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A Novel Technique for Protection of Parallel Transmission Line Using Wavelet Transform

S.Sendilkumar[1] V. Arulalan[2] S. Selvi[3] B.Akila[4] G.Thiagu[5] S.Santhosh[6]

Professor [1234] Associate Prof[5] Asst. Prof [6]

Department of EEE, Panimalar Engineering College,
Anna University, Chennai-600123
Email: sendilkumar2009@gmail.com[1]

Abstract

A new approach for the protection of parallel transmission line is presented in this paper using wavelet algorithm, which provides excellent time localization of the voltage and current signals during fault conditions. The three line voltages and six line currents for with and without fault of both lines processed to the wavelet transform for discrimination and fault detection. The magnitude of the measured differential current processed to the differential relay for the reliable tripping. Internal faults and normal load current of the positive and zero sequence components are calculated using impedance of the transmission line using wavelet coefficients. The proposed method of transmission line protection includes all types of shunt faults on one line and also simultaneous fault on both lines. The simulation results obtained shows that the algorithm is more reliable and accurate.

Keywords: Internal faults; Wavelet transform; Parallel transmission line; Differential current

I. Introduction

Power transmission lines are the vital links that achieves the essential continuity of service to electrical power of the end users. Distance protection relaying algorithm are commonly used to protect the transmission lines under different fault condition Distance relaying technique based on the measurement of the impedance at the fundamental frequency between the fault location and the relaying point have attracted widespread attention. Impedance is calculated from the phasors values of the voltage and current signals retrieved at the relaying point. The value of calculated impedance depicts whether the fault is internal or external to the protection zone. This relaying technique can works satisfactorily for protection of single circuit lines. However, when applied to parallel transmission line, the performance is affected by mutual coupling between two lines. The mutual inductance between pair of conductors in the two lines is not the same and, therefore, emfs are produced in the conductors of the other line. As a result, the apparent input impedance of a line on which a fault present is affected by load currents or current being fed to the fault by parallel healthy line and the operation of the distance relay can be affected. Different approaches have been attempted for protection of parallel lines by comparison of line currents of corresponding phases and positive and zero sequence current for fault detection. Adaptive distance protection schemes was proposed[1] in which correction factor, based on the information of the surrounding system of the protected line under difference operating condition was used in the impedance calculation. Also traveling wave based parallel line protection has been presented [2]. In [3] a technique based on comparing of currents in the corresponding phases of the lines to detect faults and discriminate faults an healthy phases is proposed. In [4, 5] a comparison between the measured impedance of corresponding was suggested. The objective of this paper is to present the application of wavelet transform for the protection of parallel transmission line.

II. Introduction to Wavelet Transform

Wavelet transform is a powerful signal processing tool used in power system analysis. The wavelet transform is like the Short Time Fourier Transform (STFT), allows time localization of different frequency components of a given signal, the important difference in STFT uses a fixed width windowing function. As result, both frequency and time resolution of the resulting transform will be a prior fixed but in the case of wavelet transform, the analyzing functions, which are called wavelet, will adjust their time widths to their frequency in such a way that, higher frequency wavelets will be very narrow and lower frequency wavelets will be wide. It has been found using wavelet for the proposed power system model it shows for internal fault currents window is narrow; for normal load current window is very wide. Multi resolution analysis refers to the procedure to obtain low pass approximation and high pass details from the original signal. An approximation contains the general trend of the signal while detail embodies the high frequency contents of the original signal. Approximations and details are obtained through a succession of convolution processes. The original signal is divided into different scales of resolution, rather than different frequencies. Details and approximations of the original signal X (n) is obtained by passing it through a filter bank, which consists of low pass filter removes the high frequency components, while the high pass filter picks out the high frequency contents in the signal being analyzed. With references to Figure.1 the multi resolution procedure [6,7] is defined as follows

The wavelet basis functions can be computed from a function $\psi_{i,j}(x)$ called the generating or mother wavelet through translation and scaling (dilation) parameters
Where j is the translation parameter and i is the scaling parameters. Mother wavelet

function is not unique, but it must satisfy a small set of conditions. One of them is multiresolution condition and related to the two- scale difference equation

$$\psi_{i,j}(x) = 2^{-i/2}\psi(2^{-i}x - j) \quad (1)$$

$$\phi(x) = \sqrt{2}\sum_{k} h(k)\phi(2x - k) \quad (2)$$

Where Φ(x) is scaling and h(k) must satisfy several conditions to make basis wavelet functions unique, orthonormal and have a certain degree of regularity. The mother wavelet is related to the scaling function as follows:

$$\psi(x) = \sqrt{2}\sum_{k} g(k)\phi(2x - k) \quad (3)$$

Where g (k) = $(-1)^k$ h (1-k) at this point, if valid h(x) is available, one can obtain g(x). Note that h and g can be viewed as filter coefficients of half band low-pass and high-pass filters, respectively. In this paper, different fault events are decomposed to two levels; A2 is the approximation level containing the fundamental frequency component and D1 and D2 are the detail level with high frequency is considered[8,9].

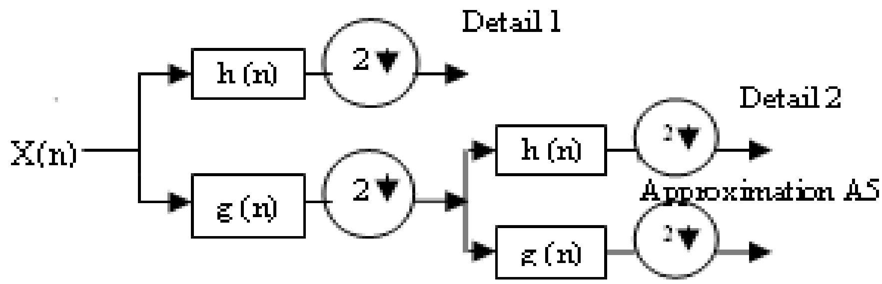


Figure1. Decomposed levels of discrete wavelet transform

III. Relaying Algorithm

Figure.2 gives the flow chart of the proposed system it clearly indicates the flow of the control and gives the sequence of events. The algorithm highlights the repetitive nature of the algorithm and the continuous check for performing fault detection [5].

