.

In [12], a concept of wavelet transform as an important online tool is introduced for protective relaying algorithm with short data windows comparing to DFT (Discrete Fourier Transform). The significance of modern technique is to isolate the impulse i.e., high frequency component and distinguish the fundamental frequency component through small data window. Using wavelet function Daubechies (Db8), the voltage signal on a transmission line during L-G fault for four levels wavelet decomposition is analyzed. The test results provide the simulation of 10- and 20-samples data windows (based on 5-KHZ sampling rate) equivalent to 1/100 and 1/5 power frequency cycle (based on 50Hz power supply). This technique helps to reduce the tripping time and enhances the procedure of protective relays. The calculations of fundamental frequency component are very efficient and protect the frequency circuit.

Osman et al. [13] presents a digital distance protection scheme based on analyzing the calculated voltage and current signal at relay location in transmission with multi resolution analysis (MRA). The important aspect of this technique is to measure the impedance of the fundamental frequency between the relay and the fault point. As the wavelet basis function, the wavelet Daubechies Db1 (with 2 filter coefficient) is used for fault detection and it is efficient to detect transients. With 8 filter coefficient, the wavelet Daubechies Db4 is utilized for the estimation of the voltage and current. The algorithm is executed on a Texas Instrument (TMS-320-C30) DSP board with wavelet based protection of a physical model of transmission line. After fault inception, the proposed technique detects all faults in less than one cycle. At different locations and different loading conditions the distance protection algorithm is examined through the real time tests which consist of solid ground faults, phase faults, high impedance faults and non-linear ground faults and line charging. The frequency response characteristics are performed on 500kV line with frequency up to 500Hz in a transmission line model consisting of four equivalent π sections of 50km. At one end of transmission line model is a 3-phase, 208V utility system and at the other end 3-phase, 3kVA, 208V, synchronous machine.

Wei Chen et al. [14] present the wavelet based direction protection technique in transmission line. The power system of EHV and UHV is implemented with less data communication using ultra high speed (UHS) directional

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protection. The power systems simulation program PSCAD/EMTDC is used for verification. The modulus maxima of wavelet transform has been analyzed with transient traveling wave. The analysis of simulation gives idea about general problems such as effect of widely used Coupling Capacitor Voltage Transformer (CCVT), the influence of fault resistance and line trap. The oscillations of faults close to impedance discontinuity are solved by wavelet based traveling wave protective relay. A 500kv power system is used for simulation and the power system simulation program PSCAD/EMTDC is used for the verification.

Solanki et al. [15] shows a technique to determine and classify faults for EHV overhead transmission lines. The technique is related to the detection of fault generated transient signals by wavelet analysis. The detection of fault transient signals has been taken through fault current and voltage waveform which leads to high frequency transient signals. After specific analysis of different mother wavelets, Symlets2 is found to be the foremost candidate. The wavelet analysis has the capacity to develop high speed protection relays with precise fault detection and classification. 400kv power transmission line system having length of 190km with 2 generator model is used.

In [16], a scheme of differential protection for a power transformer is presented. The technique is focused on the transient current which is emphasized by fault. Using spectral energies of subtract transients the accurate extraction could be obtained between internal and external faults. To withdraw the transients, the wavelet Daubechies (Db6) is utilized to forge five level filter banks. The DWT filter banks are designed for elimination of the transient signals precisely. The inrush fault shows the restraint signal four times higher than that of an internal fault. The extraction of inrush current signal from internal fault is done with the help of proposed relay. For simulation the EMTP program incorporating transformer modeling subroutine BCTRAN is used.

Chunju et al. [17] represents the protection technique used in the transmission line. For identifying internal and external fault, the transient characteristics of the faulted modal voltage and current are used. In transmission line, the Daubechies Db4 and Symlets5 mother wavelet are productive to recognize high impedance fault. The operation time of distance protection is 20ms. Its zone 1 can only be up to 80% due to error of measurement and uncertainty. After the fault inception, the test output shows that the advanced method is able to detect all the faults in less than one cycle. This protection scheme has the ability to recognize the single line to ground fault with high fault resistance, precisely and it has good judgment, reactivity and feasibility. A 500kv EHV transmission line model is used.

