FAULT LOCATION AND DISTANCE ESTIMATION ON POWER TRANSMISSION LINES USING DISCRETE WAVELET TRANSFORM

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ABSTRACT

Fault location is very important in power system engineering in order to clear fault quickly and restore power supply as soon as possible with minimum interruption. In this study a 300km, 330kv, 50Hz power transmission line model was developed and simulated using power system block set of MATLAB to obtain fault current waveforms. The waveforms were analysed using the Discrete Wavelet Transform (DWT) toolbox by selecting suitable wavelet family to obtain the pre-fault and post-fault coefficients for estimating the fault distance. This was achieved by adding non negative values of the coefficients after subtracting the pre-fault coefficients from the post-fault coefficients. It was found that better results of the distance estimation, were achieved using Daubechies 'db5'wavele,t with an error of three percent (3%).

KEYWORDS: *Transmission line, Fault location, Wavelet transforms, signal processing*

I. INTRODUCTION

Fault location and distance estimation is very important issue in power system engineering in order to clear fault quickly and restore power supply as soon as possible with minimum interruption. This is necessary for reliable operation of power equipment and satisfaction of customer. In the past several techniques were applied for estimating fault location with different techniques such as, line impedance based numerical methods, travelling wave methods and Fourier analysis [1]. Nowadays, high frequency components instead of traditional method have been used [2]. Fourier transform were used to abstract fundamental frequency components but it has been shown that Fourier Transform based analysis sometimes do not perform time localisation of time varying signals with acceptable accuracy. Recently wavelet transform has been used extensively for estimating fault location accurately. The most important characteristic of wavelet transform is to analyze the waveform on time scale rather than in frequency domain. Hence a Discrete Wavelet Transform (DWT) is used in this paper because it is very effective in detecting fault- generated signals as time varies [8].

This paper proposes a wavelet transform based fault locator algorithm. For this purpose, 330KV,300km,50Hz transmission line is simulated using power system BLOCKSET of MATLAB [5].The current waveform which are obtained from receiving end of power system has been analysed. These signals are then used in DWT. Four types of mother wavelet, Daubechies (db5), Biorthogonal (bio5.5), Coiflet (coif5) and Symlet (sym5) are considered for signal processing.

II. WAVELET TRANSFORM

Wavelet transform (WT) is a mathematical technique used for many application of signal processing [5].Wavelet is much more powerful than conventional method in processing the stochastic signal because of analysing the waveform in time scale region. In wavelet transform the band of analysis can be adjusted so that low frequency and high frequency components can be windowing by different scale factors. Recently WT is widely used in signal processing application such as de noising, filtering, and image compression [3]. Many pattern recognition algorithms were developed based on the wavelet transform. According to scale factors used the wavelet can be categorized into different sections. In this work, the discrete wavelet transform (DWT) was used. For any function (f), DWT is written as.

$$DWT_{\Psi}f(m,k) = \frac{1}{\sqrt{a_o^m}}\sum_n x(n)\psi[\frac{k-n_o b_o a^m}{a_o^m}] \quad (1)$$

Where ψ is the mother wavelet [3], a_o^m is the scale parameter

n_o, b_o, a^m are the translation parameters.

III. TRANSMISSION LINE EQUATIONS

A transmission line is a system of conductors connecting one point to another and along which electromagnetic energy can be sent. Power transmission lines are a typical example of transmission lines. The transmission line equations that govern general two-conductor uniform transmission lines, including two and three wire lines, and coaxial cables, are called the telegraph equations. The general transmission line equations are named the telegraph equations because they were formulated for the first time by Oliver Heaviside (1850-1925) when he was employed by a telegraph company and used to investigate disturbances on telephone wires [1]. When one considers a line segment dx with parameters resistance (*R*), conductance (*G*), inductance (*L*), and capacitance (*C*), all per unit length, (see Figure 3.1) the line constants for segment dx are Rdx, $G\,dx$, $L\,dx$, and $C\,dx$. The electric flux ψ and the magnetic flux Φ created by the electromagnetic wave, which causes the instantaneous voltage $u(x,t)$ and current $i(x,t)$,
are:

$$d\psi(t) = u(x,t)Cdx \quad (2)$$
$$d\phi(t) = i(x,t)Ldx \quad (3)$$

Calculating the voltage drop in the positive direction of *x* of the distance dx one obtains

$$u(x,t) - u(x+dx,t) = -du(x,t) = -\frac{\partial u(x,t)}{\partial x}\,dx = \left(R + L\frac{\partial}{\partial t}\right)i(x,t)dx \quad (4)$$

