Fast and Accurate Fault Detection in Transmission Line using Wavelet Transform

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Abstract

An accurate fault detection and classification is required to transmit power from generating station to various load centres reliably. A new approach for fault detection for interconnected system using the time synchronized phasor measurements. The scheme is depending on comparing positive sequence voltage magnitudes for specified areas and positive sequence current phase difference angles for each interconnected line between two areas on the network. The paper performance of discrete Fourier transforms method for phasor estimation. The MATLAB/SIMULINK program is extensively used to implement the idea. It is used to simulate the power system, phase measurement function, synchronization process, and fault detection.

Keywords: Fault Detection/Location Index, Discrete Fourier Transforms (DFT), Phasor Measurement and Transmission lines

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I. Introduction

The main function of the electrical transmission and distribution systems is to transport electrical energy from the generation unit to the customers generally, when fault occurs on transmission lines, detecting fault is necessary for power system in order to clear fault before it increases the damage to the power system. In Last Decade several techniques have been employed to determine the fault location in underground cable such as. Agecable. Bridge technique. Traveling wave but each technique has different solutions. A technique selection is also available for fault detection and But Its Depend on Length of cable and types of fault. Fault Detection is important from the view point of improving system availability and reliability. The concept of fault diagnosis can be regarded as a three step algorithm. First of all, one or several signals are generated which reflect faults in the process behavior. These signals, generally called indicators, are composed from existing mea- surements and sometimes corresponding reference signals. The second step is the fault detection. In this step the indicators are evaluated to determine the presence of faulty behavior and a decision has to be made determining the time and location of the possible faults from the indicators. Finally, in the last step, the nature and the cause of the fault is studied by analyzing the relations between the symptoms and determine which component of the system failed to operate. This corresponds to fault isolation.

Locating transmission line faults quickly and accurately is very important for economy, safety and reliability of power system. Existing methods for fault location such as measuring the changes of impedance or voltage and current of line before and after a fault occurred seriously rely on fault type, grounding resistance, load conditions and system running way. The appropriate percentages of occurrences various faults are listed below

- Single line to ground fault – 70-80%
- Line-Line to ground fault - 10-17%
- Line-Line fault – 8-10%
- Three phase – 2-3%

When faults occur in the power system, they usually provide significant changes in the system quantities like over-current, over or under-power, power factor, impedance, frequency and power or current direction. The most common and also the one used in this thesis is the over-current and so over-current protection is widely used.

In recent years, there have been many activities in using fault generated travelling wave methods for fault location and protection. The travelling wave current-based fault location scheme in which the distance to fault is determined by the time differences measured at the sending end between an incident wave and the corresponding wave reflected from the fault have been developed for permanent faults in underground low voltage distribution networks by S. Navaneethan et. al. in ref. [4]. However, due to the limitation of the bandwidth of the conventional CT (up to a few GHz) and VT (up to 50 kHz), the accuracy of fault location provided by such a scheme is not satisfactory for a power cable. Also there have been many activities in using power frequency (low frequency) for fault location and protection

The problem of detecting and classifying faults in a transmission line has been going for a very long time. It has been one of the major concerns of the power industry. Normally, protective relays, recording devices and special control and protection software systems are responsible for detecting the fault occurrences and isolating the faulted portion from the system. Thus it is necessary for the faults to be detected quickly and precisely. It is also equally important to know the details about the fault that has occurred so that it can be corrected soon. A variety of fault location schemes have been developed over the years. Common systems include impedance-based locators [1,2], or those which measure the impedance seen by one or both ends of the transmission line, and traveling wave-based locators [3], or those which rely on the timing of fault detections. In addition to categorizing these fault location methods by the way in which they locate faults, they can also be classified into one-terminal and two-terminal based on whether they require information from one end or both ends of the transmission line, respectively.

II. DISCRETE WAVELET TRANSFORM

Wavelet theory is the mathematics, which deals with building a model for non-stationary signals, using a set of components that look like small waves, called wavelets. It has become a well-known useful tool since its introduction, especially in signal and image processing. The DWT is easier to implement than Continuous Wavelet Transform CWT because CWT is computed by changing the scale of the analysis window, shifting the window in time, multiplying the signal and the information of interest is often a combination of features that are well localized temporally or spatially This requires the use of analysis methods sufficiently, which are versatile to handle signals in terms of their time-frequency localization. Frequency based analysis has been common since Fourier's time; however frequency analysis is not ideally suited for transient analysis, because Fourier based analysis is based on the sine and cosine functions, which are not transients. These results in a very wide frequency spectrum in the analysis of transients Fourier techniques cannot simultaneously achieve good localization in both time and frequency for a transient signal. The main advantage of WT over Fourier Transform is that the size of analysis window varies in proportion to the frequency analysis. WT can hence offer a better compromise in terms of localization. The wavelet transform decomposes transients into a series of wavelet components [11], each of which corresponds to a time domain signal that covers a specific octave frequency band containing more detailed information [11]. Such wavelet components appear to be useful for detecting, localizing, and classifying the sources of transients.

