IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 1 Ver. IV (Jan – Feb. 2015), PP 44-50
www.iosrjournals.org

Detection and Location of Faults in 11KV Underground Cable by using Continuous Wavelet Transform (CWT)

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Abstract: *This paper describes a technique to detect, classify and locate faults on an underground cable system based on the principles of continuous wavelet transform (CWT). Due to the fault in the power system a high frequency current and voltage generates and propagate along the power. These generated signals contain a lot of information and can be used for fault detection and location. The high frequency components generated are extracted using the wavelet technique and analysis of the extracted signals is carried. The MATLAB simulink version 7.6 is used to model the underground cable network and faults at various locations are simulated. The resulting waveforms are subjected through a wavelet transform to extract the required signals for analysis. The results show that the wavelet transform is very effective to extract the transient components from the fault signals and detection and location of faults can be done accurately. In this paper three phase 11KV; 100km long cable is considered for the analysis purpose.*

Keywords: *Cable, CWT, fault location, transient, signals, simulation*

I. Introduction

In the modern electrical power systems of transmission and distribution systems, underground cable is used largely in urban areas and compared to overhead lines, fewer faults occur in underground cables. However if faults occur, it's difficult to repair and locate the fault. Faults that could occur on underground cables networks are single phase-to-earth (LG) fault; double phase-to-earth (LLG) fault, phase-to-phase (LL) fault and three phase-to-earths (LLLG) fault [1]. The single line to earth fault is the most common fault type and occurs most frequently. Fault detection and location based on the fault induced current or voltage travelling waves has been studied for years together. In all these techniques, the location of the fault is determined using the high frequency transients. The main idea behind these techniques is based on the reverberation of the fault generated travelling waves in the faulty system. Fault location based on the travelling waves can generally be categorized into two: single-ended and double ended. For single-ended, the current or voltage signals are measured at one end of the line and fault location relies on the analysis of these signals to detect the reflections that occur between the measuring point and the fault. For the double-ended method, the time of arrival of the first fault generated signals are measured at both ends of the lines using synchronized timers. The double-ended method does not require multiple reflections of the signals. However, single-ended location is preferred as it only requires one unit per line and a communication link is not necessary.

This paper presents a wavelet technique have been applied that can extract the high frequency fault signals for determination of cable fault and location. The technique applied here determines the fault position by measuring the travelling time of the high frequency current signals. In this paper 11kV distribution cable is modeled using MATLAB Simulink software, the response for the different fault was examined and then wavelet transform is applied with band pass filter to derive the exact location of the fault.

II. Wavelet Transform

Wavelet transform is much like the Fourier transforms, however with one important difference: it allows time localization of different frequency components of a given signal. Windowed Fourier transform also partially achieves this same goal, but with a limitation of using a fixed width windowing function. In the case of wavelet transform, the analyzing functions, which are called wavelets, will adjust their time widths to their frequency in such a way that, higher frequency wavelet will be narrow and lower frequency ones will be broader. So this property of multi resolution is particularly useful for analyzing fault transients which contain localized high frequency components superposed on power frequency signals. Thus, wavelet transform is better suited for analysis of signals containing short lived high frequency disturbances superposed on lower frequency continuous waveform by virtual of this zoom in capability [2]. Given a function f (t), its continuous wavelet transform (WT) will be calculated as follows:

$$WT(f,a,b) = \frac{1}{\sqrt{a}} \int f(t)\, \psi * \frac{(t-b)}{a}\, dt \tag{1}$$

Where, a and b are the scaling (dilation) and translation (time shift) constants respectively, and ψ is the wavelet function (mother wavelet).
The continuous wavelet transform (CWT) computes the inner product of a signal (t), with translated and dilated versions of an analyzing wavelet, ψ (t) the definition of the CWT is:

$$C(a,b;f(t),\psi(t)) = \int_{-\infty}^{\infty} f(t)\frac{1}{\sqrt{a}}\,\psi * \frac{(t-b)}{a}\,dt$$

You can also interpret the CWT as a frequency-based filtering of the signal by rewriting the CWT as an inverse Fourier transform.

$$C(a,b;f(t),\psi(t)) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \hat{f}(\omega)\,\sqrt{a}\,\hat{\psi}(\omega)\,(aw)) * e^{jab}\,d\omega$$

Where f$(\omega)$and $\psi(\omega)$ are the Fourier transforms of the signal and the wavelet.

