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Transient Energy and its Impact on Transmission Line Faults

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Abstract—Transmission and distribution lines are vital links between the generating unit and consumers. They are exposed to atmosphere, hence chances of occurrence of fault in transmission line is very high which has to be immediately taken care of in order to minimize damage caused by it. In this paper Discrete wavelet transform of voltage signals at the two ends of transmission lines have been analyzed. The transient energy of the detail information of level five is calculated for different fault conditions. It is observed that the variation of transient energy of healthy and faulted line can give important information which can be very useful in classifying and locating the fault.

Keywords—Wavelet, Discrete wavelet transform, Multi resolution analysis, Transient energy

I. INTRODUCTION

TRANSMISSION lines constitute a major part of the power system. Transmission and distribution lines are vital links between the generating unit and consumers to achieve the ontinuity of electric supply. To economically transfer large locks of power between systems and from remote generating ites, High Voltage (HV) and Extra High Voltage (EHV) verhead transmission systems are being used. Transmission nes also form a link in interconnected system operation for bi-irectional flow of power. Transmission lines run over undreds of kilometers to supply electrical power to the onsumers. They are exposed to atmosphere, hence chances of ccurrence of faults in transmission line is very high, which has ɔ be immediately taken care of in order to minimize damage aused by it. It will also facilitate quicker repair, improve ystem availability and performance, reduce operating cost and ave time and effort of maintenance crew searching in ometimes in harsh environmental conditions. It has always een an interest for engineers to detect and locate the faults in ɿay lead to blackouts. Various fault detection and location ɿethods have been proposed for this purpose; which can be ategorized as below [1]: the power system as early as possible. 'ast clearing and restoration is very essential as it not only rovides reliability but sometimes also stops propagation of disturbances which

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- Technique based on fundamental frequency currents and voltages, mainly on impedance measurement.
- Technique based on travelling wave phenomenon.
- Technique based on high frequency components of currents and voltages generated by faults.
- Knowledge based approaches.

Most conventional and popular method of fault detection is the technique based on measurement of fundamental frequency currents and voltages or impedance measurement. It may apply single ended measurement, double ended measurement or multi ended measurement. Method using single ended measurement is most popular and economical as it doesn't require any communication link. Travelling wave methods consider the voltage and current waves, travelling at the speed of light from the fault towards the line terminals. These methods are considered as very accurate, however, also as complex and costly for application. Techniques based on high frequency components of currents and voltages generated by faults mainly comprise wavelet based protection system [2]-[6]. Most of the proposed schemes employ multilevel wavelet decomposition, which requires multilevel filtering followed by complex computation. Wavelet transform in conjunction with AI/Fuzzy/expert system based technique have the advantage of fast response and increased accuracy as compared to conventional techniques [7]-[9]. Recently, a lot of research efforts have been focused on fault location techniques both in transmission and distribution network using knowledge based (artificial intelligence) methods, such as artificial neural networks, fuzzy set theory and expert systems.Wavelet transform is a new signal processing technique developed from Fourier transform. There are many applications of wavelet transform in power system including high impedance fault detection, identification of power system disturbance, phase selection etc. [5]. Solanki and Song have proposed an algorithm which is principally based on the detection of fault generated transient signal. Various wavelet features of signal of all three phases are used to identify fault type and location [10]. Some other works are based on synchronized output of three phase currents at the two ends of the transmission line [11]. Bior-2.2 mother wavelet is used for analyzing faulted current signals. Sum of detail coefficient are calculated and compared with a threshold value to detect and classify the faults. To locate the fault artificial neural network has been employed. Fan et al. [5] depicted that transient characteristic of voltage and current can be utilized to obtain the transient energy of the fault, which is employed to identify the fault position. Bhowmik et al. [6] have used Discrete wavelet transform (DWT) very effectively for parameterization and characterization of the fault signal. A back propagation neural network classifier is then used for identification of the fault type and location. Valsan and Swarup [12] have presented a high speed computationally efficient scheme of protection of transmission line. Wavelet transform is used for extracting information from fault transient and only the first level high frequency details of the voltages and currents are used. Faults signal from both ends are compared using protection logic and external and internal faults are discriminated. Fault classification is achieved using local terminal current information. An estimate of the location of the faults is obtained utilizing single faulted phase current information from both terminals. Kale et al. [9] have proposed a method which uses combination of wavelet transform and neural network. Artificial neural network can classify non-linear relationship between measured signals by identifying different patterns of the associated signals. The proposed algorithm consists of time frequency analysis of fault generated transients using wavelet transform followed by pattern recognition using artificial neural network to identify the location and type of fault. Nan and Kezunovic [13] have proposed a solution based on wavelet transform and self-organized neural network. Voltage and current signals are decomposed using MRA. Pattern formed based on high frequency signal is taken as input to the neural network. Zhang et al. [14] have developed a transient positional protection scheme for transmission line which is developed using complex wavelet analysis. The transients developed during disturbance in transmission lines carry important information regarding the type and location of fault. The wavelet analysis provides a kind of mathematical microscope to capture the deterministic features from the fault signals. Wavelet decomposes a signal into so called dilation and translational parameters [15]-[24]. These parameters represent the information of different frequency components contained in the fault signal. Different features of these frequency components are extracted and can help in classifying and detecting different types of fault. A lot of research work is being done in this field as it is said to be ultra fast method for diagnosing a fault in the transmission system. Due to this feature it finds a promising tool for wide area measurement and protection system [23].