If $dx\ is$ cancelled from both sides of equation (4), the voltage equation becomes

$$\frac{\partial u(x,t)}{\partial x} = -L\frac{\partial i(x,t)}{\partial t} - Ri(x,t) \quad (5)$$

Similarly, for the current flowing through *G* and the current charging *C*, Kirchhoff's current law can be applied as

$$i(x,t) - i(x+dx,t) = -di(x,t) = -\frac{\partial i(x,t)}{\partial x}\,dx = \left(G + C\frac{\partial}{\partial t}\right)u(x,t)dx \quad (6)$$

If $dx\ is$ cancelled from both sides of (6), the current equation becomes

$$\frac{\partial i(x,t)}{\partial x} = -C\frac{\partial u(x,t)}{\partial t} - Gu(x,t) \quad (7)$$

The negative sign in these equations is caused by the fact that when the current and voltage waves propagates in the positive *x*-direction, $i(x,t)$ and $u(x,t)$ will decrease in amplitude for increasing x. The expressions of line impedance, Z and admittance Y are given by

$$Z = R + \frac{\partial L(x,t)}{\partial t} \quad (8)$$
$$Y = G + \frac{\partial C(x,t)}{\partial t} \quad (9)$$

Differentiate once more with respect to *x*, the second-order partial differential equations

$$\frac{\partial^2 i(x,t)}{\partial x^2} = -Y\frac{\partial u(x,t)}{\partial t} = YZi(x,t) = \gamma^2 i(x,t) \quad (10)$$

$$\frac{\partial^2 u(x,t)}{\partial x^2} = -Z\frac{\partial u(x,t)}{\partial t} = ZYu(x,t) = \gamma^2 u(x,t) \quad (11)$$

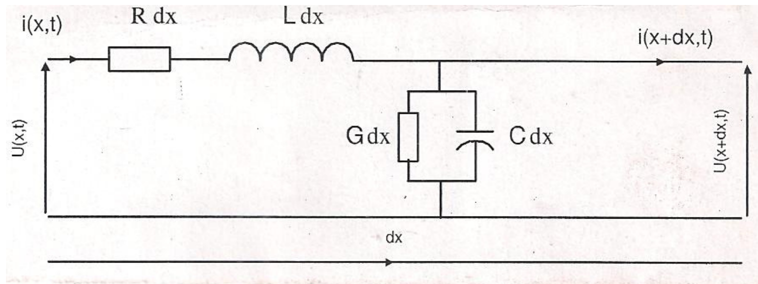

Figure 1 Single phase transmission line model

In this equation, γ is a complex quantity which is known as the propagation constant, and is given by

$$\gamma = \sqrt{ZY} = \alpha + j\beta \quad (12)$$

Where, α is the attenuation constant which has an influence on the amplitude of the wave, and β is the phase constant which has an influence on the phase shift of the wave.
Equations (7) and (8) can be solved by transform or classical methods in the form of two arbitrary functions that satisfy the partial differential equations. Paying attention to the fact that the second derivatives of the voltage v and current $i$functions, with respect to *t* and *x*, have to be directly proportional to each other, so that the independent variables *t* and *x* appear in the form [1]

$$u(x,t) = A_1(t)e^{\gamma x} + A_2(t)e^{-\gamma x} \quad (13)$$

$$i(x,t) = \frac{1}{Z}[A_1(t)e^{\gamma x} + A_2(t)e^{-\gamma x}] \quad (14)$$

Where *Z* is the characteristic impedance of the line and is given by

$$Z = \sqrt{\frac{R+L\frac{\partial}{\partial t}}{G+C\frac{\partial}{\partial t}}} \quad (15)$$

A_1 and A_2 are arbitrary functions, independent of x

To find the constants $A_1$and A_2 it has been noted that when $x = 0$, $u(x) = u_R$ and $i(x) = i_r$ from equations (13) and (14) these constants are found to be

$$A_1 = \frac{VR+ZI_R}{2} \quad (16)$$

$$A_2 = \frac{VR-ZI_R}{2} \quad (17)$$

Upon substitution in equation in (13) and (14) the general expression for voltage and current along a long transmission line become

$$u(x) = \frac{V_R+ZI_R}{2}e^{\gamma x} + \frac{V_R-ZI_R}{2}e^{-\gamma x} \quad (18)$$

$$i(x) = \frac{\frac{V_R}{Z}+I_R}{2}e^{\gamma x} - \frac{\frac{V_R}{Z}-I_R}{2}e^{-\gamma x} \quad (19)$$

