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Detection, Classification and Location of Overhead Line Faults using Wavelet Transform

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Abstract

Objectives: To develop a wavelet Transform method to identify and categorize transmission line faults and also determines the location of the fault. **Method**: A Simulink model is developed for the test system. Various faults at different locations are simulated. DWT coefficients of the current signals are obtained. Fault index is calculated and is used to identify and categorize the fault. **Findings:** The method proposed using wavelet transform in the present work will accurately discriminate between normal and fault condition, identify the type of fault and determine its location. The method proposed is relatively very simple and can be easily realized and practically implemented. **Application/Improvements:** Transmission line protection relay should be highly reliable, selective and act quickly so that minimum damage is caused, area affected by power interruption is less and stability of the system is not lost. Hence, efficient fault detection methods are necessary to help operators to take required measures during power system disturbances. This will ensure the secure and stable operation of the power system.

Keywords: Fault Detection, Fault Index, Line Faults, Location, Wavelet Transform

1. Introduction

Ever increasing demand for electrical power and formation of national grid necessitates use of more and more EHV and UHV transmission lines. These transmission lines require adequate and highly reliable protection so that power interruption duration is minimum and fault does not spread to other portion of the power system[1]. It is essential to detect the type of disturbance accurately and quickly so that the effect of these disturbances is minimised and localized. In order to determine the causes and sources of disturbances, Faults on overhead transmission lines can be symmetrical or unsymmetrical faults. Line faults can cause severe damage to the line and the system, if it is not detected early and cleared quickly. Line faults corrupt the power quality also in addition to damaging the equipment. Hence is very much essential to provide adequate and fast acting protection scheme to transmission lines to identify the type of fault and its location and also isolate the faulty line quickly.

Long transmission lines are usually protected by distance relay. Distance protection schemes however have the problems of under reach and over reach. Also non simultaneous operation of breakers at the two ends of the line can affect the system stability. With the advancements in VLSI technology, the present trend is towards digital protection schemes using artificial neural network, fuzzy logic, transform methods and their combination[2].

During power system disturbances and faults, current and voltage signals will have transients and will be non-stationary. Such signals can be analysed using time frequency methods. Short time Fourier transforms is one of the commonly used techniques. The limitation of STFT is fixed window length and hence obtaining both better time and frequency resolutions is not possible. The wavelet transform gives better results when used for

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the analysing such signals. In the literature, one can find Wavelet Transform being used for various applications and domain. An algorithm to identify simultaneously integer, non-integer and sub harmonics of power system waveforms using wavelet transforms is proposed in[3]. Adaptive decomposition wavelet transform is used for the identification and categorization of voltage swells[4]. Haar wavelet transform and simulated annealing algorithm is used to monitor and detect transformer winding displacement and deformation of transformer core[5]. In order to improve the accuracy and efficiency, artificial intelligence methods like ANN and fuzzy logic are either independently used are combined with wavelet analysis for fault detection[6–9].

Accurate determination of exact location of fault on a long transmission line is very important. This will help to take up the repair work quickly and restore the normal condition. Different techniques are proposed for the detection of fault location using wavelet Transforms[10–12]. Most of the methods described above use slightly complicated techniques which may be difficult to implement practically.

Thus, it is advantageous to formulate a simple and precise method to discriminate between normal and fault condition, categorize the fault and find its location. In the present work, a simple technique based on discrete wavelet transform is proposed to determine whether it is normal or fault condition. In the event of fault, the algorithm developed will determine whether it is symmetrical or un-symmetrical fault. A simple technique is used to locate the single line to ground fault using line sequence impedance values and measured voltage, current.

This paper is organised as follows. Section 2 gives the fundamental concepts of wavelet transforms. Details about system used for analysis and methodology used are highlighted in Section 3. Discussion and analysis of results obtained from fault simulation study can be found in Section 4. Finally, inference from the work carried and results obtained are outlined in Section 5.

2. Wavelet Transform

Wavelet transforms are time-frequency multi resolution analysis. It overcomes the limitation of short time Fourier transforms since it automatically changes the window length for different-frequencies. In case of wavelet analysis, for the portion of waveform containing frequency components of higher magnitude narrow time window is used. Similarly for the portion of the waveform containing relatively low frequency components, wide time window is used. A suitable mother wavelet is used to decompose the test signal. High and low frequency forms of mother wavelet are used for the analysis and are used to obtain approximate and detail components, representing different frequency range.