In [18], classification and detection of transmission line fault with the wavelet based method during power swing is illustrated. The decomposition of analyzed signals into various frequency bands has been detailed on wavelet transform of multi resolution. The delay of the operation of relay is to be done in fault conditions, where the distance-relay is unable to extract the fault from stable power-swing. The application of wavelet transform for detection and classification of fault in power swing is used for relay operation blocking or monitoring. For multi resolution analysis, the wavelet Daubechies-8 (Db8) is used to detect the fault as mother wavelet. Various faults like ground fault and phase faults are determined by distinguishing a feature from components based on results of wavelet transform. The EMTP transmission line relay testing is studied by the power system model is introduced by the IEEE PES Power System Relaying Committee (PSRC) WG D10.

Kulkarnisakekar et al. [19] explains transmission line protection scheme where the fault detection is done by wavelet transform and the classification of fault by Artificial Neural Network (ANN). The occurrence of fault and detection is carried out very fast through the new signal processing tools with increase in speed of processing. Depending on the application of ANN the adaptive protection scheme is tested to enhance the efficiency such as shunt fault, varying fault cases such as different fault resistance and fault inception angle. DWT (Db4 level 1) is used for simulation. The results show that the faults are classified in one cycle. The simulation is completed with each type of fault (SLG, LLG, LL, LLLG each section of transmission line) at various fault inception angles between 0 and 90 and fault resistance 0.0001 to 40 via SIMULINK and SIMPOWERSYSTEM toolbox of MATLAB. As compared to earlier techniques in transmission line distance protection the ample of line length is protected.

Kale et al. [20] describes a new theory for the selection of a faulted phase in transmission line which is related to traveling wave theory. It has the ability to fulfill the necessity of efficiency and rate of motion. Faulted phase selection is indifferent to independent parameters like fault location, fault resistances, fault inception angle and fault type. To determine the faulted phase selection, Simulink of MATLAB software is used, to simulate the double end fed power system of 400 KV, 200Km transmission line system. All the faults including single phase, two phases and three phases are estimated. It is shown in the result that faulted phase selection in completed inside a quarter of cycle.

AtthapolNgaopitakkul [21] states the algorithm for fault classification on transmission line. The technique used to classify the fault on transmission line is a combination of discrete wavelet transform and fuzzy logic. The system used

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Vol. 6, Issue 11, November 2017

for simulation is a double circuit structure and loop structure of 500kv and 500MVA load. The Alternative Transient Program (ATP)/EMTP model is used to simulate fault signals. Mother wavelet DB4 is used in this system. The accuracy obtained in results is very high with the use of this combinational method.

In [22], a powerful system for detection of different disturbances with the help of neural networks is described. The system consists of AI kernel and an acquisition card. In acquisition card 640 samples in every 100 milliseconds is obtained. In ANN output thresholds are defined, the output value may be considered as disturbance, if the output value is above 0.7 and below 0.3 it is treated as ideal signals.

In electrical networks, the power system transient cause serious disturbances. With the help of time-frequency analysis technique of DWT and MRA algorithm power system transient disturbances are detected by choosing the most suitable wavelet function [23]. The wavelets db4, coif4, bior3.1, and sym5 are used. In which Db4 and coif4 are more efficient in medium and high frequency disturbances, Bior3.1 is efficient in high frequency disturbances and Sym5 is efficient in low medium and high frequency disturbances. IEEE 1159 system is used for simulation.

In [24], the analysis of time-varying harmonics in voltage and current waveforms are discussed. The Discrete Fourier Transform is proposed by international harmonic measurement standards. It is given as an extension of [70]. IEC 61000-4-7 system is used for sampling. The algorithm simultaneously uses different levels of the wavelet decomposition tree to compute the harmonic distortion based on wavelet-packet transform.