$$\mathrm{DWT}(f,m,n) = \frac{1}{\sqrt{a_0^m}} \sum_k f(k) h^* \left(\frac{n-ka_0^m}{a_0^m}\right) \quad (1)$$

where, the parameters a_0^m and k a_0^m are the scaling and translation constant respectively, k and m being integer variables and h is the wavelet function which may not be real, as assumed in the above equation for simplicity. In a standard discrete WT (DWT), the coefficients are sampled from the continuous WT on a dyadic grid, $a_0 = 2$ yielding $a_0^0 = 1, a_0^{-1} = 1/2$ .Actual implementation of the (DWT) involves successive pairs of high-pass and low-pass filters at each scaling stage of the WT. At each detail, there is a signal appearing at the filter output at the same sample rate as the input; thus, by using a sample rate F and scaling by two $a_0 = 2$ Eq.(2) shows the association of each scale 2m with a frequency band containing distinct components of signals. Frequency band of scale

$$a_0 = 2 \quad 2^m = f/2^{m+2} \to f/2^{m+1} \quad (2)$$

By stretching (dilating) and shifting (translating) a 'mother wavelet', one is able to capture features that are local both in time and frequency. This property alone makes wavelets more suitable for analyzing non-stationary or transient signals.

The wavelet transform is suited for analyzing signals that display strong transients, for example discontinuity, or rupture. More precisely, if x(t) has such singularities, these will affect only the coefficients at time points near the singularities. In contrast, the standard Fourier transform described above depends on the global properties of x(t) and any singularity in it will affect all coefficients. The continuous wavelet transform (CWT) of $x \in L_2(R)$ by $\psi \in L_2(R)$ is a projection of a function x onto a particular wavelet ψ a,b(t):

$$(W_\psi^x)(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \psi\left(\frac{t-b}{a}\right) dt \quad (3)$$

$$x(t) = \frac{1}{C_\psi} \int_{-\infty}^{\infty} (W_\psi^x)(a,b) \psi\left(\frac{t-b}{a}\right) \frac{da}{a^2} db \quad (4)$$

Where a > 0 and b are scale and translation parameters, respectively, ψ is the mother wavelet, C is a constant that depends on ψ, and (W_x) (a, b) is the continuous wavelet transform. We can interpret 4 as an inner product of x(t) with the scaled and translated versions of the basic functions ϕ:

$$(W_\psi^x)(a,b) = \int x(t) \psi(a,b)(t) dt \quad (5)$$

Where $\psi_{(a,b)}(t) = \frac{1}{\sqrt{a}} \psi \frac{t-b}{a}$ is the dilated (by a) and translated (by b) version of the mother wavelet ψ. The most obvious difference between the Fourier transform and the CWT is that the wavelet basis functions are indexed by two parameters instead of just one. The scale a is assumed to be restricted to R+, which is natural since a, although tenuously, is interpreted as reciprocal of frequency. As explains, this relation may be established in the case of an oscillatory mother wavelet ψ, because then as 'a' decreases the oscillations become more intense and show high-frequency behavior. Similarly, when ‘a’ increases the oscillations become drawn out and show low-frequency behavior.

III. REVIEW OF EXISTING FAULT DETECTION

Faults on transmission lines need be found out as quickly as possible otherwise they can destroy whole power systems. Generally, fault location methods can be classified into two technique
A. Travelling Wave Technique
B. Impedance Base Technique

A. *Travelling Wave Technique*

The traveling wave fault location method is known as the most accurate method currently in use. Fault location on transmission lines using traveling wave was first proposed by Rohrig in 1931 [3]. In this method, when faults occur on transmission lines, an electrical pulse originating from the fault propagates along the transmission line on both sides away from the fault point. The time of pulse return indicates the distance to the fault point. This method is suitable for a long and homogenous line. The disadvantage of the traveling wave method is that propagation can be significantly affected by system parameters and network configuration [5].

It is also difficult to locate faults near the bus or faults that occurred near zero voltage inception angle [6]. Under this method, we have single-ended fault location algorithm and double-ended fault location algorithm. In single-ended algorithm, traveling time of the first wave away from the fault point to terminal and the arrival of same wave after reflecting back from fault point is always proportional to fault distance[4,5] In single-ended algorithm, fault location is proportional to the first two consecutive transient arrival time. From measurements of the first two consecutive transient arrival times, fault location can be calculated. The double ended algorithm was developed by Dewe et al. [9] in 1993. In doubleended algorithm, fault location is proportional to the arrival time of waves at each end away from the faults.