From the preceding equations, you can see that stretching a wavelet in time causes its support in the frequency domain to shrink. In addition to shrinking the frequency support, the center frequency of the wavelet shifts towards lower frequencies. This depicts the CWT as a band pass filtering of the input signal. CWT coefficients at lower scales represent energy in the input signal at higher frequencies, while CWT coefficients at higher scales represent energy in the input signal at lower frequencies. However, unlike Fourier band pass filtering, the width of the band pass filter in the CWT is inversely proportional to scale. The width of the CWT filters decreases with increasing scale. This follows from the uncertainty relationships between the time and frequency support of a signal: the broader the support of a signal in time, the narrower its support in frequency. The converse relationship also holds.

In the wavelet transform, the scale or dilation operation is defined to preserve energy. To preserve energy while shrinking the frequency support requires that the peak energy level increases. The quality factor or Q factor of a filter is the ratio of its peak energy to bandwidth. Because shrinking or stretching the frequency support of a wavelet results in commensurate increases or decreases in its peak energy, wavelets are often referred to as constant-Q filters.

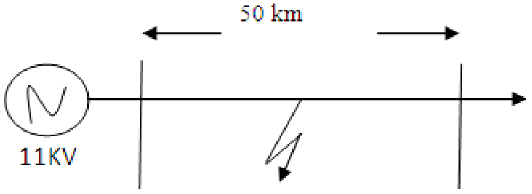
III. Fault Detection And Location

By comparing the transient signals at all phases the classification of fault can be made .If the transient signal appears at only one phase then the fault is single line to ground fault The transient signals generated by the fault is no stationary and is of wide band of frequency, when fault occurs in the network, the generated transient signals travels in the network. On the arrival at a discontinuity position, the transient wave will be partly reflected and the remainder is incident to the line impedance. The transient reflected from the end of the line travels back to the fault point where another reflection and incident occur due to the discontinuity of impedance. To capture these transient signals wavelet analysis can be used.
The fault location can be carried out by comparing the aerial mode wavelet coefficient to determine the time instant when the energy of the signal reaches its peak value. The distance between the fault point and the bus of the faulted branch will be given by

$$D = \frac{v\ x\ t_d}{2} \qquad (2)$$

Where D is the distance to the fault, td is the time difference between two consecutive peaks of the wavelet transform coefficients of the recorded current and v is the wave propagation velocity of the aerial mode.

A. Modeling and Simulation: First 11 KV, 100km underground cable is modeled in MATLAB simulink with 7.6 version and response of the complete system is for different configuration and faults evaluated. Wavelet transform effectively acts as a band pass filter which extracts a band of high frequency transient current signals from the faulted cable. The total length of the cable considered is 100km. Results from simulations are obtained with 800 Hz sampling rate and with Wavelet transform of Daubechies Db-4. The travelling wave velocity of the signals in the 11kV underground cable system is 1.9557x10^5 km/s, and sampling time of 10μs is used. Fig 1 depicts the single line diagram of the simulated system which is 11kv, 50Hz, 50km under ground cable.