G.Keerthana et al**.** [25] discusses the failure in transmission line which interrupts the reliability of the operation in power system. DWT is used for the extraction of the hidden factors from the fault signal. This method uses Daubechies6 (mother wavelet) which is useful for detecting and localizing different types of fault transients. MATLAB/Simulink is used for verifying the simulation results. 3 generator 3 bus systems are used as test rig.

The technique for the detection of transmission line faults is represented. Wavelet transform [Daubechies] is used for the detection and extraction of disturbance features of various types of electric power quality disturbances. A 100KM transmission line of 138kV, 100MW, 60Hz system is used for study. This provides an easy selection of threshold to detect fault at different distances and inception angles in the range of 0-180^0. A 100 km transmission line of rating 138kV, 100MW, 60Hz is fed from both ends. Synchronized sampling of three phase currents and voltages is carried out at both the ends with the help of a GPS satellite [26].

In [27], the EHV transmission line protection is illustrated. Author gives the ultra-high-speed [UHS] directional protection scheme using wavelet transform. In fault feature analyses, 500KV transmission line system is used. The wavelet transform technique extracts high-frequency transient components from two composite relaying signals. The wavelet transform (WT) is used for investigating the possibility of improving the UHS protection.

In [28], protection of parallel transmission lines is discussed. The scheme is utilized for the detection and classification of faults on parallel transmission lines which includes the combination of wavelet transform and neural network. Daubechies 8 wavelet is used for analyzing the signals. For fault simulation 220 KV, 100 Km double circuit transmission line system is selected. This is an accurate technique for automation of identification of faults on parallel transmission lines.

Mamta Patel and R N Patel [29] presents the fault detection and its classification on a transmission line. The technique applied is wavelet MRA and feed forward back propagation neural network. A 220 kV power system is simulated using MATLAB®/Simulink, SimPowerSystem toolbox, wavelet toolbox and neural network toolbox for different fault conditions on the line. The method uses D1 and D5 wavelet. The classification of faults is precise and the location of the faults is identified with 95% accuracy.

Occurrence of fault in transmission and distribution line is very high because it runs over hundreds of kilometers to supply electrical power to the consumers is pointed out in [30]. A technique based on measurement of fundamental frequency currents and voltages or impedance for fault detection in transmission line is most suitable. The occurrence of faults in the transmission line produces transients. Artificial intelligence methods as ANN or fuzzy logic system can be used to classify and locate fault. For finding faults with different locations on the line a 220 kV power system is simulated using MATLAB/Simulink, SimPowerSystem toolbox, and wavelet toolbox.

Chengzong Pang and MladenKezunovic [31], discusses the phenomenon of large fluctuations of power between two areas of a power system called as power swing. The distance relay should be able to detect the fault occurs during the power swing. This method extracts the traveling waves from transient signals induced by faults and calculates the energy of high frequency components extracted by using the wavelet transform. For transmission-line relay testing, EMTP reference model is used which is introduced in the IEEE PES. ATP is used to simulate the power swing. Db8 wavelet is used in this paper.

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In [32], improved method for the transmission line boundary protection based on wavelet transform and ANN is explained. Using local end data and exact fault type, the external fault is differentiated with internal fault. To complete this objective, signal processing and artificial intelligence is used. The db5 wavelet is selected as the mother wavelet for detecting the short duration, fast decaying fault generated transient signals and the extracted features will be handled using a self-organized neural network. A 500-kV, where lengths of three lines are set identically to 200 miles and capacitances of 0.1 µf model is used for simulation.

Parikh et al. [33] represents the technique for fault zone identification in a series compensated transmission line. Method used for this is a combined wavelet-support vector machine (SVM) technique. The proposed technique consists of two stages. In first stage DWT technique is employed to capture the features of fault currents and in second stage these features are passed to the SVM to detect the fault zone. This algorithm has an overall accuracy of 93.917%. A set of 25200 test cases in a sample power system proves the effectiveness for a large test data. A 400-kV, 50-Hz power system consisting of two sources representing two areas connected by a tie line of 300 km with a series capacitor placed at the middle of the line model is used for simulation.