Because of that limitation, wavelet transform has developed by Magnago et al. in [14]. The author of [17] made a comparison between fourier transform and wavelet transform. In wavelet transform, dilation of a single wavelet is done for analysis. It uses short windows at high frequencies and long windows at low frequencies [9]. It can represent signal both in time and frequency domain, which helps to figure out sharp transitions and fault location. The ability of wavelet transform to locate both time and frequency makes it possible to simultaneously determine sharp transitions of signals and location of their occurrence [16].

B. *Impedance Base Technique*

Impedance based method uses the fundamental frequency of voltage and current phasors from installed transducers such as numerical relays and fault recorders. Under this technique, phasor voltage and current can be taken from both terminals or from single terminal of a transmission line. Two-terminal algorithm provides more accurate results compared to single-end algorithm because this two-terminal algorithm is not affected by fault resistance and reactance. Phasor voltage and current data can be collected from two-ends of a transmission line either by synchronized or unsynchronized. Synchronized data can be collected using GPS, PMU. For the unsynchronized data, users have to first compute the synchronization error and fault location is calculated. Since the synchronized method has to use the communication device, it is more expensive than the unsynchronized method.

Impedance based method is widely used because of its simplicity and low cost. M.T. Sant et al. in 1979 introduced the online digital fault locator which measures the ratio of reactance of the line from the device to fault point [10]. After calculating the line impedanceper unit length, the fault distance on the line is calculated. If fault distance is calculated on the measurement of reactance from one end of the line, accurate fault location cannot be determined because of fault resistance. If the fault is ungrounded, fault resistance will be small and it does not affect the precision of the fault location. In case of grounded fault, fault resistance will be high and it will affect the fault location. Wiszniewski in 1983 presented the 17 new method which eliminate above error [13]. Fault distance is calculated by measuring the reactance at one end of the line. The author calculates the phase shift between the total current at one end of the line and current flowing through fault resistance. T. Takagi et al. in 1981 developed a new method which used current and voltage data from one terminal to calculate fault distance on lines [12, 13]. A similar technique was proposed in [10, 17, and 12].

This method turned out to be inaccurate when fault resistance was present and fault currents were contributed from both ends of the line. In 1988, M.S. Sachdev and R. Agarwal proposed new fault location technique [5]. This method used post fault voltage and current from two end terminals which were not required to be synchronized. The same technique was proposed by D. Novosel et al. in 1996 [6]. Similarly, the author of [7] proposed a method for multi-terminal single transmission lines using asynchronous samples from each terminal. In 1992, the author of [8] proposed a fault location technique for multi-terminal two parallel transmission lines. In 1981 the author of [9] and in 1982 the author of [10] suggested a fault location method using synchronized voltage and current from both end terminals of lines. Later on, more papers [11, 2, and 8] were issued following the same techniques for fault location calculation. M. Kezunovic et al. in 1996 introduced new fault location method. A digital fault recorder was equipped with Global Positioning System (GPS) to retrieve synchronized data from two end terminals [3]. This reduced the computational burden. The solution was found to be more accurate. The voltage and current samples from both ends were taken at a sufficiently high sampling rate. Fault location technique proposed in [4] used Phasor Measurement Unit (PMU) at both ends of a line to get synchronized voltage and current data from both ends.

In 1992, Adly A. Girgis et al. [10] proposed fault location algorithm applicable for two and three terminal lines. In this method they considered synchronization errors in sampling the voltage and current from two ends of the line. The author of [15] developed a fault location algorithm based on voltage and current data from single-end terminals and two-end terminals of transmission lines. In [8] data were taken from unsynchronized two-terminal lines to calculate fault location on a line. In [16] the samples of voltages and currents at both ends of line were taken synchronously and used to calculate fault location. In [17], fault location algorithm was based on synchronized samples of voltage and current data from two ends of the line. [6] 18 presented a new fault location algorithm based on phasor measurement units (PMUs) for series compensated lines. Fault resistance and line capacitance were neglected, and balanced pre-fault loading condition were considered. The author of [13] proposed a new concept called 'distance factor'.

The algorithm he used to calculate fault location was independent of fault, pre-fault currents, fault type, fault resistance, synchronization of fault locator placed at both ends of the line and pre-fault condition either balanced or not. The procedure was based on fundamental components of fault and pre-fault voltage at two ends of a transmission line. The author of [14] described a very accurate fault location technique which used post-fault voltage and current from both terminals. This technique was applicable to untransposed lines. Techniques were applicable for the transposed lines. The author of [12] proposed fault location algorithms which used data from one end of the transmission line. This algorithm required only current signals as input data.