Simulation studies: In this paper the authors select all the possible cases to illustrate the performance of the proposed technique under fault conditions. First LG fault is selected as simulation case and fault locations are tabulated along with % error to compare the deviation from the actual values using continuous wavelet transform. Similarly for simulation and their results are tabulated. LLG and LLLG faults selected

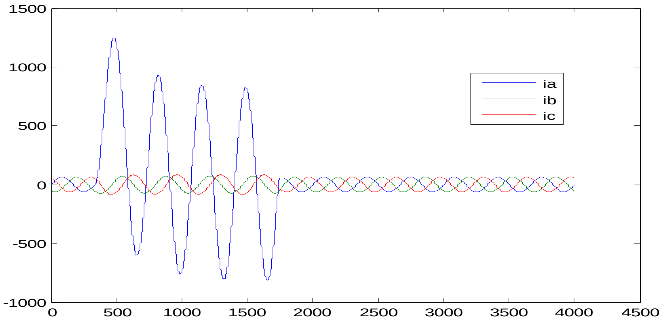
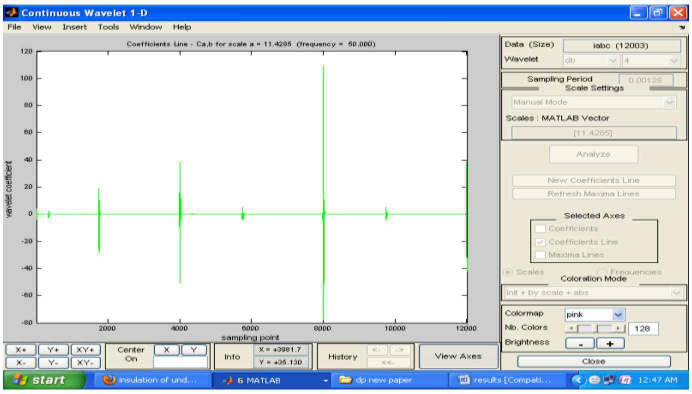


Fig 2: phase current for LG (AG)fault at 25 km


Coefficients Line - Ca,b for scale a = 11.4285 (frequency = 50.000)

Data (Size): iabc (12003)
Wavelet: db 4
Sampling Period: 0.00125
Scale Settings: Manual Mode
Scales : MATLAB Vector: [11.4285]
Selected Axes: ☐ Coefficients ☑ Coefficients Line ☐ Maxima Lines
● Scales ○ Frequencies
Coloration Mode: init + by scale + abs
Colormap: pink
Nb. Colors: 128
X = +3981.7
Y = +35.130

Fig 3: Single line to earth fault (AG) at 25km

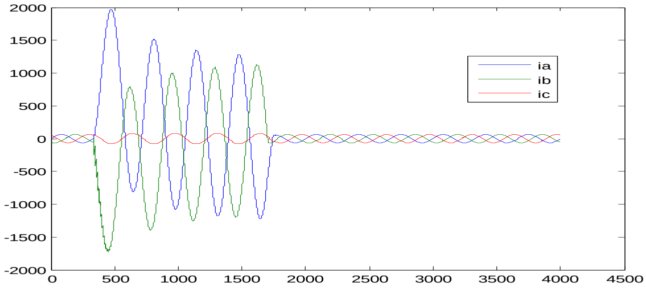
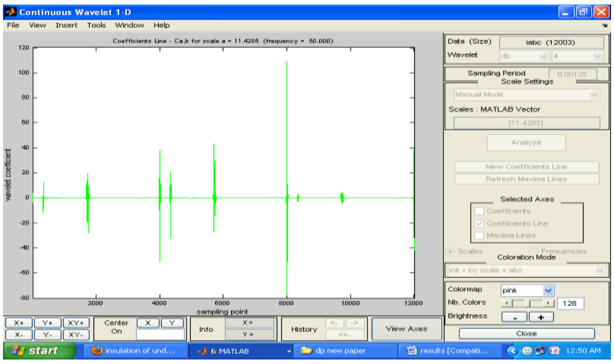


Fig 4: Phase current for LLG fault (ABG) at 25km


Coefficients Line - Ca,b for scale a = 11.4285 (frequency = 50.000)

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Sampling Period: 0.00125
Scale Settings: Manual Mode
Scales : MATLAB Vector: [11.4285]
Selected Axes: ☐ Coefficients ☑ Coefficients Line ☐ Maxima Lines
● Scales ○ Frequencies
Coloration Mode: init + by scale + abs
Colormap: pink
Nb. Colors: 128
X =
Y =

