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Transmission Line Fault Detection Based On Wavelet Transform

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***Abstract:* -- The paper describes a very accurate fault location technique which uses post-fault voltage and current derived at both line ends. Firstly, the simulation is carried out in MATLAB to obtain the fault voltages and currents at both ends of a transmission line. Then, with the help of Graphical User Interference method simulated data is used for estimating the location of unbalanced and balanced faults on line. It is observed that solution fully considers the impacts throughout the line and fault is identified with voltage and current waveform. Evaluation studies based on MATLAB/SIMULINK. Simulation studies have been undertaken to verify the accuracy of the algorithm. The paper presents the theory of the technique and the results of simulation studies to determine its performance.**

***Index Terms:* — distributed parameter line model, fault location, MATLAB, unsynchronized, Graphical User Interference**

I. INTRODUCTION

The need for very high accuracy in fault location is generally becoming more important because, in EHV systems, there is often little visual evidence of a fault, and post- fault clearance tests performed at reduced system voltage can be inconclusive. The degree of accuracy required is therefore increasing and is much higher than can be obtained using simple conventional impedance to fault measuring techniques. Even a small measurement error may require detailed local examination over several kilometers of a typical line.

Transmission and distribution lines are exposed to faults that are caused by different reasons such as short circuits, birds, and storms. Most of these faults result in mechanical damage of power lines also. Power line faults must be located accurately to allow maintenance crews to arrive at the scene and repair the faulted section as soon as possible. As we know Rugged terrain and geographical layout cause some sections of power transmission lines to be difficult to reach. Therefore, robustness of the accurate fault location determination under a variety of power system operating constraints and fault conditions is an important requirement. Generally, fast and accurate fault location will expedite supply restoration and enhance the supply quality and reliability [1]. When any kind of faults occur in a power system, the first action must be to clear the fault from the system. Once the protection action is taken, the most accurate distance of fault information should be provided to aid the user in locating the fault to remove the cause of the fault. Fault location can be estimated from current and voltages measured from one-end or two-end of the line [2]. Following the occurrence of a fault, the utility tries to restore power as quickly as possible. Rapid restoration of service reduces customer complaints, outage time, loss of revenue, and crew repair expense. All of these factors are increasingly important to the utilities facing challenges in today's market. To aid in rapid and efficient service restoration, algorithms have been developed to provide an estimate of the fault location. In this paper for the enhancement of the computational efficiency, instead of EMTP software, MATLAB software is used. Further, by using these voltages and currents phasor values, iterative method is used for calculating an accurate fault location. It is observed that Newton-Raphson based iterative method gives better results.

II. WAVELET THEORY

Wavelet theory is applicable to several subjects. All wavelet transforms may be considered forms of time-frequency-representation for continuous-time (analog) signals and so are related to harmonic analysis. Almost all practically useful discrete wavelet transforms use discrete-time filter banks. These filter banks are called the wavelet and scaling coefficients in wavelets nomenclature. These filter banks may contain either finite impulse response (FIR) or infinite impulse response (IIR) filters. The wavelets forming a continuous wavelet transform (CWT) are subject to the uncertainty principle of Fourier analysis respective sampling theory: Given a signal with some event in it, one cannot assign simultaneously an exact time and frequency response scale to that event. The product of the uncertainties of time and frequency response scale has a lower bound. Thus, in the scale gram of a continuous wavelet transform of this signal, such an event marks an entire region in the time-scale plane, instead of just one point. Also, discrete wavelet bases may be considered in the context of other forms of the uncertainty principle.

There are several types of WTs and depending on the application, one method is preferred over the others. For a continuous input signal, the time and scale parameters are usually continuous, and hence the obvious choice is continuous wavelet transform (CWT). On the other hand, the discrete WT can be defined for discrete-time signals, leading to discrete wavelet transform (DWT).

a. CWT (continuous shift and scale parameters)

The CWT is defined as:

$$CWT(f,a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} f(t)\psi\left(\frac{t-b}{a}\right)dt$$

where 'a' is the scale constant (dilation) and 'b' is the translation constant (time shift). The ψ(t) is the wavelet function that is short, oscillatory with zero average and decays quickly at both ends. This property of ψ(t) ensures that the integral in above equation is finite and that is why the name wavelet or small wave is assigned to the transform. The term ψ(t) is referred to as the mother wavelet. and its dilates (a) and translates (b) simply are referred to as wavelets. Wavelets have a window that is automatically adapted to give an appropriate resolution. The window is shifted along the signal and for every position the spectrum is calculated. This process is repeated many times with a slightly shorter (or longer) window for every new cycle. At the end of this process, the result will be a collection of time-frequency representations of the signal, all with different resolutions. Because of this collection of representations we can speak of a multi-resolution analysis (MRA).