II. Wavelet Transfofm

A wavelet is a waveform of effectively limited duration that has an average value of zero. Wavelet analysis is the breaking up of a signal into shifted and scaled version of the original wavelet or mother wavelet. Several families of wavelets that have proven to be especially useful are [8]:Haar, Daubechies, Biorthogonal, Coiflets, Symlets, Morlet, Mexican Hat, and Meyer. A continuous wavelet transform (CWT) is defined as the sum over all time of the signal multiplied by scaled/shifted versions of wavelet function. Scaling a wavelet simply means stretching or compressing it. The smaller the scale factor, the more compressed is the wavelet. Calculating wavelet coefficients at every possible scale generates an awful amount of data and involves a lot of time for analysis. Instead we can choose scales and position based on powers of two- so called dyadic scales and positions. This is known as discrete wavelet transform which is a fast algorithm yielding a fast wavelet transform. The wavelet transform can be explained with help of two fundamental equations [5]:

Scaling equation:

$$\Phi(t) = \sqrt{2}\sum_{n=-\infty}^{+\infty} h(n)\Phi(2t-n) \tag{1}$$

Wavelet equation:

$$\Psi(t) = \sum_{n=-\infty}^{+\infty} g(n)\Phi(2t-n) \tag{2}$$

Where h (n) is a low band filter and g (n) is high band filter. Φ(t) and ψ(t) are scaling function and wavelet function respectively. Discrete signal can be decomposed to obtain information in different scales by discrete wavelet transform. With the given coefficient, if the sampling data is $\{C_{j+1,k}\}$ then the decomposition equation is:

$$C_{j,k} = \sum_l h_{l-2k}\, C_{j+1,l} \tag{3}$$

$$D_{j,k} = \sum_l g_{l-2k}\, C_{j+1,l} \tag{4}$$

Where $0 \le k \le N-1$, $k \in Z$; $C_{j,k}$ is the kth calculation value on scale j of low band frequency; $D_{j,k}$ is the kth calculation value on scale j of high band frequency. In wavelet analysis we often speak about these quantities as approximation and details. Approximations are the high scale, low frequency components of the signal and details are the low scale, high frequency component. Fig. 1 shows the multilevel decomposition of signal C(j+1). In the first level decomposition it is decomposed into approximation C(1,K) which is a low frequency component and detail D(1,k) which is high frequency component. In second level decomposition C(1,k) is decomposed into detail D(2,k) and approximation C(2,k). In this way multilevel decomposition of a signal is achieved.The important elements in analyzing transient signal using wavelet transform are to select mother wavelet and to decide the number of multiple decomposition steps. As for mother wavelets, Harr, Daubechies, Biorthogonal, Coiflets and Symlets may be listed, where forms and properties are different depending on their types. Optimum mother wavelet should be selected comparing the abilities of removing harmonics as well as extracting characteristics (from fault signals).