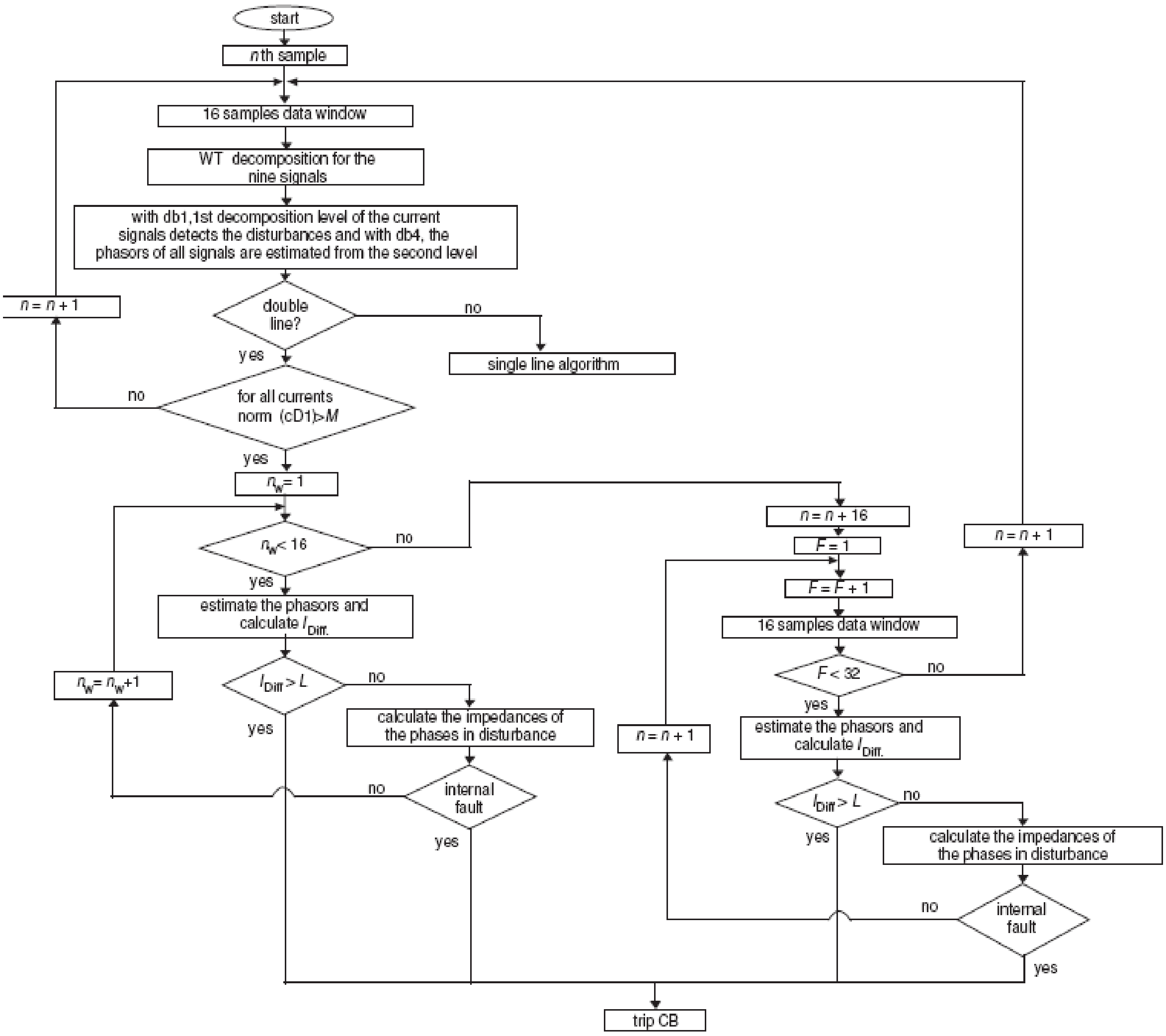


Figure.2. Flow chart of the proposed system

IV. System Studied

The system taken for study is shown in the Figure.3 simulated using SIMULINK [6]. This model consists of two generators connected at both ends of the transmission lines consists two sections of AB and BC. The sections AB consists two 225km long parallel lines and BC consists a 100km long transmission line. Ra and Rb are the relaying points to obtain the data for different fault condition.