The equation for voltage and currents can be rearranged as follows

$$u(x) = \frac{e^{\gamma x}+e^{-\gamma x}}{2} V_R + Z\frac{e^{\gamma x}-e^{-\gamma x}}{2} I_R \quad (20)$$

$$i(x) = \frac{1}{z}\frac{e^{\gamma x}-e^{-\gamma x}}{2} V_R + \frac{e^{\gamma x}+e^{-\gamma x}}{2} I_R \quad (21)$$

Recognizing the hyperbolic functions$sinh, and\ cosh$, the above equations (20) and (21) are written as follows:

$$u(x) = cosh\gamma x V_R + Z sinh\gamma x I_R \quad (22)$$

$$i(x) = \frac{1}{z} sinh\gamma x V_R + cosh\gamma x I_R \quad (23)$$

The interest is in the relation between the sending end and receiving end of the line. Setting $x = l, u(l) = V_s and\ I(l) = I_s$, the result is

$$V_s = cosh\gamma l V_R + Z sinh\gamma l I_R \quad (24)$$

$$I_s = \frac{1}{z} sinh\gamma l V_R + cosh\gamma l I_R \quad (25)$$

Rewriting the above equations (24) and (25) in term of ABCD constants we have

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad (26)$$

Where $A = cosh\gamma l\ , B = Z sinh\gamma l\ , C = Z sinh\gamma l\ and\ D = cosh\gamma l$

IV. TRANSMISSION LINE MODEL

In this paper fault location was performed on power system model which is shown in figure 2. The line is a 300km, 330kv, 50Hz over head power transmission line. The simulation was performed using MATLAB SIMULINK.

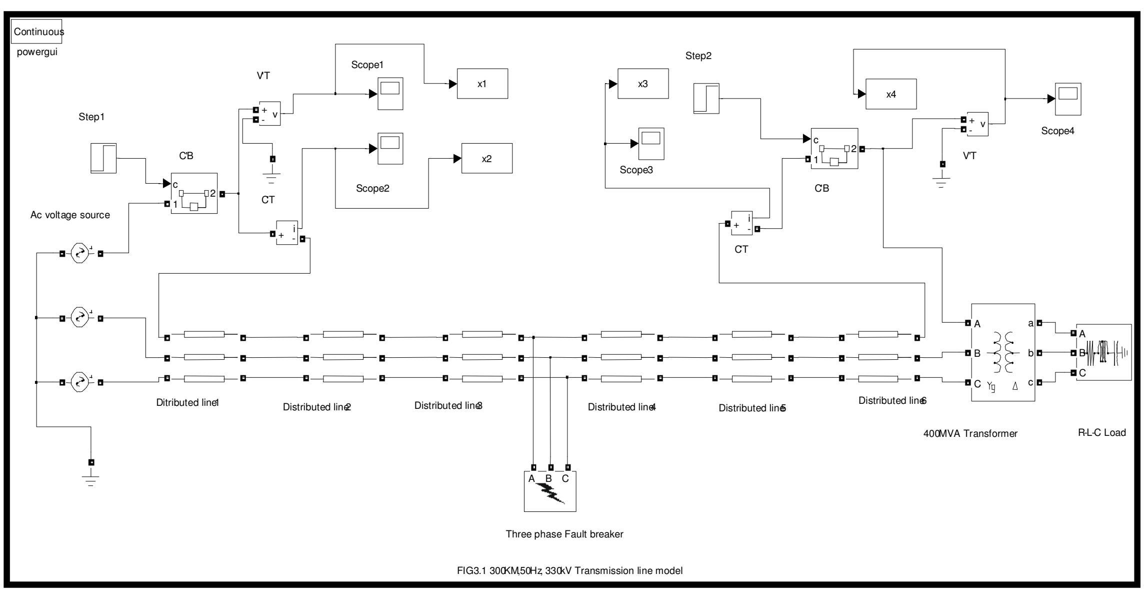

Figure 2: Simulink transmission line model

The fault is created after every 50km distance, with a simulation time of 0.25sec, sample time = 0, resistance per unit length = 0.012ohms, inductance per unit length = 0.9H and capacitance per unit length = 127farad.