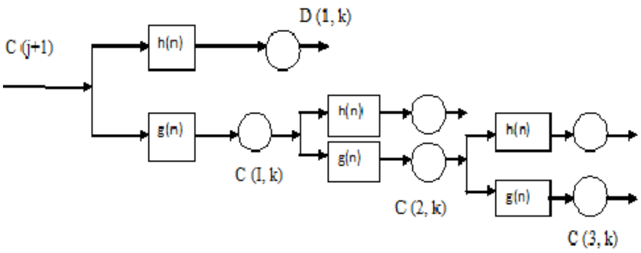

Fig. 1 Multiple level decomposition of the signal using DWT

The number of decomposition steps is influenced from the sampling frequency of the original signals. In the first decomposition step, it is decomposed into D1 component of high frequency band and A1 component of low frequency band. The frequency band of D1 component is (f_s/2-f_s/4) Hz and A1 component is (f_s/4-0). In the second decomposition step A1 component extracted from the first decomposition step is again decomposed. Thus, D2 component of high frequency band and A2 component of low frequency band is achieved. The frequency band of D2 component is (f_s/4-f_s/8) Hz and the frequency band of A2 component is (f_s/8-0) Hz. As the signal of the desired component can be extracted via repetitious decomposition, number of decomposition steps should be decided by comparing the scale of sampling frequency with that of the frequency component of the desired signal.

III. Proposed Method

A 220 kV power system is simulated using MATLAB® /Simulink, SimPowerSystem toolbox, and wavelet toolbox for faults with different locations on the line. The single-line diagram of the system under study is shown in Fig. 2.

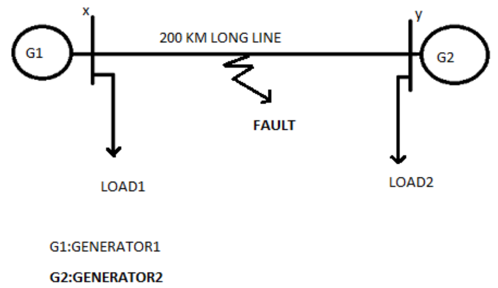

Fig. 2 Single line diagram of transmission line

Short circuit capacity of the equivalent thevenin sources on wo sides of the line is considered to be 1.25 GVA and X/R is 0. The transmission line is 200Km long and is simulated sing the distributed parameter model. Load L1 is 20KW and akes total 900 positive VAR and load L2 is 125KW and it also akes total 900 positive VAR. The line voltage signals are used s the input signals of the wavelet analysis. Signals from both e ends of the transmission system are being analyzed. The nput signals are sampled at a frequency of 320 KHz which ives 6400 samples per cycle. Daubechies 'db5' wavelet is mployed since it has been demonstrated to perform well. The ault transients of the different cases are analyzed through iscrete wavelet transform at the level 5. Level 5 contains frequency ranging from 10Khz-5KHz. Both approximations and details information related to fault voltages are extracted from the original signals with help of multi-resolution analysis. When a fault occursin the power system, it can be seen that variations within the decomposition coefficients of the voltage signal contain useful fault signature. All the ground faults are studied with change in location of fault position. Discrete wavelet transform detailed coefficient at level 1 to level 5 was studied. Some of the results are shown below.

IV. Rersuls and Discussions

The fault signals for different earth faults were analyzed. The fault appeared on the second cycle during the simulation of the transmission line model. As stated earlier, in using multi-resolution analysis the decomposition of fault signals at the two ends was done. In the first step the signal is decomposed into D1 component of high frequency band and A1 component of low frequency band. Decomposition was done up to fifth level and D5 detail information was further analyzed. The fifth level detail D5 contains harmonics ranging from 5 KHz to 10 KHz.The fault signals are discretised for analysis so they can be said to be discrete time signal [15]. The total energy of discrete time signal can be represented by:

$$\mathbf{E} = \sum_{n=-\infty}^{\infty} |x(n)|^2 \qquad (5)$$

For calculating energy of a signal for a particular duration, the limit or data numbers will change accordingly. A program was developed in MATLAB to find the energy in the first three cycles individually. The actual values can be obtained by multiplying the graph value with 6400.