IV. POWER SYSTEM SIMULATION MODEL

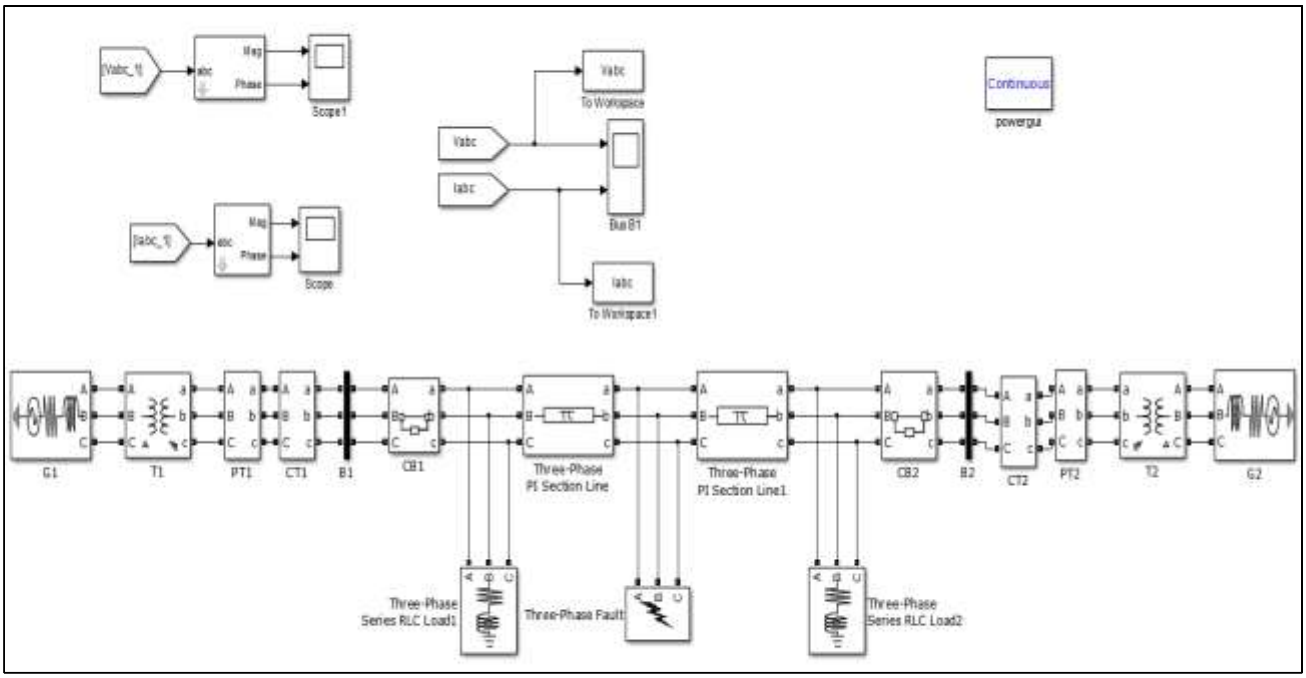

Fig. 1: Typical transmission line model in MATLAB

The simulation is developed as a one-end frequency based technique and used both voltage and current effect resulting from remote end of the power system. One The simulation is developed as a one-end frequency based technique and used both voltage and current effect resulting from remote end of the power system. One Cycle of waveform, covering pre-fault and post-fault information is abstracted for analysis. The discrete wavelet transform (DWT) is used for data preprocessing. Discrete Wavelet Transform is applied for determining the fundamental component, which can be useful to provide valuable information to the Distance relay to respond to a fault. It is applied for decomposition of fault transients, because of its ability to extract information from the transient signal, simultaneously both in time and frequency domain. MATLAB software is used to simulate different operating and fault conditions on high voltage transmission line, namely single phase to ground fault, line to line fault, double line to ground and three phase short circuit.

V. SIMULATION RESULTS & DISCUSSION OF FAULT CASE

A. AG fault:

When this type of fault occurs, during the time slot from 0.08 to 0.016 signal is distorted. Voltage amplitude Vabc changes from Va,Vb:2x10^5 to Vc: 0.5x10^5, and current (Iabc) decreases from Ic:300A to Ia,Ib:100A.

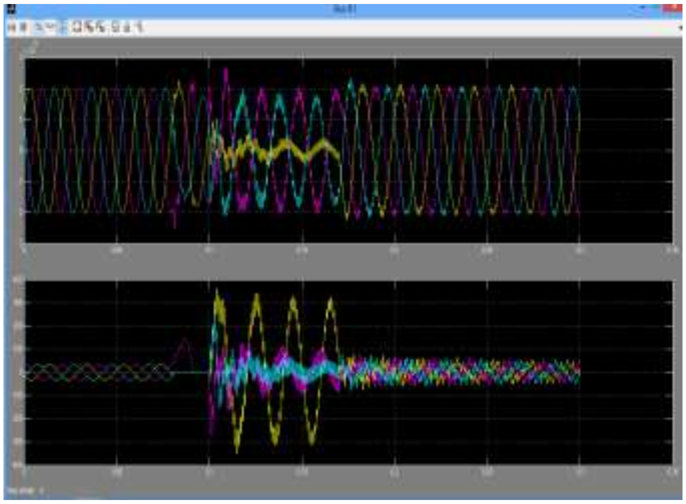

Fig. 2: Discrete wavelet transform output for AG fault

B. BG Fault:

In this fault during the time slot from 0.08 to 0.016 signal is distorted. Voltage amplitude Vabc changes from Va,Vc:2x10^5 to Vb: 1x10^5 , and current (Iabc) decreases from Ib:350A to Ia,Ic:120A.