Fig 5: Double line to earth fault (ABG) at 25km by wavelet transforms

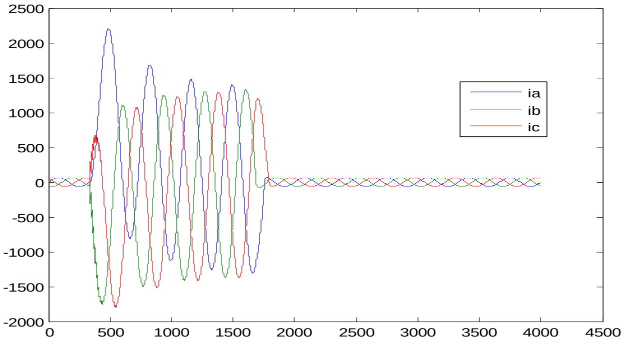
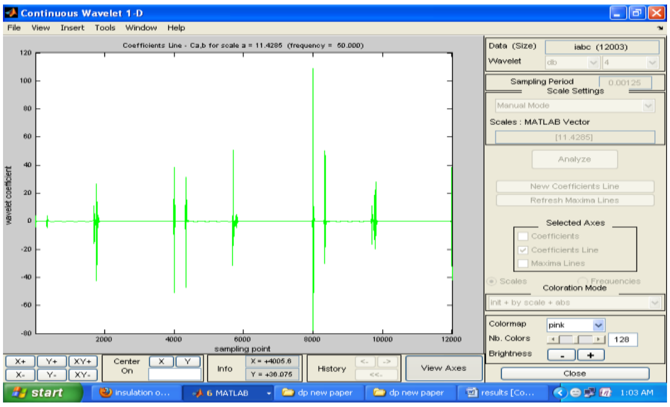


Fig 6: Phase current for LLLG fault (ABCG) at 25km.



Coefficients Line - Ca,b for scale a = 11.4285 (frequency = 50.000)

Data (Size) iabc (12003)

Wavelet db 4

Sampling Period 0.00125

Scale Settings

Manual Mode

Scales : MATLAB Vector

[11.4285]

Selected Axes

☐ Coefficients

☑ Coefficients Line

☐ Maxima Lines

● Scales ○ Frequencies

Coloration Mode

init + by scale + abs

Colormap pink

Nb. Colors 128

Brightness - +

X = +4005.6

Y = +36.075

Fig 7: Triple Line To Earth Fault (ABCG) At 25 Km By Wavelet Transforms

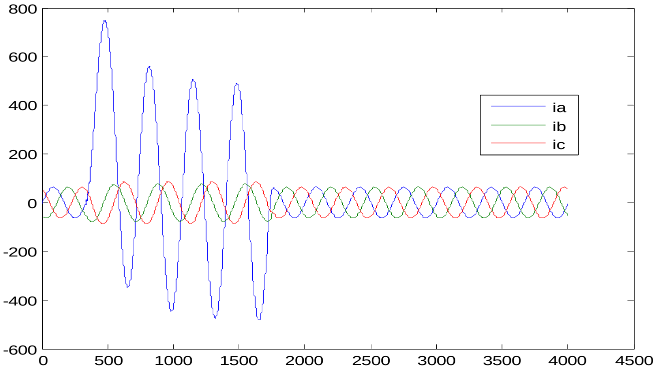
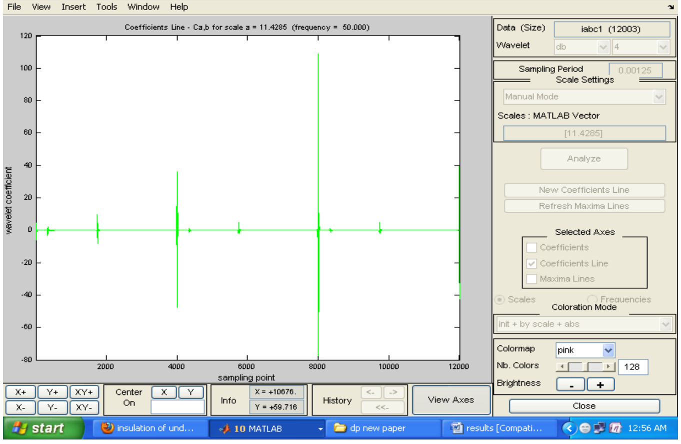