A. *Single Line to Ground (L-G) Faults:*

Fig. 3 shows waveforms of the three phase voltages at terminal X when a single line to ground fault occurs in phase A, 10 km from terminal X. Fig. 4 shows the three phase voltage waveform at terminal Y at the same instant with same conditions. Both the figures clearly show the abrupt change in waveform VaX and VaY as ground fault occurred in phase A. Fault signal VaX and VaY have been analyzed using discrete wavelet transform which are depicted in Fig. 5 and Fig. 6. Detail information from level one to level five has been shown in both the figures. It clearly reflects the instant of occurrence of fault. Fig. 7 and Fig. 8 show the signal D5 of the voltage signals VaX and VaY respectively. In the first cycle all the lines are faultless and hence the transient energy varies in a limited band as shown in Fig. 9. The figure shows the transient energies of all the three phases while location of fault is changing. The data is for single line to ground fault in phase A. It has been observed that for all types of ground faults the data of transient energy just before the occurrence of fault varies in a band of 1% of the average transient value. For other ground faults also transient energy changes in this limited band. Same type of data was observed for other types of faults as well as for data at terminal Y.

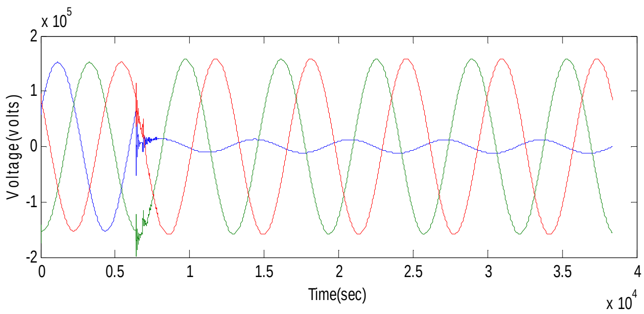