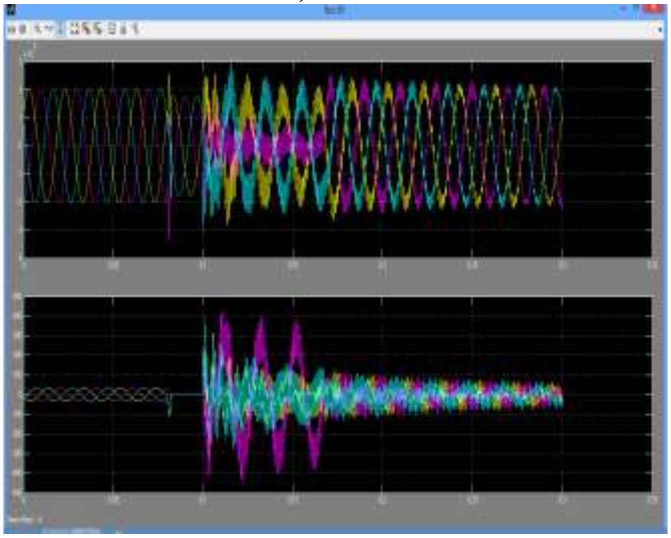

Fig. 3: Discrete wavelet transforms output for BG fault

C. CG Fault:

In this fault during the time slot from 0.08 to 0.016 signal is distorted. Voltage amplitude Vabc changes from Va,Vb:2x10^5 to Vc: 1x10^5, and current (Iabc) decreases from lc:400A to la,lb:200A.

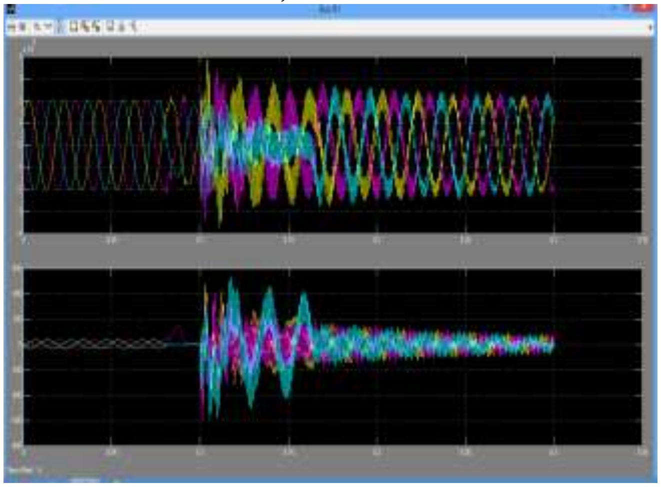

Fig. 4: Discrete wavelet transforms output for CG fault

D. AB Fault:
In this fault during the time slot from 0.08 to 0.016 signal is distorted. Voltage amplitude (Vabc) changes from Vc:2x10^5 to Va,Vb: 1x10^5, and current (Iabc) decreases from la,lb:200A to lc:50A.

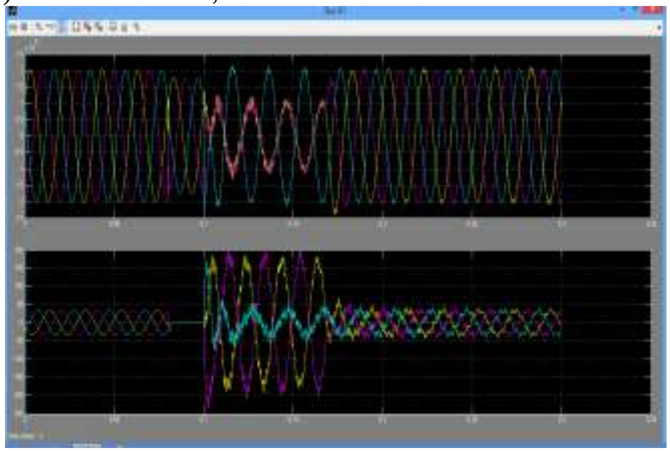

Fig. 5: Discrete wavelet transforms output for AB fault

E. BC Fault:
In this fault during the time slot from 0.08 to 0.016 signal is distorted. Voltage amplitude (Vabc) changes from Va:3x10^5 to Vc,Vb: 1x10^5, and current (Iabc) decreases from Ic,Ib:500A to Ia:400A.