Fig 8: Phase Current For LG (AG)Fault At 50 Km



Coefficients Line - Ca,b for scale a = 11.4285 (frequency = 50.000)

Data (Size) iabc1 (12003)

Wavelet db 4

Sampling Period 0.00125

Scale Settings

Manual Mode

Scales : MATLAB Vector

[11.4285]

Selected Axes

☐ Coefficients

☑ Coefficients Line

☐ Maxima Lines

● Scales ○ Frequencies

Coloration Mode

init + by scale + abs

Colormap pink

Nb. Colors 128

Brightness - +

X = +10676.

Y = +59.716

Fig 9: Single line to earth fault (AG) at 50km

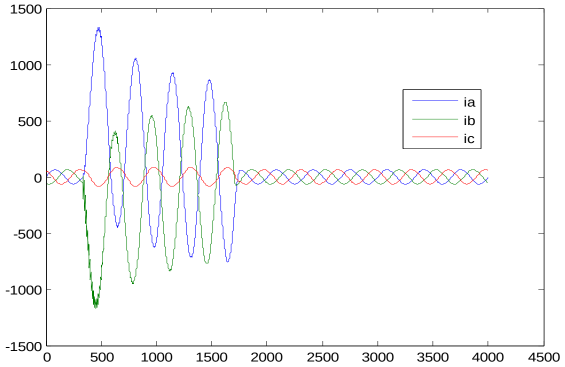
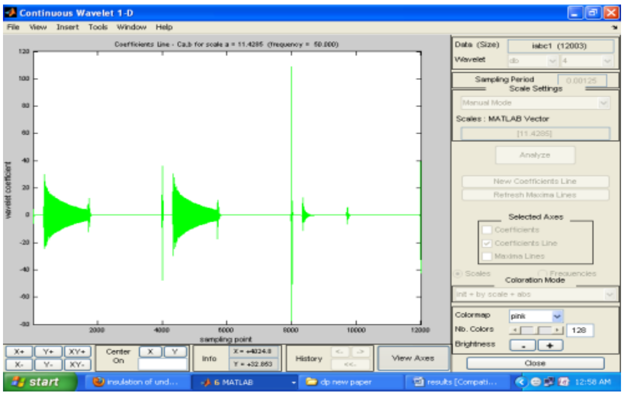


Fig 10: phase current for LLG (ABG)fault at 50 km



Data (Size) iabc1 (12003)

Wavelet db 4

Sampling Period 0.00125

Scale Settings: Manual Mode

Scales : MATLAB Vector [11.4285]

Colormap pink

Nb. Colors 128

Brightness

X = +4024.8

Y = +32.863

Fig 11: Double line to earth fault (ABG) at 50km

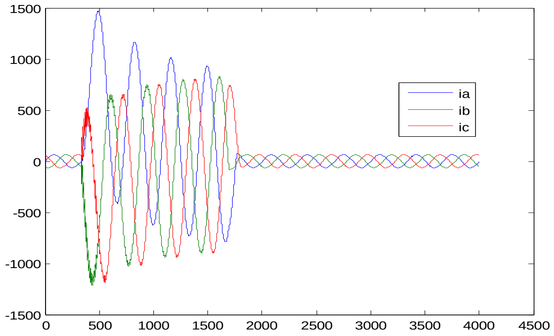
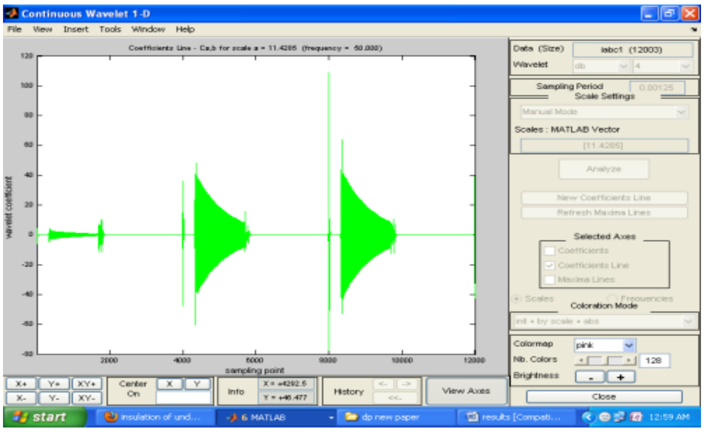