Daubechies wavelet is the most widely used mother wavelet for analyzing power system signals. Mother wavelets should match the signal to be analyzed. Daubechies wavelets closely match thepower system signals during disturbances. Hence Daubechies wavelet is normally used for analyzing current and voltage signals during faults. Various frequency band components obtained in the form of approximate and detail components provide useful signatures to accurately determine whether it is normal or fault condition and in the event of fault, categorize it. Multi-level decomposition is done using wavelets. However, depending on the frequency band of interest, coefficients from appropriate level is used for the analysis.

If x (t) represents a time varying signal, then Equation (1) can be used to find its Continuous Wavelet Transform.

$$CWT(a,b) = \left(\frac{1}{\sqrt{a}}\right)\int_{-\infty}^{\infty} x(t).\varphi\left(t-\left(\frac{b}{a}\right)\right)dt \quad) \quad (1)$$

Here ‘b’ and’ a’ are the time shift and the magnitude parameters respectively. Ψ (t) is the mother wavelet.

The factor $\left(\frac{1}{\sqrt{a}}\right)$

is used to ensure that all the scaled wavelets will have the same energy as the original wavelet. Mother wavelets must meet the following requirement.

$$\int_{-\infty}^{\infty} \varphi(t).\, dt = \mathbf{0} \quad (2)$$

DWT is the discrete version of the DWT and is used for the analysis of power system signals. DWT coefficients of the test signal are obtained using the chosen mother wavelet. Any proposed algorithm should be practically realizable. Hardware implementation of DWT would require high pass and low pass filters at every level. The first level would include higher frequency components with wide frequency band. As we move towards higher levels, we will have relatively lower frequency components with narrow frequency band. However at first level we will have a very good time resolution i.e. narrow time window while at higher levels we will have wide time window.

3. Methodology

Sample power system considered for the analysis is shown in Figure 1. Table 1 gives the system data. Figure 2 shows the Simulink model developed for the study. Methodology used is described through the following steps.

- Simulate symmetrical and unsymmetrical line faults at different points (distance) on the line.
- Perform simulation and get three phase voltage and current values during normal and fault condition.
- Use MATLAB functions (code) to find out DWT coefficients.
- Calculate the fault index value using detail coefficients at level 3.
- Select a suitable threshold value of fault index and use it to differentiate between normal and fault condition and to identify the type of the fault.
- Use MATLAB / SIMULINK to obtain sequence components of voltage and current and use them to find the distance of fault point from relay location.

After obtaining the detail coefficients, fault index value for all the three phases is calculated using the following relation.

$$F(i) = \sum_{M}^{(M+40)} |di| \qquad (3)$$

Where, di is the detail coefficient at level '3' of the transient signal under observation at that particular instant of time. M to M+40 is time interval under observation which is one cycle of power frequency. Fault index values obtained during the fault are used to determine the type of the fault.

Thus fault index values are taken as a discriminating factor in detecting and classifying the type of fault.

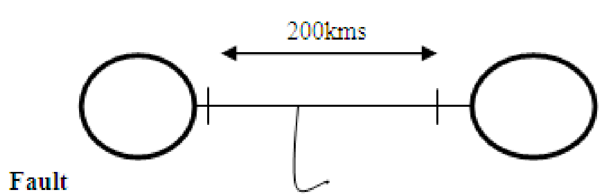

Figure 1. One-line diagram of single circuit transmission model.

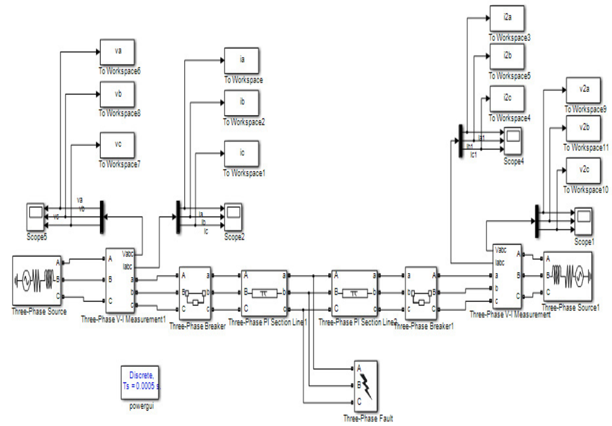

Figure 2. Developed MATLAB/Simulink model.