b. DWT (discrete shift and scale parameters)

The DWT is defined as:

$$DWT(f,m,n)=\frac{1}{\sqrt{a_0^m}}\sum(k)\psi^*\left(\frac{n-ka_0^m}{a_0^m}\right)$$

Where the parameters 'a' and 'b' are replaced by a_0^m and (ka_0^m).The parameters 'k' and 'm' are integer variables.

The actual implementation of the DWT involves successive pairs of high-pass and low-pass filters at each scaling stage of the wavelet. The successive stages of decomposition are known as levels or details denoted by detail_1 or 'd1' for short, detail_2 or 'd2' for short, etc. The multi-resolution analysis (MRA) details at various levels contain the features that can be used for detection and classification of faults.

The choice of mother wavelet, ψ (t) plays a significant role in detecting and localizing different types of fault transients. Each mother function has its own features depending on the application requirements.

c. Fourier transform

The plot of amplitudes at different frequency components for a periodic wave is known as discrete (line) frequency spectrum because amplitude values have significance only at discrete values of $n\,\omega_0$ where $\omega_0 = 2\pi/T$ is the separation between two adjacent (consecutive) harmonic components. If the repetition period T increases, ω_0 decreases. Hence, when the repetition period T becomes infinity, that is $T\rightarrow\infty$, the wave f(t) will become non periodic, the separation between two adjacent harmonic components will be zero that is $\omega_0 = 0$. Therefore, the discrete spectrum will become a continuous spectrum. When $T\rightarrow\infty$, the adjacent pulses virtually never occurred and the pulse train reduces to a single isolated pulse. The exponential form of Fourier series is given in equation below can be extended to periodic waveforms such as single pulses or single transients by making a few changes.

Assuming f (t) initially periodic, from equation below, we have

$$f(t)=\sum_{-\infty}^{\infty} c_n e^{jn\omega_0 t}$$

where,

$$c_n=\frac{1}{T}\int_{-T/2}^{T/2} f(t)e^{-jn\omega_0 t}dt$$

In the limit, for a single pulse, we have

$$T\rightarrow\infty,\ \omega_0=\frac{2\pi}{T}\rightarrow d\omega \text{ (a small quantity)}$$

$$\text{Or}\qquad 1/T=\omega_0/2\pi\rightarrow d\omega/2\pi$$

Furthermore, the n^{th} harmonic in the Fourier series in $n\,\omega_0 \rightarrow n\,d\omega$. Here 'n' must tend to infinity as 'ω_0' approaches zero, so that the product is finite, i.e. $n\,\omega_0 \rightarrow \omega$.

In the limit, the $\sum$ sign leads to an integral and we have,

$$c_n = \frac{d\omega}{2\pi}\int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt$$

And,

$$f(t) = \int_{-\infty}^{\infty}\frac{d\omega}{2\pi}\left[\int_{-\infty}^{\infty} f(t)\mathbf{e^{-j\omega t}}dt\right]e^{j\omega t}$$

When evaluated, the quality in bracket is a function of frequency only and is denoted as F(jω) where

F (j ω)=$\int_{-\infty}^{\infty}\mathbf{f(t)e^{-j\omega t}dt}$

It is called the Fourier transform of f (t).
Substituting for f(t) above, we obtain

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} f(j\omega)\mathbf{e^{j\omega t}}d\omega$$

Or equivalently,

$$f(t) = \int_{-\infty}^{\infty} f(j\omega)\mathbf{e^{j\omega t}}df$$

This is called the inverse Fourier transform. Now the time function f(t) represents the expression for a single pulse or transient only.

a. Discrete Fourier transform:

The Discrete Fourier transform (DFT) computes the values of the Z-transform for evenly spaced points around the unit circle for a given sequence.If the sequence to be represented is of finite duration, i.e. have only a finite number of non-zero values, the transform used is discrete fourier transform (DFT). DFT finds its applications in digital signal processing including linear filtering, correlation analysis and spectrum analysis.
Let x (n) be a finite duration sequence. The N-point DFT of the sequence x (n) is expressed by

$$X(k) = \sum_{n=0}^{N-1} x(n)e^{-j2\pi nk/N},\quad k = 0,1,2,\ldots N-1$$

And the corresponding IDFT is

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k)e^{j2\pi nk/N},$$
$$n=0,1,2,\ldots\ldots,N-1.$$

b. *fast fourier transform* :