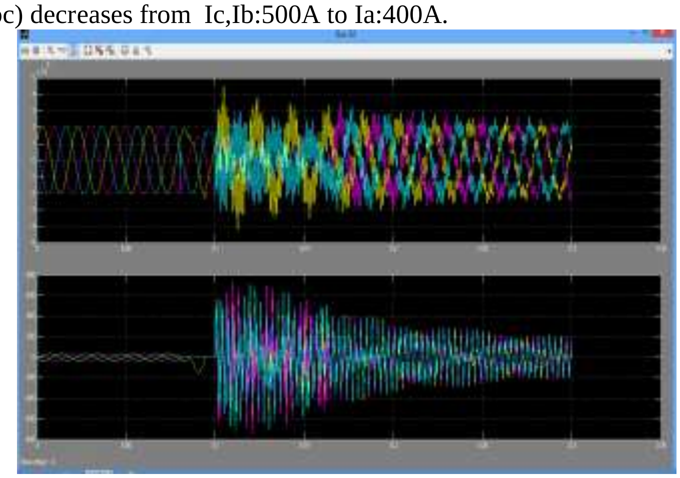

Fig. 6: Discrete wavelet transforms output for BC fault

F. AC Fault:
In this type of fault during the time slot from 0.08 to 0.016 signal is distorted. Voltage amplitude (Vabc) changes from Vb:2 x10^5 to Vc,Vb: 1x10^5, and current (Iabc) decreases from Ic,Ib:150A to Ia:40A.

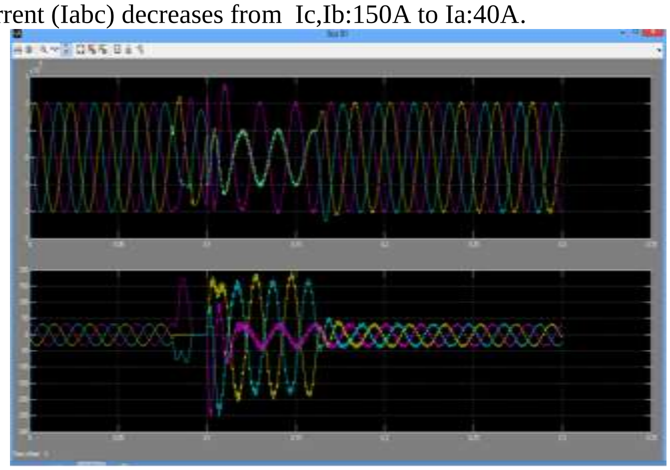

Fig. 7: Discrete wavelet transforms output for AC fault

G. ABG Fault:
In this type of fault during the time slot from 0.08 to 0.016 signal is distorted. Voltage amplitude (Vabc) changes from Vc:x10^5 to Vb,Va: 0.7 x10^5, and current (Iabc) decreases from Ib,Ia:400A to Ic:10A

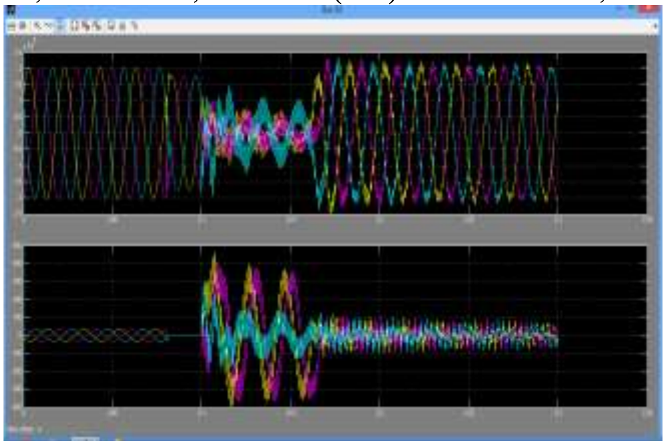

Fig. 8: Discrete wavelet transform output for ABG fault

H. BCG Fault:
In this type of fault during the time slot from 0.08 to 0.016 signal is distorted. Voltage amplitude (Vabc) changes from Va:0.7 x10^5 to Vb,Vc: 0.5 x10^5, and current (Iabc) decreases from Ib,Ic:300A to Ia:100A.

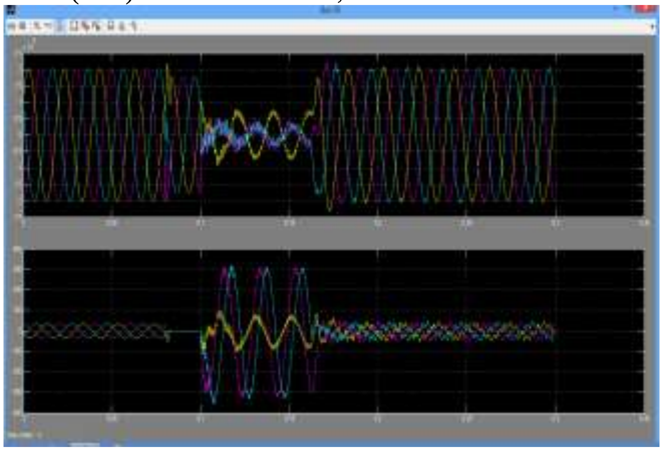

Fig. 9: Discrete wavelet transforms output for BCG fault

I. ACG Fault:
In this type of fault during the time slot from 0.08 to 0.016 signal is distorted. Voltage amplitude (Vabc) changes from Vb:1.5 x10^5 to Va,Vc: 0.8 x10^5, and current (Iabc) decreases from Ia,Ic:400A to Ia:200A.