Table 1. System data

Sl.no	Entity	Parameter	Value
1	Generator 1	Line voltage (RMS) (Vs)	400KV
2	Generator 2	Line voltage (RMS) (Vr)	400KV at angle 30
3	System	Frequency	50Hz
4	Transmission line	Zero sequence component	96.45+j335.26
5	Transmission line	Positive sequence component	9.78+j110.23
6	Fault	Fault duration	2 cycles
76	Circuit Breaker	Circuit breaker operating time	1 cycle

3.1 Fault Location

Consider an SLG fault as shown in Figure 3. Let the fault point be at say a distance of 'm' from one end and hence will be at a distance (1-m) from the other end. Let RF represent resistance of the fault and VF its voltage. For the fault considered, fault current directions are as shown in Figure 3. Net fault current can therefore be obtained by adding the individual fault currents.

Let

m = Line length (in per unit).

Z1, Z2 and Z0 = Sequence impedances of the line.

VA and VB = Phase to ground voltages as seen from ends A and B respectively.

VA1, VA2 and VA0 = Sequence components of VA.

Vf = voltage to ground at fault point.

Phase to ground fault voltage, VF seen from both sub-stations is given by

$$Vf = VA - IA0 * x * (Z1 + Z2 + Z0) \quad (4)$$

$$Vf = VB - IB0 * (1 - x) * (Z1 + Z2 + Z0) \quad (5)$$

Where IA0 and IB0 are the zero sequence components of currents IA and IB respectively, given by

$$IA0 = \frac{IA}{3} \quad (6)$$

$$IB0 = \frac{IB}{3} \quad (7)$$

Hence fault location from station 'A'

$$\mathbf{x} = \frac{\mathbf{V_A - V_B + \left(\frac{I_B}{3}\right)(Z_1 + Z_2 + Z_0)}}{\mathbf{\frac{(I_A + I_B)}{3}(Z_1 + Z_2 + Z_0)}} \quad (8)$$

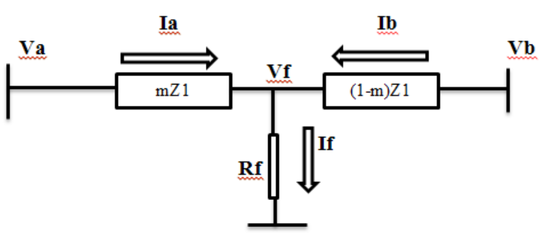

Figure 3. Diagram showing line fault.

4. Result Analysis

Various faults are simulated at different locations. The current waveforms during normal, SLG and DLG faults are shown in Figure 4, Figure 5 and Figure 6.

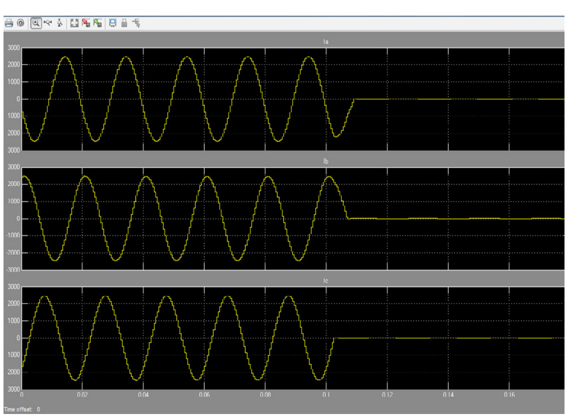

Figure 4. Currents during normal condition.

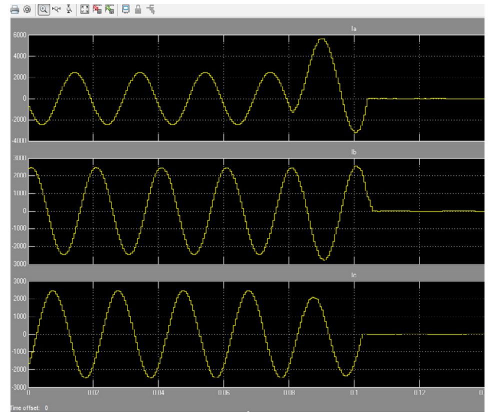

Figure 5. Currents during AG fault.