Fernando H and Ali Abur [34] studies power industry transmission line fault location. The method suited is wavelet transform for analyzing power system fault location. Daubechies4 wavelet as the mother wavelet in all the transformations is used. It proves that the Wavelet transform possess some unique features that make it very suitable for this particular application. A 345KV, 200 miles model with ATP/EMTP program is used for simulation.

Dong-Jiang Zhang et al. [35] describes the new protection scheme for protecting power transmission lines called as transient positional protection (TPP). By using complex wavelet analysis the proposed scheme is developed. It detects the fault position according to their relative travelling time and polarities with the utilization of primary voltage readings. Complex Morlet Wavelet is used, which can specify the shape of the wavelet without changing the center of its function in the frequency domain. The frequency-dependent transmission line model based on a 400-kV EHV vertical constructed line is simulated in PSCAD/EMTDC.

Liang et al. [36] approaches the fault detection and classification with the use of wavelet MRA and wavelet transform. This is a powerful signal analysis tool has been used successfully in many areas for about 10 years. MRA examine the feature of signal at different frequency band. This algorithm proves its effectiveness in high impedance fault detection. To provide fault data a 3 generator 6 bus power system is simulated by ATP. The fault was simulated on a line of 174.4km length. To get high frequency signal a low pass digital filter having 300Hz cut of frequency is used.

B. HVDC

A high-voltage, direct current (HVDC) electric power transmission system is also called a power super highway or an electrical super highway. It is a well-proven technology used to transmit electricity over long distances by overhead transmission lines or submarine cables. It is also used to interconnect separate power systems, where traditional alternating current connections cannot be used.

In [37], a modern protection algorithm in multi terminal high voltage DC (MTDC) system for DC line faults is proposed. The effect of fault on neighboring DC lines is unlimited considering the increase in DC current. Thus the location of the fault should be detected at the earliest. The simulation program PSCAD/EMTDC is utilized for the investigation of fault behavior and detection through four terminal MTDC model while the later part of simulation is done using MATLAB. Mallatfast dyadic wavelet transform (FDWT) algorithm's criteria are based on are fault detection by using the voltage wavelet coefficients (criterion1), the current wavelet coefficients (criterion2) and the voltage derivative and magnitude (criterion3). The lack of selectivity in fault detection of current wavelet coefficient is resolved using the redundant Triple Modular Redundancy (TMR) technique. The main target of the protection algorithm is to detect a DC fault in 1ms beyond the communication between the participating converter stations. The 4-terminal MTDC system is used.

A new high-speed HVDC line protection is illustrated using wavelet technique. The fault occurs during voltage zero crossing in power system which is a problem for travelling wave protection. After the analysis of different faults in HVDC power systems, wavelet transform and protection criteria based on wavelet technique is proposed. The application of wavelet technique leads to a faster, easier and more reliable solution for the fault detection and protection of HVDC lines. A 1000 MW (500 kV, 2kA) DC line is used to transmit power from a 500 kV, 5000 MVA, 60 Hz

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Vol. 6, Issue 11, November 2017

network to a 345 kV, 10000 MVA, 50Hz network. The DC line is 300 km long and the speed of the travelling wave is 296112 km/s. It is the standard model of 12-pulse HVDC system under the MATLAB environment [38].

C. POWER TRANSFORMER

A power transformer is a static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current for the purpose of transmitting electrical power.

Saleh et al. [39] introduces a modernistic algorithm for differential protection of three phase power transformers which is based on wavelet packet transform. The presented algorithm is a two level resolution WPT, based on estimating the WPT coefficients, of the next level highest frequency sub-band. These coefficients and time locations simultaneously help to determine the type of examined currents. The Daubechies Db4 is most favorable mother wavelet for current diagnosis application. Under various operating conditions the simulation results show the effective, reliable and fast capabilities of WPT algorithm to analyze different types of currents flowing in a power transformer. The WPT algorithm is tested on a 3-phase, 5 kVA, 230/550–575–600, 60 Hz, core type delta-star power transformer. The differential current is sampled at 10 kHz.