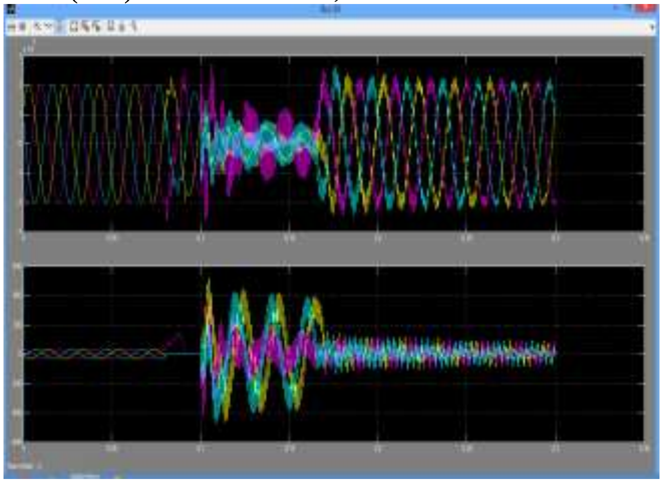

Fig. 10: Discrete wavelet transforms output for ACG fault

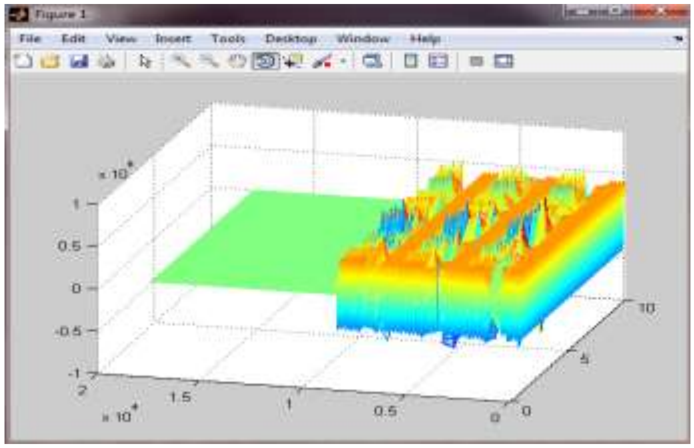

Fig. 11: Wavelet fault Features 3D View

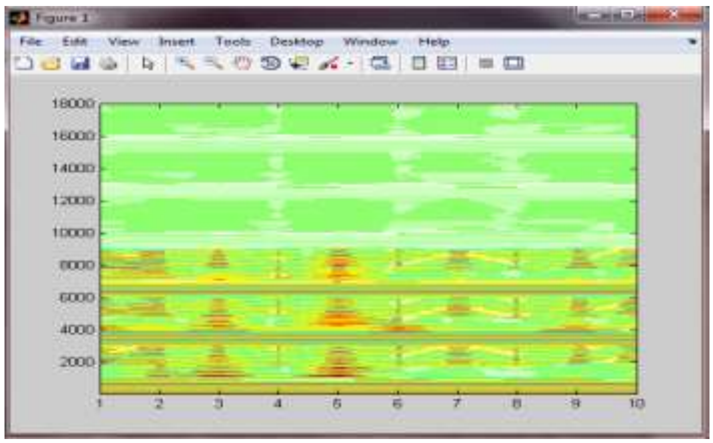

Fig. 12: Wavelet fault Features Contour plot

VI. CONCLUSIONS

Most high-impedance faults can be detected using harmonic current phase-angle analysis and localized by using reclose sectionalize technology. In simulink model detectors such as sectionalizes, various typical HIF patterns must be programmed to the module in the form of detection flags. Sectionalizes will constantly be looking for these typical patterns of a HIF as provided in this work. If the current patterns meet the detection criteria, adjusted sectionalizes will communicate with each other in trying to locate the fault. The work assumes phase since they account for the greater majority of HIFs. Due to the strong harmonic-angle dependence, transient conditions in distribution feeders can cause false readings. These are overseen by the detection discriminates against multi-phase and short-duration effects. For instance, capacitor switching would be of very short-duration (1-3cycles) and would happen in all three-phases. High impedance faults are normally single-phase and are sustained.