4.1 SIMULATION RESULTS

Figure 3 shows the normal load current flowing prior to the application of the fault, while the fault current is shown in figure 4, which is cleared in approximately one second.

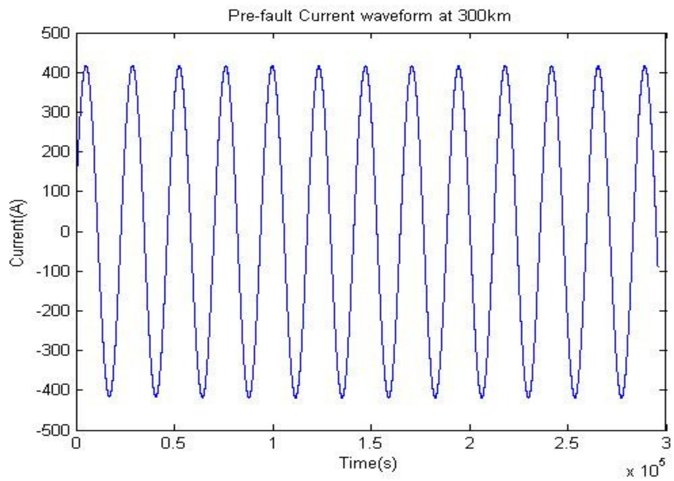

Fig 3: Pre-fault current waveform at 300km

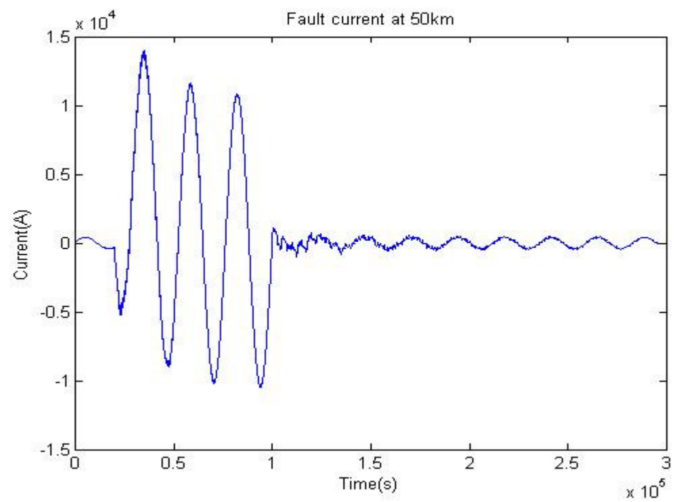

Fig 4: Fault current waveform at 50km

4.2 DISCRETE WAVELET COEFFICIENTS.

Figures 5 and 6 showed pre-fault/post fault wavelets coefficients (approximate, horizontal detail, diagonal detail and vertical detail) at 3 00km using the following db5 wavelet familioes.