Ozgonenel et al. [40] discusses about the protection of power transformer in power system. Wavelet Transform is a reliable and computationally efficient tool for distinguishing between the inrush currents and fault currents. In this study, Coiflet 6 (Coif 6) wavelet function is used for the discontinuity analysis of phase currents. It gives accurate discrimination between magnetizing inrush and fault currents in transformer protection. Different faults are simulated using ATP-EMTP model.

In [41], a scheme for power transformer protection is introduced. It includes both wavelet transform as well as fuzzy logic. Db6 wavelet function is used for the discontinuity analysis of the phase currents in this paper. A 138/13.8 kV, 30 MVA transformer is simulated using MATLAB/Simulink. Fuzzy logic is used to overcome the uncertainty in the differential current signals.

III.POWER QUALITY

It is an electrical network or the grid's ability to supply a clean and stable power supply. A perfect power supply that is always available, has a pure noise-free sinusoidal wave shape, and is always within voltage and frequency tolerance. Alexander Kusko (1976) has discussed on power quality events [42] happen during fault conditions, lightning strikes, and other occurrences that adversely affect the line-voltage and/or current waveforms.

Santoso et al. [43] represents the power quality evaluation using wavelet transform. For slow transient disturbances, Daubechies Db8 and Db18 are better and for short transient disturbances, Db4 and Db6 are good. This technique is demonstrated to detect, localize and investigate the types of power quality disturbances. An automatic scheme is considered with the uniqueness of the squared wavelet transform coefficients for enhancing the results of this technique. Classification of power disturbances is successfully achieved automatically with wavelet transform. The wave fault disturbances recorded on 15 December 1993 and on 23 December 1993.

In [44], utilization of discrete wavelet transform to analyze and detect power quality disturbances is presented. The disturbances are voltage sag, swell, outage and transient. The wavelet Daubechies Db4 is used for analyzing the disturbance signals. Simulation of power system network is carried out by EMTP. Visual inspection becomes unrealistic in front of the very large composed data. The wavelet transform has the ability to categorize and detect the power quality disturbances automatically. A 3 source system model is used for testing.

Jahromi et al. [45] analyzes the harmonics effect in wind turbine by introducing a powerful method to decrease down the effects, based on both the wavelet analysis and active filters. The number of harmonics decreased and the improvement of power quality network is completed with a harmonic model of wind turbine and harmonic reduction technique. To detect the harmonic components, two criteria are used. The wavelet Daubechies at level Db8 particularly shows the amount of harmonics in a signal. The other criterion is the drop in wavelet coefficient signal energy. The average Daubechies wavelet Db4 and Db8 are used to detect the harmonic signals. The performance of the wind farm is improved and the amount of harmonic of power converter reduces using an active filter with traction system. Automated activation of filter module(s) in accordance with the current total harmonic distortion (THDi) and the

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 6, Issue 11, November 2017

harmonic factor (HF) levels set by the IEEE 519-1992 standard. A special 3-level PWM switching strategy is given for filter modules, results 50% reduction in the overall switching losses compared with the 2-level method.

In [46], a modern approach for power quality disturbances using ANN and multi wavelet transform is presented. The multi-wavelet based neural network classifier is used for high efficiency. It is also used for detection, determination, low usage time and to localize the transient disturbance. There are total 6 types of power quality disturbances i.e. type A to type F. The multi-wavelet is DGHM and the simulation of the disturbances is completed using MATLAB program. Pure sinusoidal (type A) harmonic distortion (type E) impulsive transient are analyzed with 100% accuracy, voltage sag (type B) with 97.27%, voltage swell (type C) with 96.40% and interruption (type D) with 94.50% efficiency. It leads us to understand the analysis of multi wavelet based neural structure, provides a great potential for diagnosis of electrical power system in the location of power quality problems.