The Fast Fourier transform (FFT) is an algorithm that effectively computes the Discrete Fourier transform (DFT). The DFT of a sequence {x(n)} of length N is given by a complex valued sequence {X(k)}

$$X(k) = \sum_{n=0}^{N-1} x(n)e^{-j2\pi nk/N},\quad 0 \le k \le N-1$$

Let W_N be the complex- valued phase factor, which is an N^{th} root of unity expressed by,

$$W_N = e^{-j2\pi/N}$$

Hence X(k) becomes,

$$X(k) = \sum_{n=0}^{N-1} x(n)W_N^{nk},\quad 0 \le k \le N-1$$

Similarly, IDFT becomes,

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k)W_N^{-nk},\quad 0 \le n \le N-1$$

From the above equation, it is evident that for each value of k, the direct computation of X(k) involves N complex multiplications (4N real multiplications) and N-1 complex additions (4N-2 real additions). Hence, to compute all N values of DFT, N^2 complex multiplications and N (N-1) complex additions are required. The DFT and IDFT involve the same type of computations.

c. Evaluation studies :

Simulation using the MATLAB/SIMULINK has been carried out to evaluate the voltage and current measurements at both ends of a transmission line during the fault.

- A 500KV, 320km transmission-line system is used for the simulation. The fault distance is assumed to be at a distance 150km from terminal P.

The per-unit system is utilized with a voltage base of 500kV and an apparent power base of 100 MVA. The voltage and current phasor values from both source side P and Q obtained from SIMULINK model for line-to-ground fault are taken . The estimation accuracy is measured by the percentage error calculated as

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$$\%Error = \frac{|Actual\ location - Estimated\ location|}{Total\ line\ length} X\ 100$$

This simulated data of voltage and current phasors is fed to a MATLAB based programming in order to locate the transmission line fault location. The voltage and current waveforms at terminal P obtained from SIMULINK model during L-G fault are shown in Fig. 5. Similarly, the voltage and current waveforms at terminal Q are shown in Fig. 6.

III.SIMULATION STUDIES:

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.

A power system fault can either be shunted, series or combination of both type, shunt fault providing a current flow between two or more phases, or to earth. Shunt faults occurs through a breakdown of insulation betweend the phases, or earth. Shunt faults often occur in two different ways; abrupt changes of the lines voltage and current characteristic, due to lighting strike, birds, threes or simular; or slowly deterioration of the lines insulation.

Slow deterioration of insulation will gradually create poor components and worn material that will age over time. Sometimes the difference between slow changes and abrupt faults is not strictly clear. It's possible to talk about faults that occur suddenly, but have evolved over longer period of time. Failure like this is typical faults that are caused by phases to phase merging, due to snow, icy lines or strong wind. When a fault occurs, the fault current will increase in magnitude, the total amplitude of fault current during a fault depends upon a variety of factors, such as fault type, network, fault resistance; failure causes load currents, short circuit levels etc.

In high voltage transmission line is one of the important components in electric power system. In transmission lines connect the stations (generating station) and load centers. When the generating stations are far away from the load centers and they run over few hundreds of kilometers. It is an accurate faults location on their overhead/high voltage transmission line it is the most important requirement for a permanent fault. Transmission line protection is very important issue in electrical power system because 84-87% of electrical power system faults are occurring in overhead transmission lines.

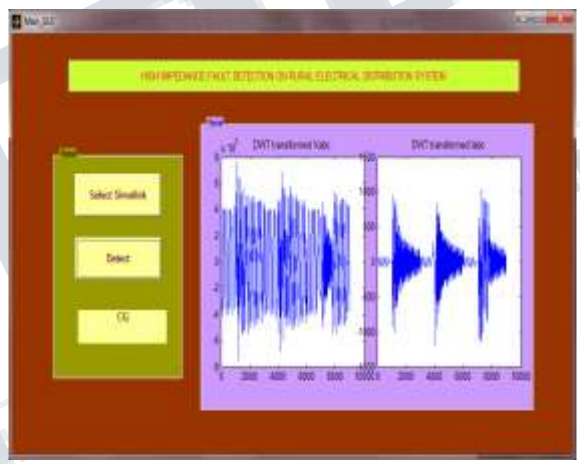

Fig.1. Graphical User Interface

IV. RESULTS & DISCUSSION OF FAULT CASE

Steps to be followed are as follows;

A. Run the circuit diagram using MATLAB software.
B. Scope will give voltage and current values with respect to time.
C. From waveforms and energy level values (with different decomposition level values) we shall be identify the type of fault on a particular bus.