Fig. 3 Three phase voltage at terminal X

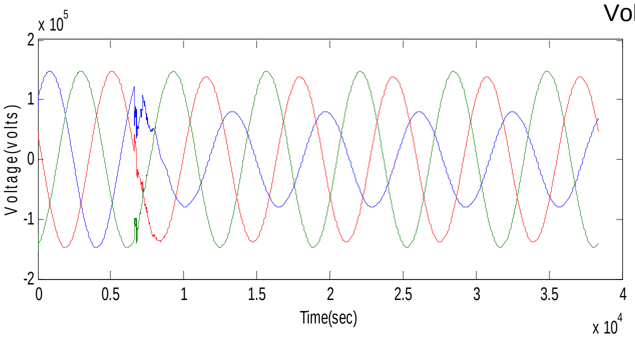

Fig. 4 Three phase voltage at terminal Y

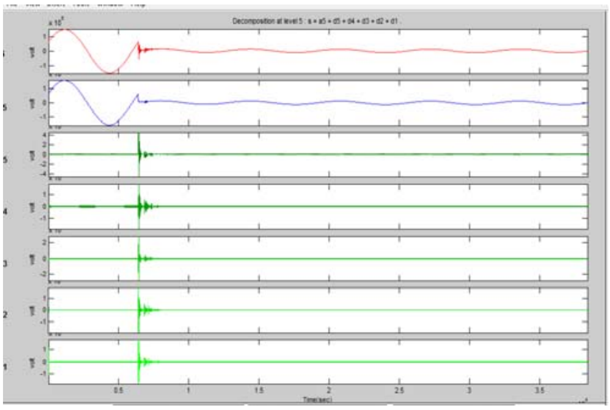

Fig. 5 DWT of the fault signal VaX

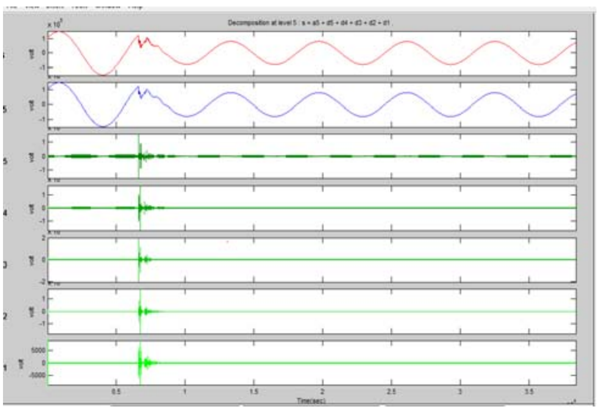

Fig. 6 DWT of the fault signal VaY

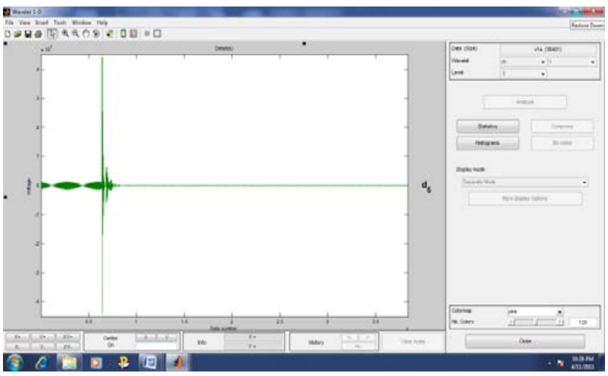

Fig. 7 Detail D5 of voltage Signal VaX

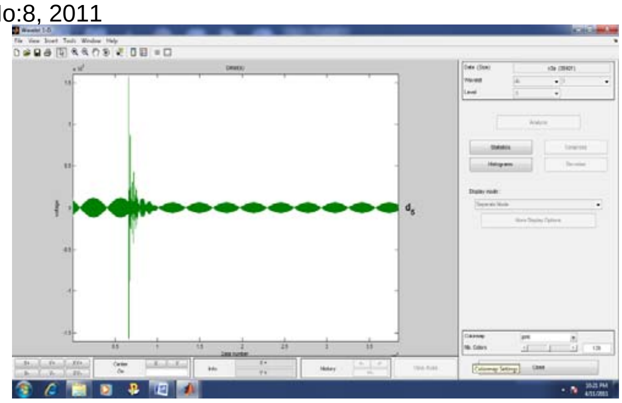

Fig. 8 Detail D5 of voltage Signal VaY

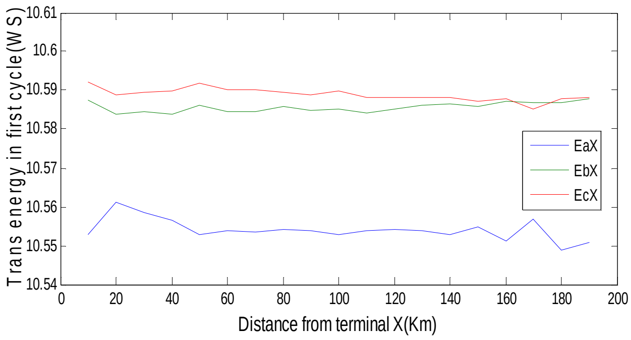

Fig. 9 Transient energy at in the first cycle (before the occurrence of fault)

Fig. 10 and Fig. 11 depict the status of transient energy in the second cycle i.e. the cycle when the fault occured. In both cases it can be clearly observed the transient energies of the faulted line has increased and is greater than the healthy line. The variation in transient energy of the faulted line is between value 20 and 51. Whereas the same for healthy line is between 14 and 43. The variation in transient energy is very much nonlinear with location of fault. Fig.12 shows the post fault situation of the transient energy. It can be seen that the post fault the transient energy catches the pre-fault value for the healthy line, but for faulted line it is different and depends on location of the fault. It can be clearly observed that for healthy lines transient energies are almost overlapping which can be also observed in Fig. 13.