Fig 12: phase current for LLLG (ABCG)fault at 50 km



Data (Size) iabc1 (12003)

Wavelet db 4

Sampling Period 0.00125

Scale Settings: Manual Mode

Scales : MATLAB Vector [11.4285]

Colormap pink

Nb. Colors 128

Brightness

X = +4292.5

Y = +46.477

Fig 13: Triple line to earth fault (ABCG) at 50km by wavelet transforms

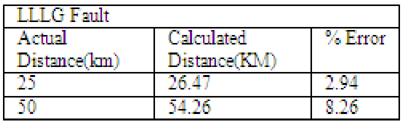
Table-1

LG Fault		
Actual Distance(km)	Calculated Distance(km)	% Error
25	24.81	0.38
50	50.12	-0.24

Table-2

LLG Fault		
Actual Distance(km)	Calculated Distance(km)	% Error
25	24.37	1.26
50	54.26	8.52

Table-3



LLLG Fault		
Actual Distance(km)	Calculated Distance(KM)	% Error
25	26.47	2.94
50	54.26	8.26

IV. Conclusions

Detection and location of faults are very important in the power system as they are the basic of protection of the power system. If detection and location of faults are not accurate the protective devices can not trip properly and required operation cannot be done, which may leads to damage of the large equipments. In this paper 11kv 50km long under ground cable was modeled using Mat lab simulink and simulation was carried at different fault points of 25km and 50 km with the fault resistance of 1Ω and continuous wavelet transform technique is applied to extract the transient current. The results are obtained with the sampling rate of 8000 Hz with a wavelet transform of Daubechies Db4.For the sampling period of 0.00125,For scale a of 11.4285 the output waveform will have a frequency of 50Hz. Fig 2, 4 and 6 shows phase currents of single line to earth fault (AG), double line to earth fault (ABG) and triple line to earth fault (ABCG) at 25 km with fault resistance of 1Ω.Fig 3,5and 7 shows the transient current extracted using the continuous wavelet transform for 25km with a fault resistance of 1Ω. Fig 8, 10 and 12 shows phase currents of single line to earth fault (AG), double line to earth fault (ABG) and triple line to earth fault (ABCG) at 50 km with fault resistance of 1ohm.Fig 9,11and 13 shows the transient current extracted using the continuous wavelet transform for 50 km with a fault resistance of 1Ω. The location of fault can be calculated from the equation (2), in the calculation of fault location 10μs sampling time is used , the difference between the transient signal arrival of first fault signal and arrival of the reflected fault signal is multiplied by 10μs.The velocity of travelling time in the cable as 1.9557×10^5 km/s,the distance to the fault from the calculated pint are tabulated in the Tables-1,Table-2 and Table-3.

Acknowledgements

The authors wish to gratefully acknowledge technical support for this research work by Smt. Dr. M. Suryakalavathi .Dept of E.E.E, J.N.T.U.HHyderbad , and her support for the completion of this work. and gratefully acknowledge to Dr.B.Ravindranath Reddy for his valuable suggestions in completions of this work Mr.G.Prashuram, Angel technology, Hyderabad for the provided support Last but not least the author thank the management of Sri Sivani College of Engineering for their great and continuous support for the completion of the research work

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