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.

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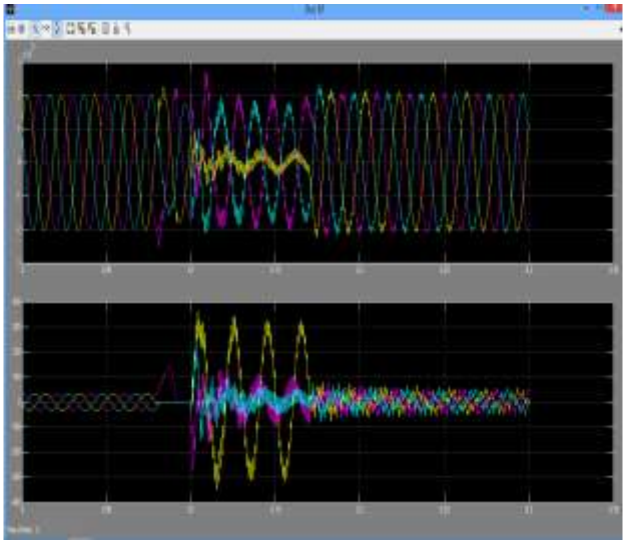

Fig.2. Discrete wavelet transform output for AG fault

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.

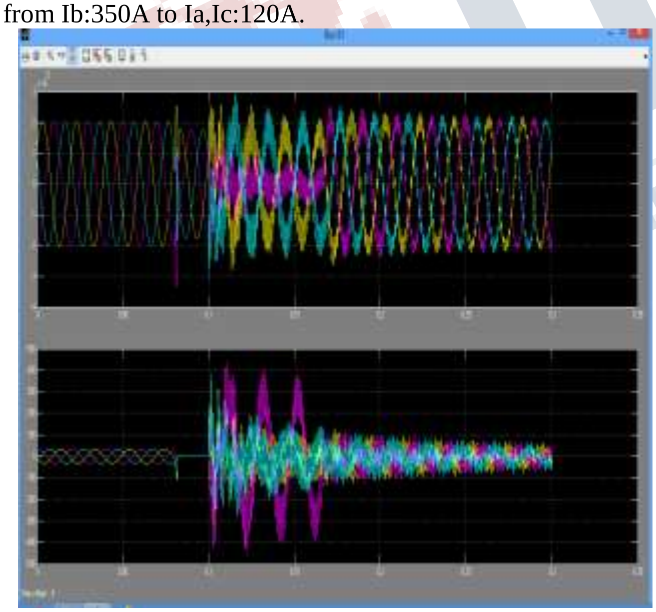

Fig.3. Discrete wavelet transforms output for BG fault

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.

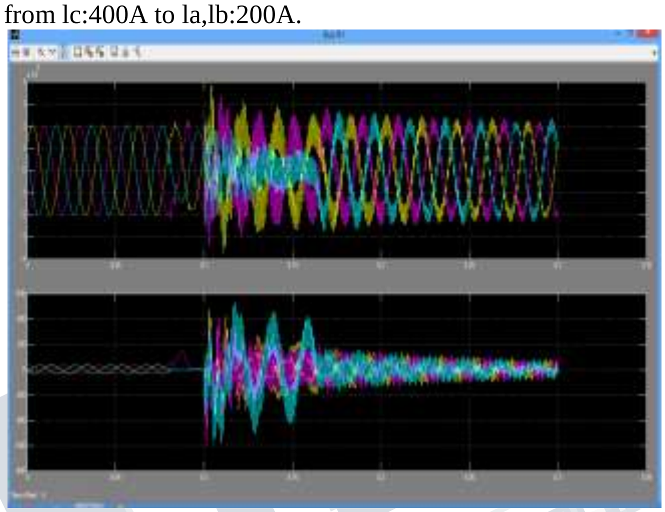

Fig.4. Discrete wavelet transforms output for CG fault

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.