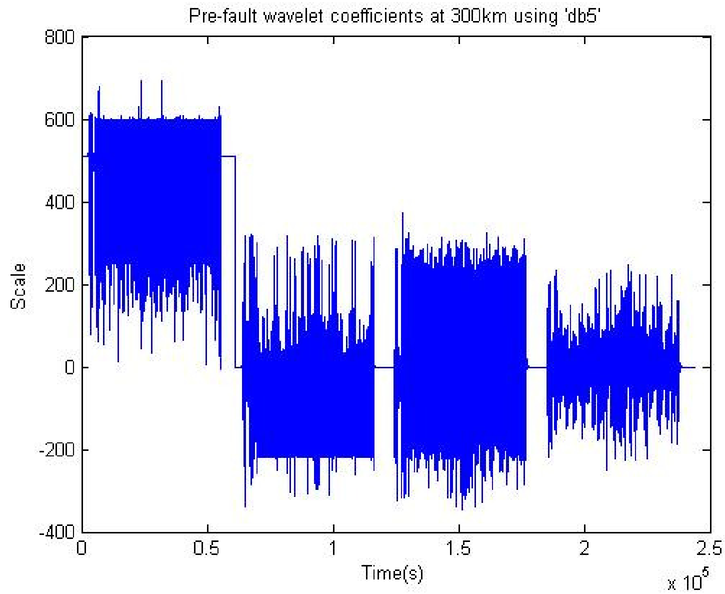

Fig 5: Pre- fault wavelet coefficients

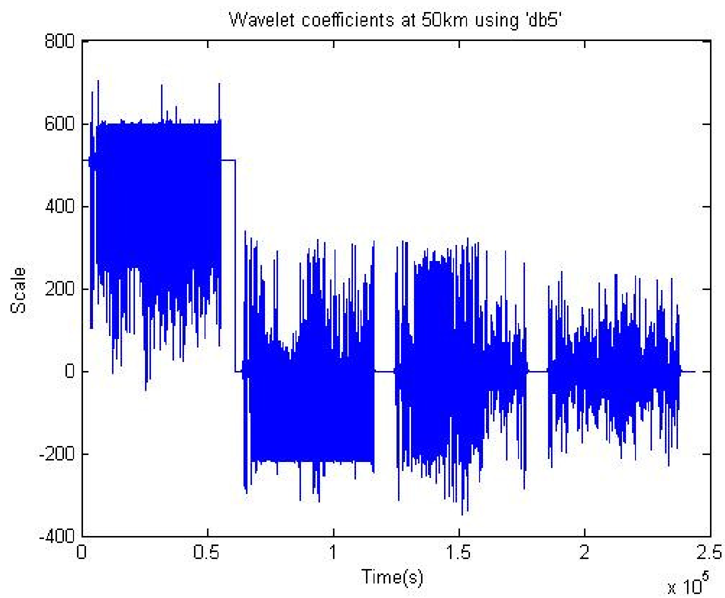

Fig. 6: Post- fault wavelet coefficients at 50km

4.2.1 TABLES OF THE COEFFICIENTS

The tables below present the minimum / maximum scales of the coefficients using db5.

Table 1: Pre-fault wavelet coefficients using db5

Coefficients	Max. Scale	Min. Scale
Approximate(A1)	693.54	0.00
Horizontal(H1)	205.00	214.44
Vertical (V1)	235.56	218.67
Diagonal (D1)	157.56	165.78

Table 2: Pre-fault wavelet coefficients using db5

Coefficients	Max. Scale	Min. Scale
Approximate(A1)	693.54	34.89
Horizontal(H1)	218.67	201.33
Vertical (V1)	201.33	218.67
Diagonal (D1)	157.56	148.89

Table 3: Differences between maximum and minimum scale of the coefficients using db5

		db5 max				db5 min			
Coefficients		A1	H1	V1	D1	A1	H1	V1	D1
Coefficients. At 50km		693.54	218.67	201.33	157.56	34.89	201.33	218.67	148.89
Pre-fault coefficients.		693.54	205.00	235.56	157.56	0.00	214.44	218.67	165.78
Differences		0.00	13.67	-34.23	0.00	34.89	-13.11	0.00	-16.89

Estimated distance (km) = 13.67 + 34.89 = 48.5

Table 4: Actual and estimated fault location

Actual location(km)	db5	bio5.5	coif5	Sym5
50	48.5	39.33	47.32	26.23
100	97.44	173.78	04.37	43.56

4.3 DISCUSSION OF THE RESULTS.

The results are presented in figures 5 and 6, and tables 1 to 4. Figure 3 is the simulation result of pre-fault current waveform which indicates that the normal current amplitude reaches 420A. When a fault was created at 50km from the sending end point, figure 4 shows that the fault current amplitude reaches up to 14 kA.

The waveforms obtained from figures 3 and 4 were imported into the wavelet toolbox of MATLAB for proper analysis to generate the coefficients. Figures 5 and 6 presents the discrete wavelet transform coefficients in scale time region. The scales of the coefficients are based on minimum scale and maximum scale. These scales for both pre-fault and post fault coefficients were recorded from the work space environment of the MATLAB which was presented in tables 1and 2.

The estimated distance was obtained by adding non negative values of the scales after subtracting the pre-fault coefficients from the post-fault coefficients; this is presented in table 4.

V. CONCLUSIONS

The application of the wavelet transform to estimate the fault location on transmission line has been investigated. The most suitable wavelet family has been made to identify for use in estimating the fault location on transmission line. Four different types of wavelets have been chosen as a mother wavelet for the study. It was found that better result was achieved using Daubechies 'db5' wavelet with an error of 3%. Simulation of single line to ground fault (S-L-G) for 330kv, 300km transmission line was performed using SIMULINK MATLAB SOFTWARE. The waveforms obtained from SIMULINK have been converted as a MATLAB file for feature extraction. DWT has been used to analyze the signal to obtain the coefficients for estimating the fault location. Finally it was shown that the proposed method is accurate enough to be used in detection of transmission line fault location.

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Authors' Biography

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