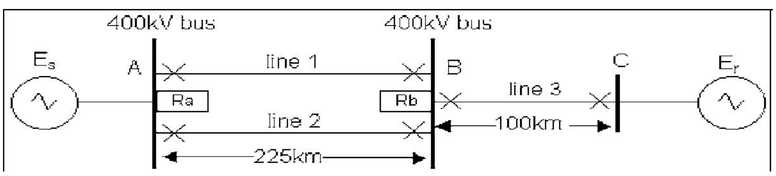


Figure.2 Simulation model

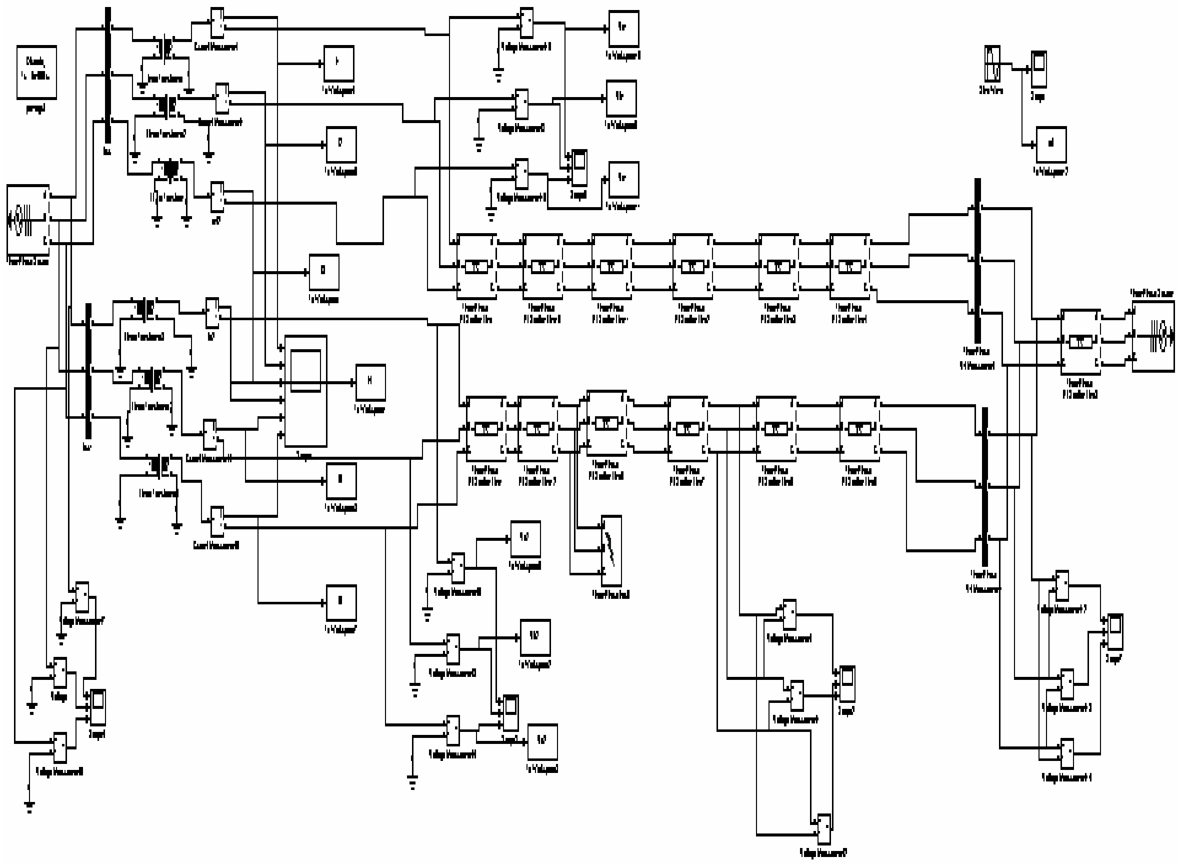
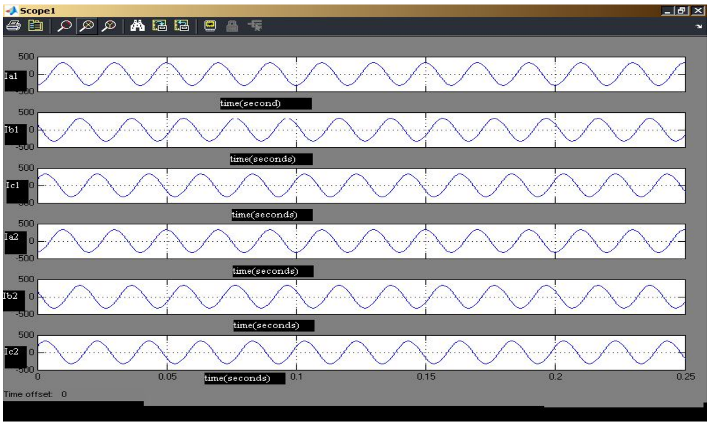


Figure.3 Simulink model of the Parallel Transmission line

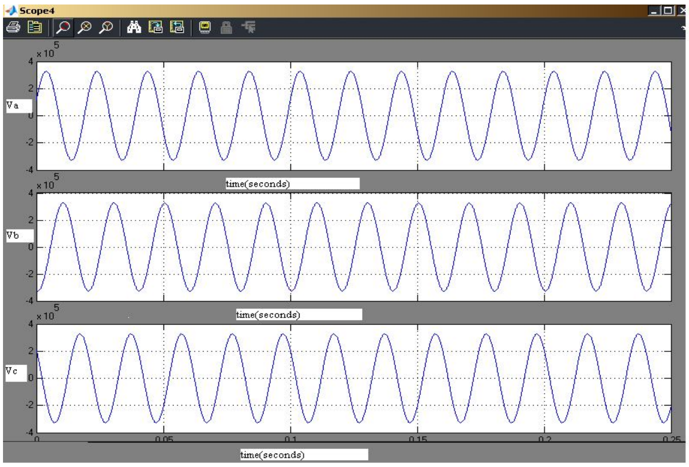
The parameters of the above model sending end Generator G1 voltage is 400kV, and impedance is 17.177+j45.529Ω; The load side Generator G2 voltage is 400kV; Transmission line: Positive sequence impedance is Z_1 = 4.983+j117.830Ω; Zero sequence impedance, Z_0=12.682+j364.196Ω, Positive sequence admittance Y_1 =j1.468*10^-3 $\Omega^{-1.}$ Zero sequence admittance, Y0 =j1.099*10^-3 Ω^{-1}.

In this paper following cases are studied
a) Normal condition, b) Single line faults, c) Line-Line fault, d) Three phase fault

Case. 1 Normal condition
Figure.4 shows the amplitudes of current and voltage waveform of phase A line 1. The given waveform is measured at sending end using Figure. 2 with out any disturbances.