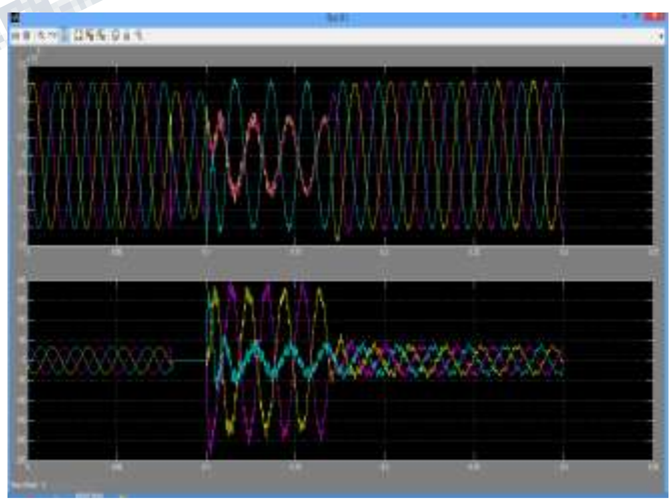

Fig.5. Discrete wavelet transforms output for AB fault

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.

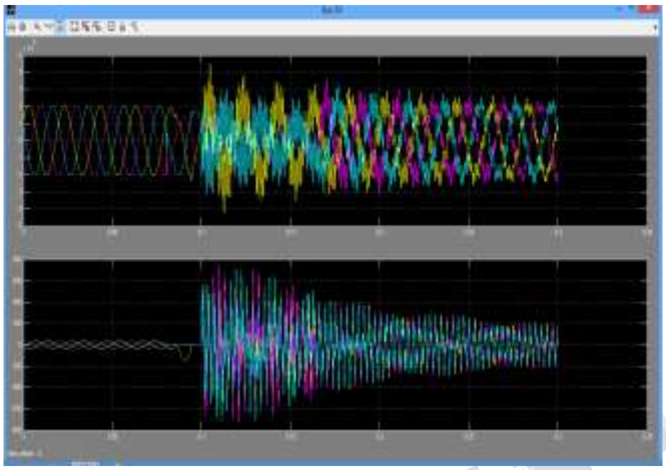

Fig.6. Discrete wavelet transforms output for BC fault

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.

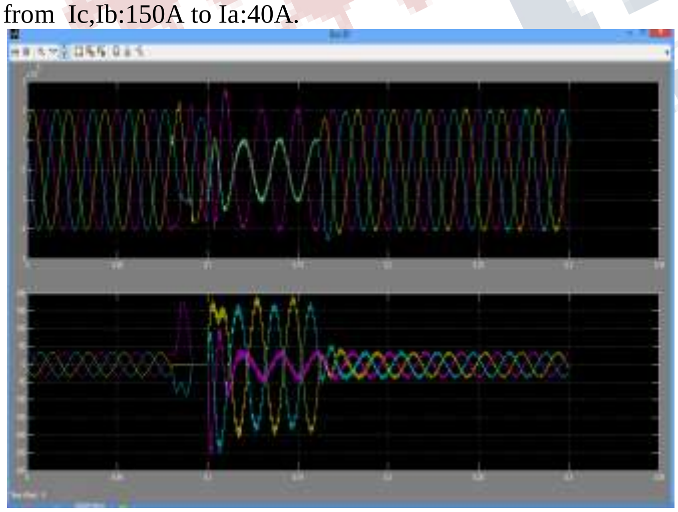

Fig.7. Discrete wavelet transforms output for AC fault

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:1 x10^5 to Vb,Va: 0.7 x10^5, and current (Iabc) decreases from Ib,Ia:400A to Ic:10A

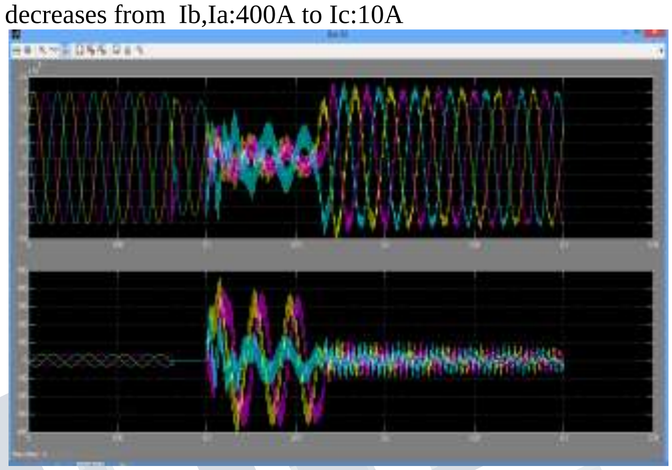

Fig.8. Discrete wavelet transforms output for ABG fault

BCG fault:

In this type of fault during the time slot from 0.08 to 0.016 signals 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.