Angrisani et al. [47] discusses power quality problem and variation in the electrical power services. To overcome this problem the combination of continuous wavelet transform (CWT) and its modulus maxima properties and DWT is used. The detection of the disturbance and its duration is done through CWT. Frequency sub-bands disturbance amplitude is found by decomposing in a distributed manner using DWT. The most relevant disturbances in electrical power systems can be detected, localized and estimated in noisy environment through wavelet transform. Using less parameter, the disturbance classification is completed. The sampling frequency is 12.8 kHz and sample number 1024. The number of Monte Carlo simulations for each case and each SNR (Signal to Noise Ratio) value is 100.

Chia-Hung Lin et al. [48] determines the problem related to the sensitivity of the electronic equipment. Power quality detection has been analysed by adaptive wavelet networks (AWNs). AWN combines the use of morlet wavelet and adaptive probabilistic networks. Disturbance events detection system (DEDS) is used to monitor eight locations. Morlet wavelets are responsible for extracting features from unknown signals and probabilistic networks. In a dynamic environment, AWN models are suitable for application.This process is very fast. A 14-bus system is used consist of five generator buses, 15 lines, 5 transformers, and 8 nonlinear devices. The buses with harmonic sources used in the measurements for 8 observation locations in the system. At each observation location, harmonic and voltage fluctuation phenomena are considered and for neighbouring buses the harmonic source causing voltage distortion are considered.

In [49], the method for harmonic analysis based on wavelet transform is proposed. The wavelet transform is utilized for extracting disturbances in power quality monitoring systems. Distortion due to different sub-band harmonics can be easily estimated and each harmonic component can be evaluated from different part of the transformed data by this method.

Kanirajan et al. [50] specify the power quality issues which have increased in recent years and to minimize these issues the classification of power quality events is required. It gives the classification of power quality events with the help of wavelet based data compression technique i.e. Daubechies 2 and Symlet.

Oyedoja et al. [51] presents, a continuous change in the power signal which usually occurs due to the presence of disturbances in power. The proposed method for the detection of disturbances is wavelet transform which uses two types of mother wavelet namely haar and dmey WT. It is useful in the identification of variation or discontinuities in signals. Diagrammatical representation of WT shows clearly the peculiarities of each kind of disturbance which is the unique quality.

Thiyagarajan et al. [52] details about the presence of harmonics in power electronics systems. The increase in harmonics distorts the shape of the voltage and current waveforms. The Wavelet transform technique uses daubechies20 to give good time resolution and poor frequency resolution at high frequencies. A 1.6 kHz frequency is used as sampling frequency with 50Hz fundamental frequency. It gives good frequency resolution and poor time resolution at low frequencies.

In [53], the method for characterization of power quality disturbances with the help of recorded voltage and current signals is described. This method includes wavelet transformation and S-transform analysis combined with ANN technique. It analyses the visualization of voltage distortions with time varying amplitudes. Daubechies-4 mother wavelet up to 5 level decomposition is carried on sag waveform. Using matlab software a 25kv distribution network is simulated.

Rafael A. Flores [54] describes the state of techniques for automatic classification of power quality events in order to solve problems in electrical networks. Method used for this is DWT for its computationally efficient implementation. This method gives very fast computation which is considered as advantage.

In [55], probabilistic neural network (PNN) classifier based on S-Transform to reduce thefeatures of the disturbance signal to a better extent without losingits original property is presented. There are 11 types of disturbances

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 6, Issue 11, November 2017

that occur frequently in distribution network. PNN uses only 4 features for effective classification of 11 types of PQ disturbances. PNN classify the PQ class with 98.64% accuracy.

This paper presents a tool to analyze transient disturbances in electrical power systems. Wavelet coefficient energies which act as fast and efficient tool is chosen for this purpose. Normalization scheme provides the analysis of oscillographic records. The proposed wavelet-based analysis is evaluated with about one and a half thousand actual oscillographic records and good results were achieved [56].