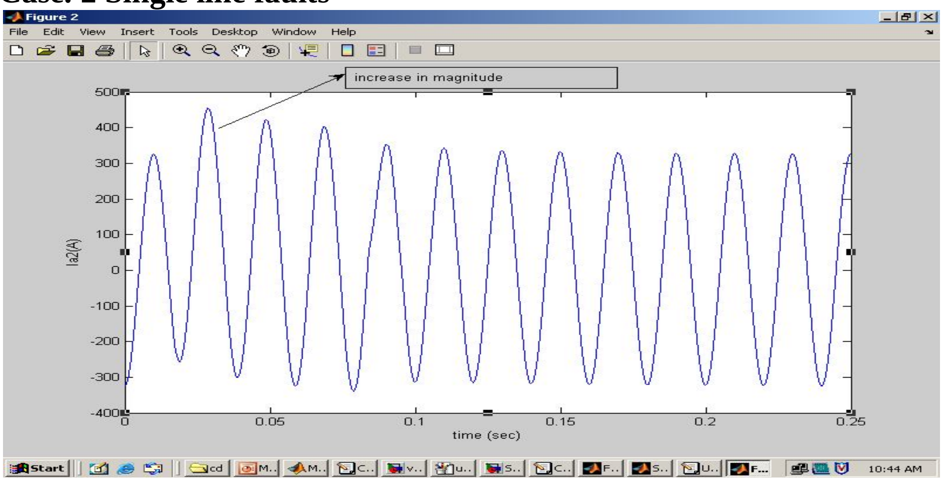
a. Current waveform



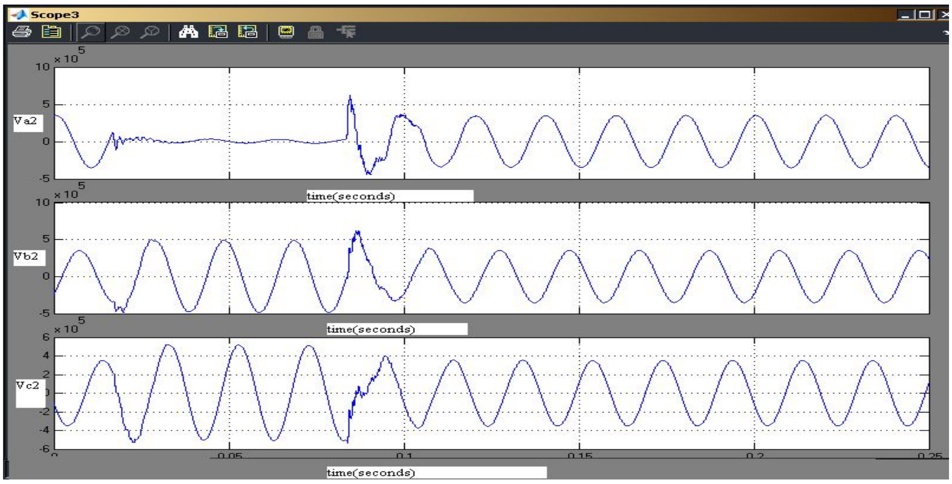
b. Voltage waveforms

Figure .4 Amplitudes of normal waveform in sending end bus A

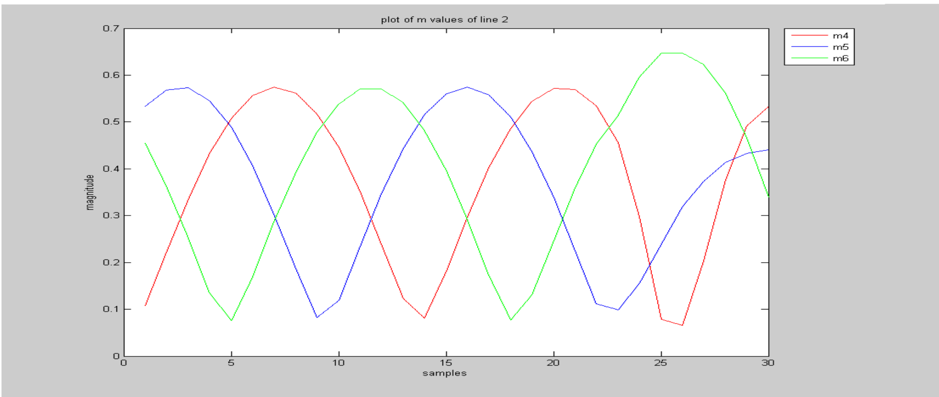
Case. 2 Single line faults



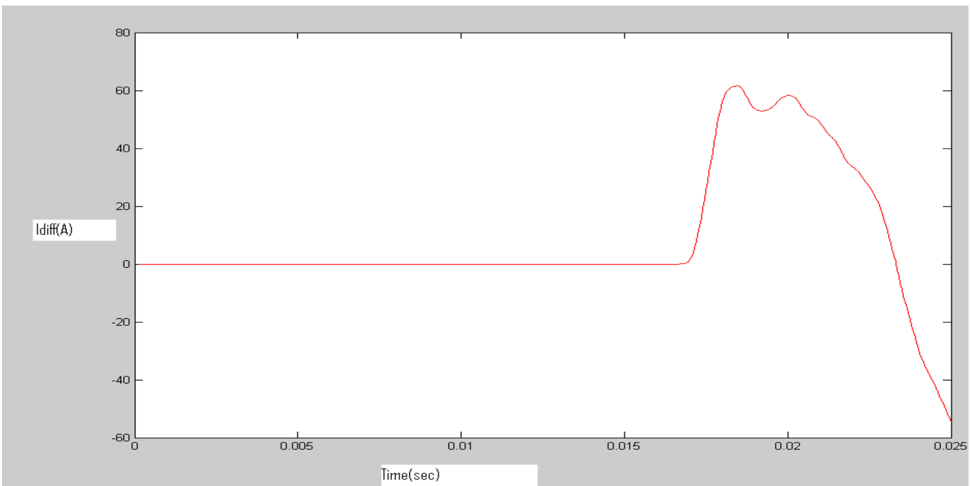
a. Current waveform



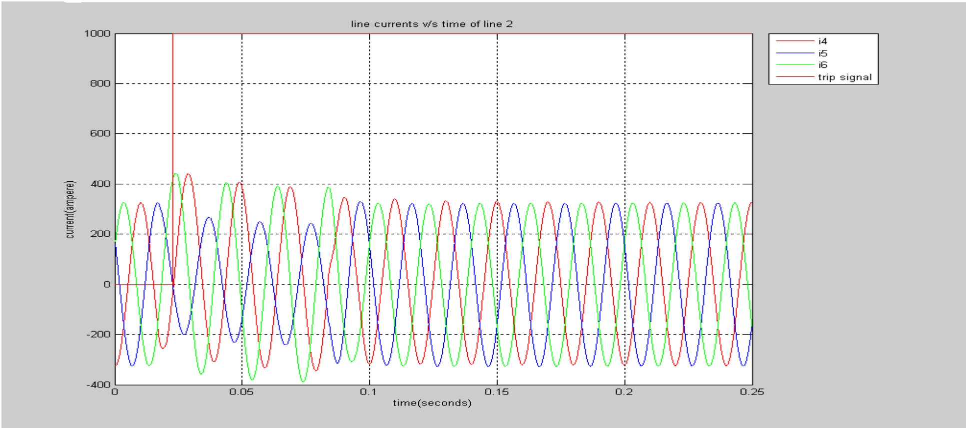
b. Voltage waveform



d. Norm of D1 coefficients



e. Ia differential current

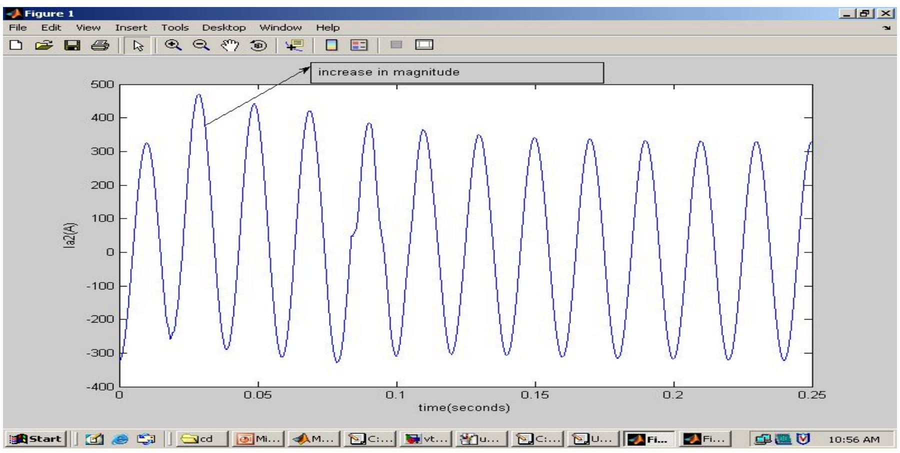


f. Current waveform with trip signal

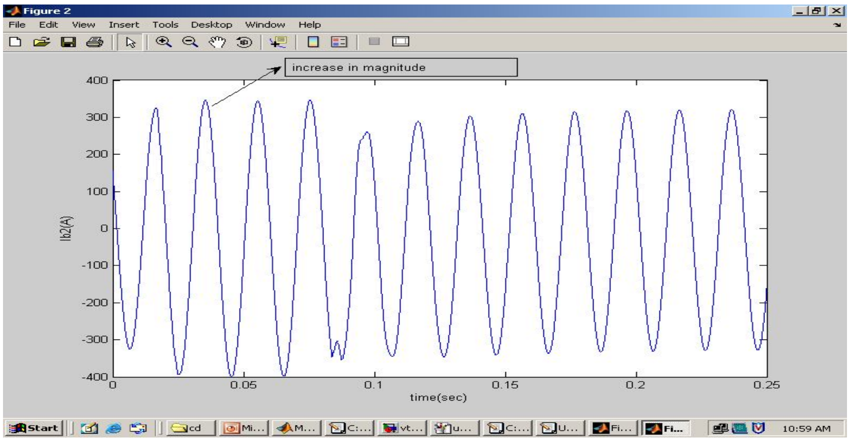
Figure.5 Single line to ground fault in phase A of line 2 from bus A

A single line to ground fault is applied on the phase A line 2 at 100 km relay bus A . The local angle is kept δ = -15 Fig.5d shows norm of D1 coefficients of disturbance detection using wavelet transform. When the D1 coefficients value increases the level M of phase A line 2 the relay A issues the trip signal as shown in the Fig.5f. It is clearly shows that only norm of the wavelet coefficients of phase A line 2 exceeds the detection level M. Fig.5e shows Ia differential current of phase A line 2 of source and load current. This difference is calculated using the magnitude of the phasors estimated from the first level approximations of the wavelet coefficients. Since Ia diff is positive value the fault is known to be on phase A of line. The trip signal which is issued after four samples of Ia diff increases the current threshold L for reliability and security.