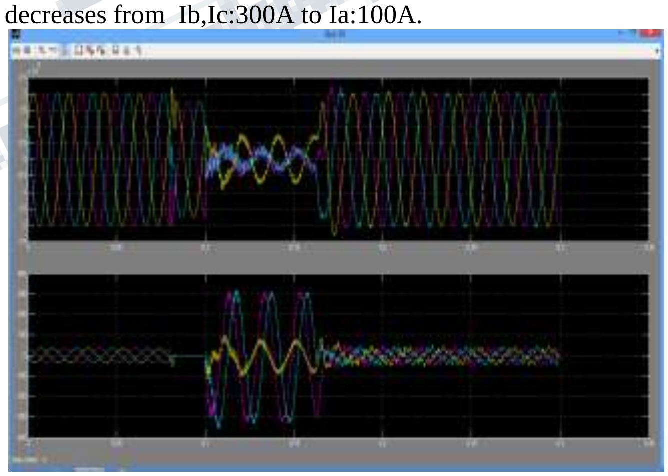

Fig.9. Discrete wavelet transforms output for BCG fault

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.

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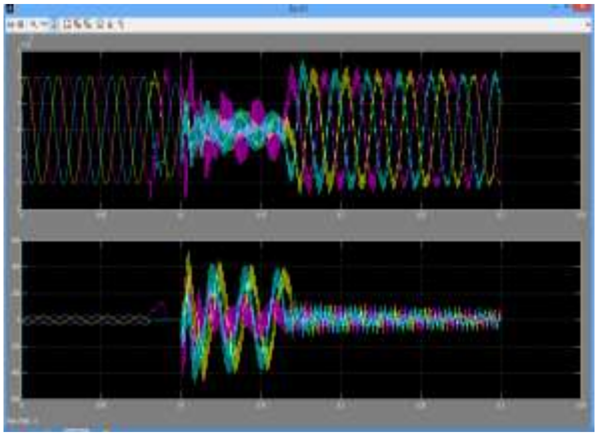

Fig.10. Discrete wavelet transforms output for ACG fault

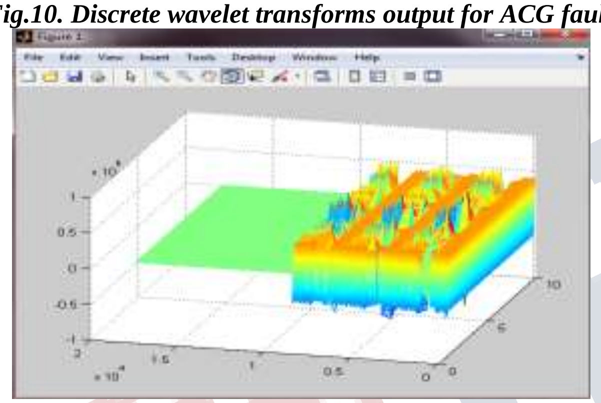

Fig.11. Wavelet fault Features 3D View

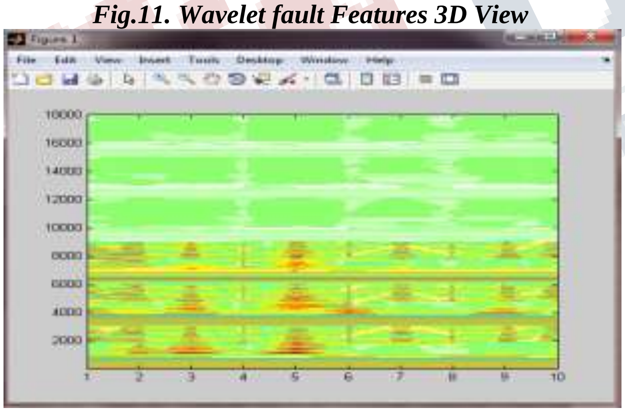

Fig.12. Wavelet fault Features Contour plot

V. CONCLUSION

Most high-impedance faults can be detected using harmonic current phase-angle analysis and localized by using reclose sectionalizes 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.

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