The DWT has been employed to decompose high frequency components from fault signals. Positive sequence current signals are used in fault detection. The maximum coefficients of the positive sequence current obtained from all buses are compared in order to detect the faulty bus on the transmission system. It is found that the fault detection algorithm can detect fault with the very high accuracy.

The application of the wavelet transform to estimate the fault location on transmission line has been investigated. The ability of wavelets to decompose the signal into frequency bands in both time and frequency allows accurate fault detection.

In this method of discrete wavelet based analysis of transmission line parameters for the fault detection took the advantages of the time and frequency localization of the DWT applied to the high-frequency components of transmission line parameter disturbances. A theoretical analysis, the complete design process, and the obtained results, in simulation, have been given in this thesis.

APPENDIX

The parameters of the power system model
Line length = 300km;
Source= 100kv;
Frequency = 50 Hz;
Transmission line R_1=0.01273, R_0=0.3864;
Load=100kv.

REFERENCES

[1] M. Kezunovic et.al "Automated transmission line fault analysis using synchronized sampling at two ends" IEEE Tranaction on Power system Vol. 11. No. 1,February 1996
[2] Gopalakrishnan, M. Kezunovic et.al "Fault Location Using the Distributed Parameter Transmission Line Model" IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 15, NO. 4, OCTOBER 2000
[3] Joe-Air Jiang, Ching-Shan Chen, Ping-Lin Fan , Chih-Wen Liu "A Composite Index to Adaptively Perform Fault Detection, Classification, and Direction Discrimination for Transmission Lines" 0-7803-7322-7/02/$17.00 © 2002 IEEE
[4] Wen-Chun Shih "Time Frequency Analysis and Wavelet Transform Tutorial Wavelet for Music Signal Analysis " Graduate Institute of Communication Engineering National Taiwan University, Taipei, Taiwan, ROC,2007
[5] Karthikeyan Kasinathan "Power system fault detection and classification by wavelet transforms and adaptive resonance theory neural networks" University of Kentucky Master's Theses,20010
[6] Atthapol Ngaopitakkul and Chaiyan Jettanasen "Combination of discrete wavelet transform and problemastic nueral network algorithm for detecting fault location on transmission system" International Journal of Innovative Computing, Information and Control Volume 7, Number 4, April 2011
[7] S.A.Shaaban, Prof.Takashi Hiyama "Transmission Line Faults Classification Using Wavelet Transform" Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010, Paper ID 225.
[8] Wanjing Xiu, Yuan Liao "Online One-End Fault Location Algorithm for Parallel Transmission Lines " Smart Grid and Renewable Energy, 2011, 2, 359-366 doi:10.4236/sgre.2011.24041
[9] Yu C.S.,2006, "A Discrete Fourier Transform-Based Adaptive Mimic Phasor Estimator for Distance Relaying Applications," IEEE Trans. On Power Delivery, Vol. 21, No. 4.
[10] Zanetta L. Jr., 2004, Fault location in transmission lines using one terminal post fault voltage data, IEEE Trans. Power Delivery, 19(2), 2004, pp. 570-575. [23]Ching-Shan Chen, Chih-Wen Liu,2000, "Application of Combined Adaptive Fourier Filtering Technique and Fault Detector to Fast Distance Protection" IEEE Transactions on power delivery, vol. 21, no. 2.
[11] K. Kunadumrongrath and A. Ngaopitakkul "Discrete Wavelet Transform and Support Vector Machines Algorithm for Classification of Fault Types on Transmission Line "Proceeding of International MultiConference of Engineering and computer scientist 2012 Vol II, IMECS 2012
[12] Eyada A Alanzi , Mahmoud A Younis "A New Faulted-Phase Identification Technique for Overhead Distribution System " Computer Engineering and Intelligent Systems ISSN 2222-1719 (Paper) ISSN 2222-2863 Vol 3, No.10, 2012
[13] Dr. A. K. Sharma et.al "Detection of Fault Location in Transmission Lines using Wavelet Transform " Int. Journal of Engineering Research and Applications Vol. 3, Issue 5, Sep-Oct 2013, pp.149-151
[14] Masayuki Abe, Nobuo Otsuzuki, Tokuo Emura, and Masayasu Takeuchi, "development of a new fault location system for multi terminal single transmission lines", IEEE
[15] Mattias Harryss "Fault Location Algorithms in Transmission Grids " Programme (60 credits) in Renewable Energy Systems ,2014
[16] Nitin U. Gawali and R.P. Hasabe "A Comparison of Different Mother Wavelet for Fault Detection & Classification of Series Compensated Transmission Line" IJIRST –International Journal for Innovative Research in Science & Technology| Volume 1 | Issue 9 | February 2015
[17] Ashish N. Kakde "Transmission Line Fault Location based on Distributed Parameter Line Model " International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (An ISO 3297: 2007 Certified Organization) Vol. 4, Issue 3, March 2015.