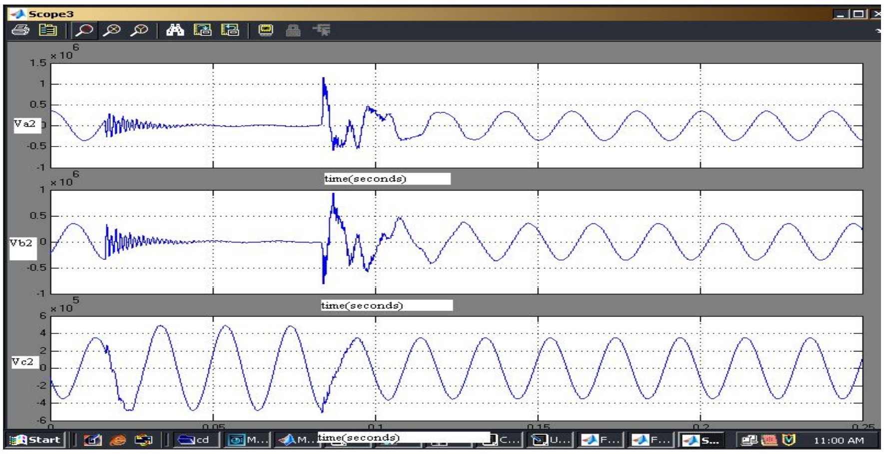
Case 3 Line to Line fault



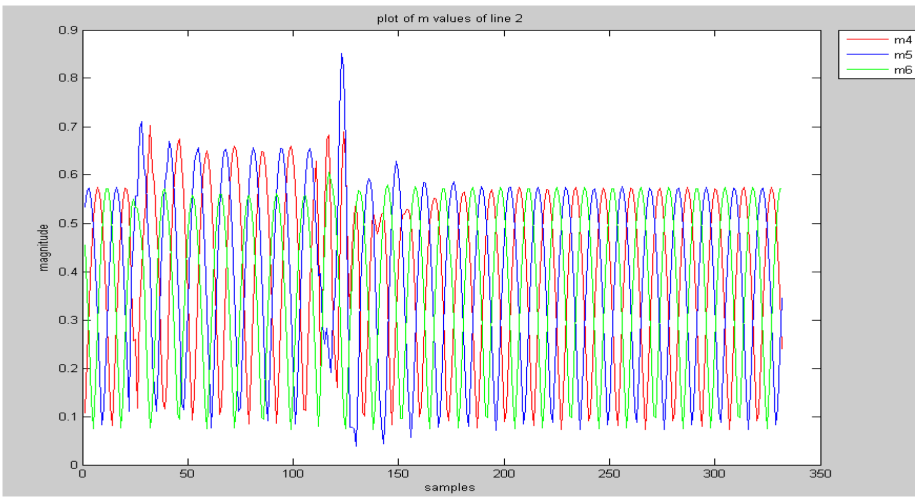
a. Current waveform of phase A



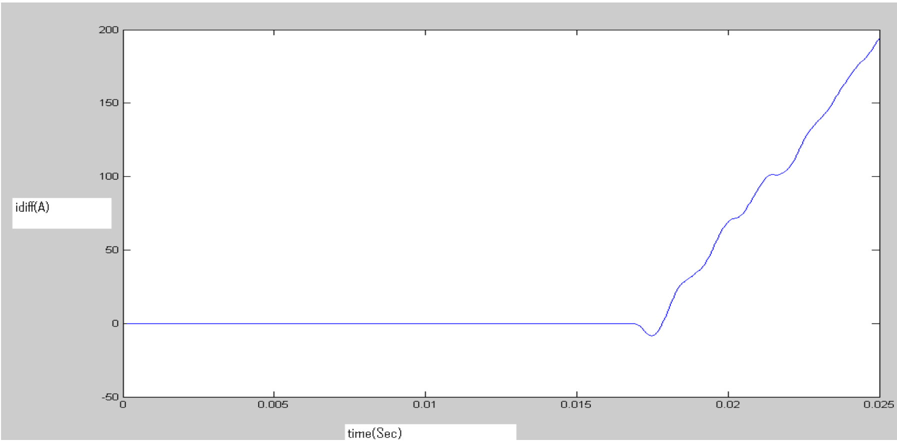
b. Current waveform of phase B



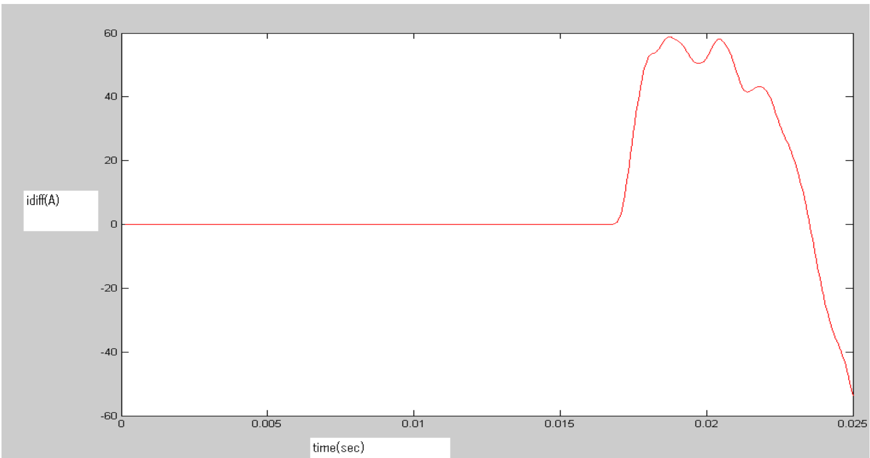
c. Voltage waveforms of phase A and B



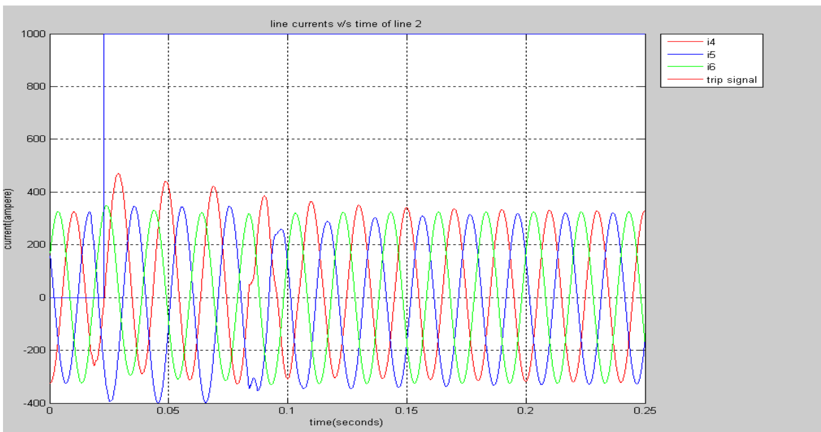
d. Norm of D1 coefficients



e. Ia differential current



f. Ib differential current

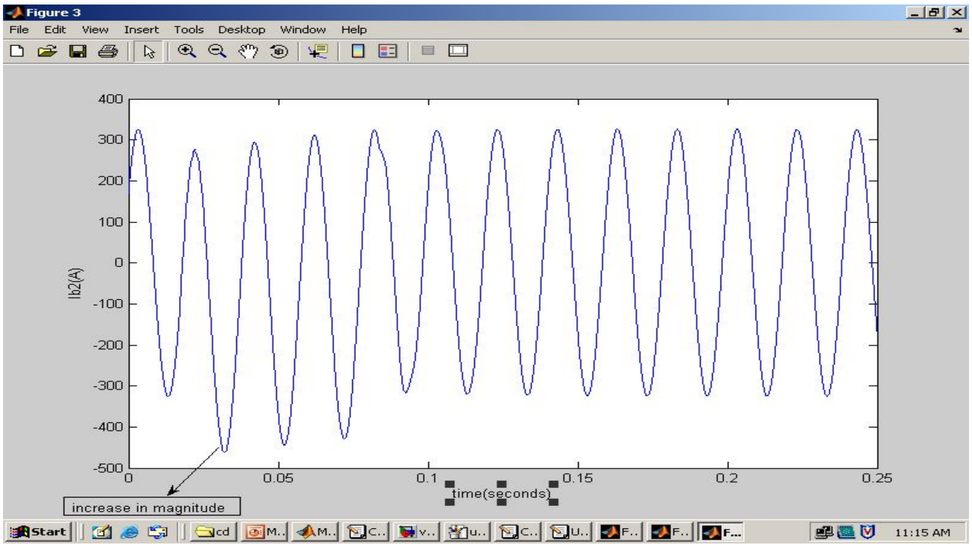


g. Current waveform with trip signal

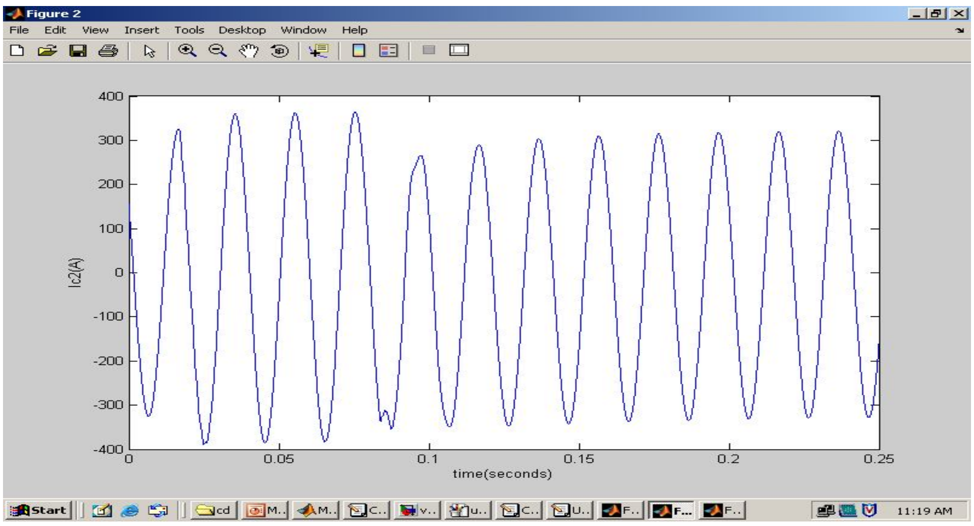
Figure 6 Double line to ground fault of phase A and B in line 2 bus A

Figure 6 shows the double line to ground fault of line 2. The relay has been tested using line to line fault on one of the two parallel line. The current difference magnitudes of ia diff and ib diff is shown in the Fig 6e and 6f.. Double line to ground fault of A and B is generated on line 2 at 120 km of relay A. These faults in line 2 causes trip single in the both phases A and B of line 2 is given in the Fig.6g