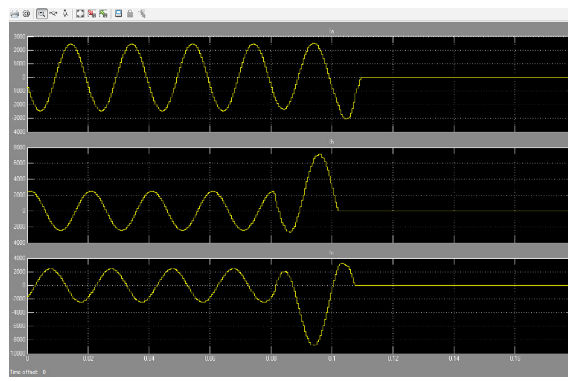

Figure 6. Currents during BCG fault.

Wavelet decomposition is then performed on these signals to obtain approximate and detailed coefficients. Daubechies, DB5, is selected as mother wavelet for the wavelet decomposition. Figure 7 shows the plot of approximate and detail coefficients for SLG fault.

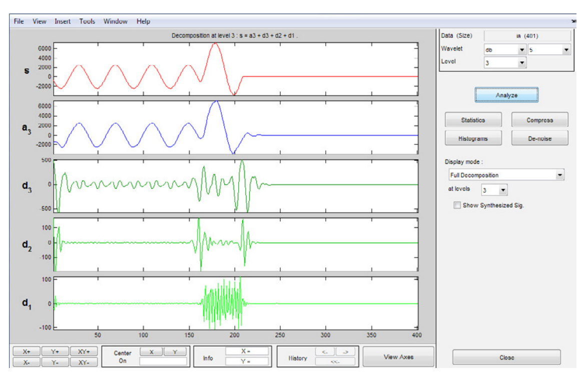

Figure 7. Plots of approximate and detailed coefficients.

Detail coefficients at level '3' of the current signals are then used to calculate the fault index values. Fault index values computed are tabulated in Table 2.

Table 2. Fault index values during the Fault

Sl.no	Fault	Location (km)	Fa	Fb	Fc
1	No Fault	100	811.5420	821.0166	825.4090
2	AG	80	2.9939e+03	790.5371	838.6455
3	AG	120	2.4388e+03	825.1568	836.4132
4	BCG	40	784.2861	1.7355e+04	1.7452e+04
5	BCG	100	812.5597	9.2597e+03	8.9472e+03
6	ABCG	120	3.5366e+03	8.4395e+03	7.6783e+03
7	ABC	160	3.0800e+03	6.9897e+03	6.9897e+03

From Table 2 it is clear that the fault index values calculated for faulty lines are much higher than fault index values of healthy lines. So a suitable threshold value is selected. These threshold values are used to differentiate between normal and fault condition and also to identify the type of the fault.

Table 3 shows the results obtained. Results show that the expression used for the fault location determination gives fairly accurate values.

Table 3. Determination of fault location

Fault type	Actual fault location	Obtained fault location
AG	100Km	107Km
AG	120Km	124Km
AG	160Km	159Km
BG	100Km	104Km
BG	120Km	122Km
BG	160Km	157Km
CG	100Km	106Km
CG	120Km	124Km
CG	160Km	159Km

Figure 8 shows the final result window in MATLAB. The result window gives fault index values before the fault occurrence and the fault index values during the fault. It also indicates whether the system is working under normal conditions or is faulty. In case of fault, it also indicates the type of fault and the fault location.

Figure 8. Result window displaying the fault index values, fault type and location.

5. Conclusion

Transmission lines are more prone to faults than any other power system equipment. In this work, line fault analysis is carried by simulating various faults at different locations on the transmission line. 3 phase current signal during normal and fault condition is analysed using discrete wavelet transform. Multi resolution wavelet analysis is performed and a simple method is developed to correctly discriminate between normal and fault condition and determine the type of fault. Detail coefficients at level 3 of the '3' phase current signals is utilized. Fault index values are calculated for all three current signals using detail coefficients. A suitable threshold value was selected and we were able to correctly categorize the type of the fault on transmission line. The mother wavelet used is Daubechies, DB5. Correct determination of fault location will help the maintenance personnel to fix the problem quickly. In this paper, sequence components of line impedance, voltage and current during fault is utilized to obtain a simple expression for the determination of the location of the fault. Results obtained were fairly accurate.

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