Haibo He et al. [57] focus on the PQ disturbances classification problem. PQ classification is based on the wavelet transform and self-organizing learning array (SOLAR) system. Daubechies Wavelet is utilized to construct the feature vector based on the MRA method. The SOLAR implemented in this scheme is a feed forward (FF) structure with all neurons arranged in multiple layers.

Gupta et al. [58] describes the supply-voltage fluctuations problem. This problem occurs when processor activity rapidly changes current consumption over a relatively small time scale called as ds/dt problem. The distributed power-delivery model is designed to analyze local on-chip voltage variations. Model of the power delivery network with a distributed on-chip power-supply grid is used.

In [59], a method for power quality (PQ) disturbance classification problem naming wavelet norm entropy-based effective feature extraction method is discussed. This method performs a feature extraction and a classification algorithm. Disturbance classification scheme is performed with wavelet neural network (WNN). It gives correct classification for about 92.5% of the different power quality disturbance signals under noise condition.

Zwe-Lee Gaing et al. [60] recognizes the power-quality disturbances in which a prototype wavelet-based neural networkclassifier is used. The classifieris constructed with DWT technique combined with the PNN model. The implemented scheme has the ability of recognizing and classifying different power disturbance types more accurately.

IV.ELECTRICAL MACHINES

A machine is a device that simply transforms the direction or magnitude of a force. Machine can be a motor or generator. Motor is classified in two parts i.e.AC motor and DC motor. Induction motor comes under AC motor which is used here. Theory of electromechanical devices, with specific emphasis [61] on the theory of rotating electric machines was introduced by D. P. Kothari and I. J. Nagrath (1985).

Induction motor is introduced by P. S. Bimbhra [62]. An induction motor, 3phase induction motor or asynchronous motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding.

In [63], a motor drive model is developed. The simulation and modeling of overvoltage problem is based on time domain method. The proposed simulation takes large time for computation. To abridge the computation time, wavelet modeling is used. Instead of EMTP, MATLAB 4.2 and ORCAD version 9.2 on a Pentium 466MHZ is used. Points considered are 512 and the simulation time is 25ms. Wavelet modeling is used effectively in the power system for solving problems of small resolution or small dimension and it decreases the computational time. The cable oscillation frequency is 1.32MHz for the 100-ft cable. The sampling frequency is greater than 2.64MHz for precise result as per the Nyquist rule.

Giaouris et al. [64], discusses the removal of noise in electrical drives. The useful information in the measurement of current is corrupted by the presence of noise in drives. This problem arises due to high frequency signals. The solution to this problem is achieved through digital low pass filter but it does not deal effectively when the signal contains time varying high frequency characteristics. The drawback of low pass filter is overcome by DB5 wavelet which is used for removing the noise. A 4-pole 400V, delta connected 7.5kW induction motor is used as test rig. It is found that result of DB5 wavelet and digital filter are similar.

In [65], the problems occurring due to rolling element bearing in machines is explained. The fault diagnosis of ball bearing is fulfilled by the methodology based on both CWT and ANN. A motor with 1797 rpm speed and 2hp load is used. To select an appropriate wavelet to extract statistical features, three wavelet selection criteria are used: Maximum energy, Minimum Shannon entropy, and Maximum energy to Shannon entropy ratio. It gives better classification efficiency for 87 different mother wavelets. It is concluded that the wavelet using Minimum Shannon Entropy ratio criterion (Complex Morlet 1-1 wavelet) gives better classification efficiency.

In [66], application of wavelet transform for machine fault diagnostics is introduced. This includes time–frequency analysis of signals, fault feature extraction, singularity detection for signals, de-noising and extraction of the weak signals, compression of vibration signals and system identification.

V.CONCLUSION

Wavelet Transform plays an important role for the analysis of electrical system. The objective is to solve the problem and to give information about the type of fault. WT helps us to know where the fault occurs in short time. The applications of the wavelet analysis have covers power system, power quality and machines briefly. The study of WT in this paper is on the basis of references spread across last two decades. In signal processing field, WT has proved to be a better tool for analysis than other.

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ISSN (Online): 2278 – 8875

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Website: www.ijareeie.com

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