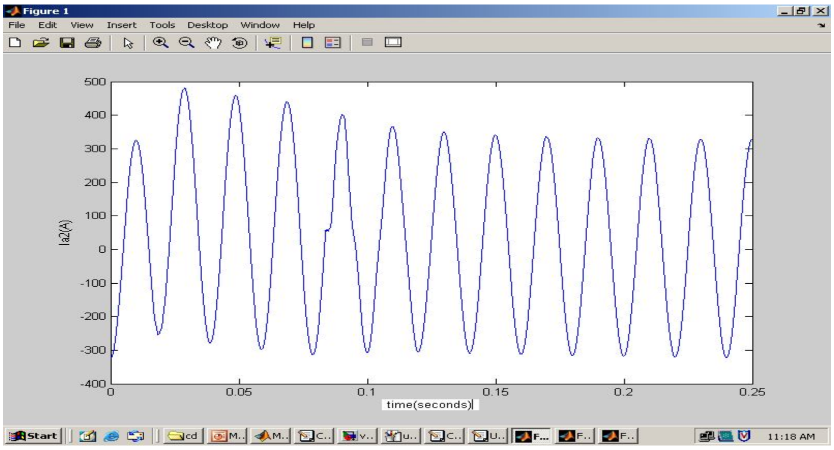
Case.4 Three phase to ground fault



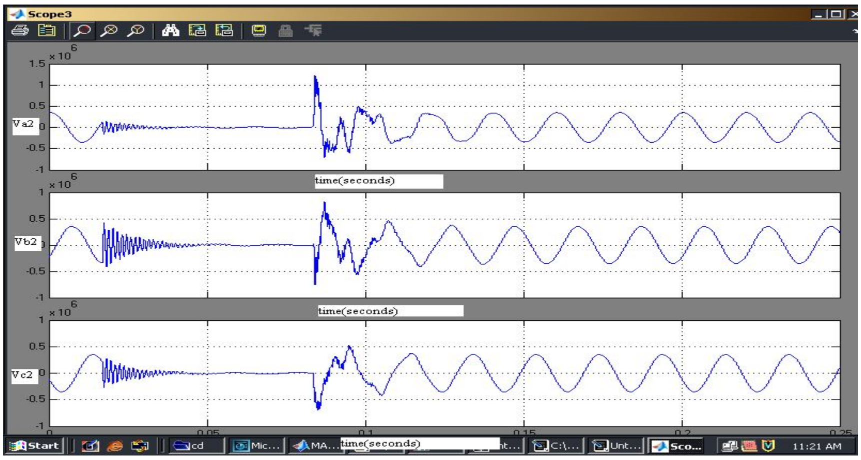
a. Current waveform of phase A



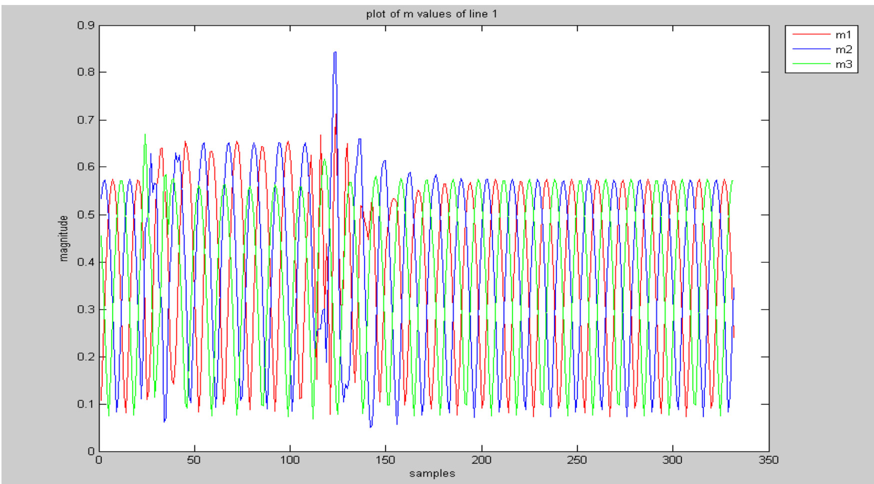
b. Current waveform of phase B



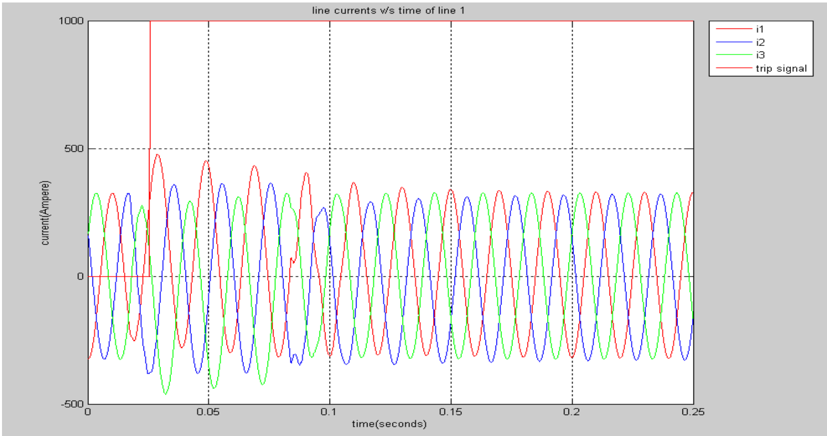
c. Current waveform of phase C



d. Voltage waveforms



e. Norm of D1 coefficients



f. Current waveform with trip signal

Figure. 7. Three phase to ground fault of line 2 phase A,B and C in bus A

The fault current magnitudes of phase A,B and C is shown in the Fig.7a and trip signal for the fault current is shown in the Fig.7f.. These fault are applied at 100 km from the relay of bus A.

V. Results and Discussion

In this paper three voltages and six current signals (at each end) are filtered using pre-band pass filters with a centre frequency of 60Hz to attenuate the DC component. These nine signals are sampled at a sampling frequency of 960 Hz. The proposed protection algorithm is divided into three operating conditions. The first one is the pre-fault operation until a disturbance is detected. The second operating condition starts immediately after the disturbance detection and it works with a new variable data window. The third operating condition starts when the variable data window reaches one full cycle of samples.

The algorithm is initiated by collecting one-cycle sampled data window for each signal. Based on a sampling frequency 960 Hz, one cycle contains 16 samples. For each new sample enter the window, the oldest one is discarded. Powerful analysing tool of wavelet transform has excellent decomposing features for all kinds of operation full cycle data window signals are decomposed. The db1 mother wavelet is used to decompose the measured six line currents at the relay location for one level. The high frequency components in the line currents can be extracted from a signal at the first decomposition level, and a disturbance can be detected by observing the norm of the detail coefficients D1. If the norm of D1 for each line current is less than a certain threshold (M), this means that the lines are healthy. The measured six line currents and the three phase voltages at the relay location are decomposed into two levels of decomposition using the db4 mother wavelet. Theoretically, the phasors should be estimated from the third decomposition level (0–60Hz). Since the compact support wavelets do not have ideal cut-off frequency characteristics, the phasors cannot be obtained from this level. It is essential to use some margins on both sides of

the frequency of interest. Therefore, the fundamental frequency (60 Hz) falls into the middle of the approximation output of the second level. From the second level of decomposition (0–120 Hz), the phasor (magnitude and angle) of each signal can be estimated by using the approximation coefficients vector of A2. Using these phasors, the sequence components of the currents of both lines can be calculated. For each new sample, a check is performed for the case of one circuit being disconnected. This can be done by observing the level of the positive sequence current magnitude of both circuits. If one line is disconnected, an alternative algorithm for single-line distance protection should be executed Once the norm of one or more current detail coefficients exceeds the threshold (M), a disturbance is detected. A new data window is started from the sample at which the disturbance has been detected. Each time a new sample enters the window, the phasors of all current and all voltage signals are estimated and the difference Idiff between the phasor magnitudes of the currents of the corresponding phases, on which a disturbance has been detected, is calculated.
For example, the difference between the magnitudes of currents of phase A corresponding phasors is:

$$\mathbf{IaDiff} = |\mathbf{Ia1}| - |\mathbf{I\,a2}|$$

If the difference is above a predetermined positive threshold level L, a trip signal should be sent to the circuit breaker of line 1. If the difference is less than the negative value of L, a trip signal should be sent to the circuit breaker of line 2. If the difference is within the L range, the distance relay will calculate the impedance(s) of the line(s) on which the wavelet transform detected a disturbance. According to the calculated impedance, the disturbance will be classified as a fault on the line (internal or external) or a disturbance that happened for any other reason. If the disturbance is classified as a fault on the line, the distance relay will determine the zone of the fault and trip the circuit breaker according to its time delay.

When the number of samples n_w collected after detecting a disturbance reaches 16, the oldest sample in the window is disregarded when a new one enters the data window. The algorithm will continue with the same procedure and with a 16-sample data window for two more cycles. If no fault is detected, the algorithm will start again from the beginning. A flowchart for the proposed parallel-lines protection algorithm is shown in Figure.2

The calculated impedances for ground faults are based on deriving the positive-, negative-, and zero-sequence current values from the estimated phasors of only the line-on fault. A compensation for the mutual coupling between the lines is not included when calculating the ground impedances because this compensation may lead to a first zone tripping for faults beyond the remote end of the parallel lines. Such overreach is not acceptable and it is therefore much more serious than the under-reach, which can occur without compensation for the mutual coupling. The first zone reach is set to 90% of the line positive sequence impedance. The value of the threshold M used to detect disturbances by monitoring the norm of D1 is chosen, based on extensive simulations on the parallel lines model for all types of faults and loading conditions being studied. It has been found that, under all normal loading conditions, M is less than 0.3.

A value of 0.4 is assigned for M to increase the detection sensitivity. The threshold L, used to detect the abnormal difference in the current magnitude of the corresponding phases on both lines, is chosen carefully to achieve a secure response. For faults on the parallel lines, L should exceed 20% of the maximum load current during normal loading conditions. If the difference is less than this value, this implies that the disturbance detected is either an external fault or an error due to the difference in current transformers characteristics and a certain inequality in the primary currents. Value of impedance is calculated for each phase of each line.

z=v/(i+(m0*i10)+(m10*i20))-zf

m0=(z0-z1)/z1

m10=z0m/z1

z0-zero sequence impedance
Z1-positive sequence impedance
Z0m-zero sequence mutual impedance
The difference between the impedances of the two lines is compared with a preset threshold value. If it is greater than the positive threshold the fault is in line 2. If it is lesser than the negative threshold the fault is in line1.

V. Conclusion
The scheme is found to detect all faults instantaneously. The relay has been successfully tested using simulations for all types of faults in various lines. All faults are identified in less than one cycle after fault inception. Wavelet Transform with its magnificent characteristics is employed to detect the disturbances in the current signals and to achieve high speed relaying. The proposed algorithm is found to perfectly aid the distance protection scheme for all possible scenarios.

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