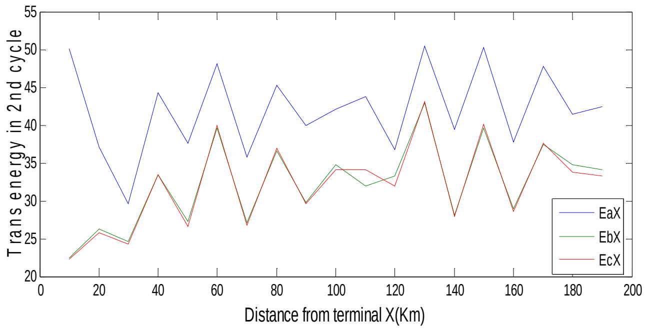

Fig. 10 Transient energy at X in the second cycle(when single LG fault occurs)

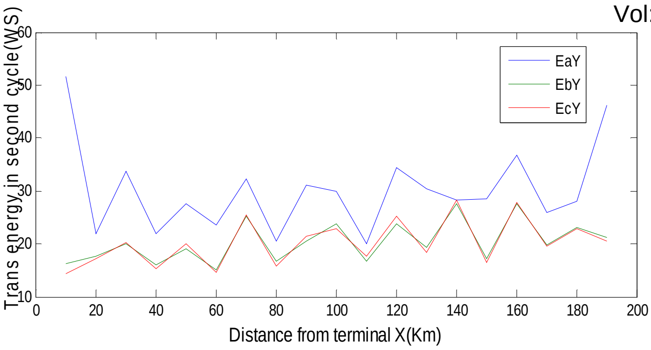

Fig. 11 Transient energy at Y in the second cycle (when single LG fault occurs)

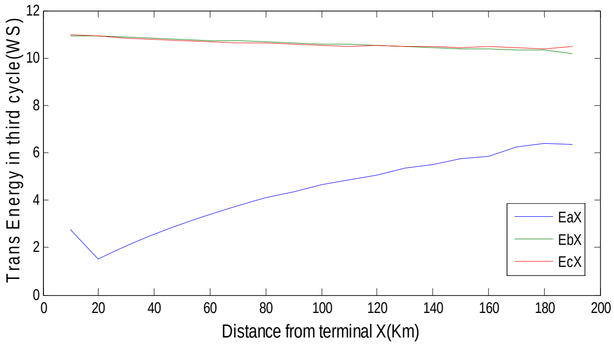

Fig. 12 Transient energy at X in the third cycle(when single LG fault occurs)

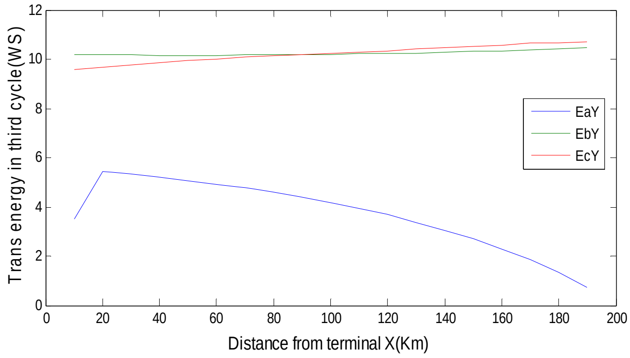

Fig. 13 Transient energy at Y in the third cycle(when single LG fault occurs)

B. Double Line to Ground (LLG) Faults:

Transient energy during double line to ground fault with different locations of the fault is shown in Fig. 14 and Fig. 15. Phase A and B are the faulted phases. It is clear that the transient energy shoots more prominently in LLG faults compared to LG fault and transient energy of both the faulted lines almost overlap each other and it is greater than the transient energy of the healthy line. Post fault scene can be viewed in Fig. 16 and Fig. 17 for values from terminal X and Y. Energies of the faulted lines are smaller than the pre-fault values.

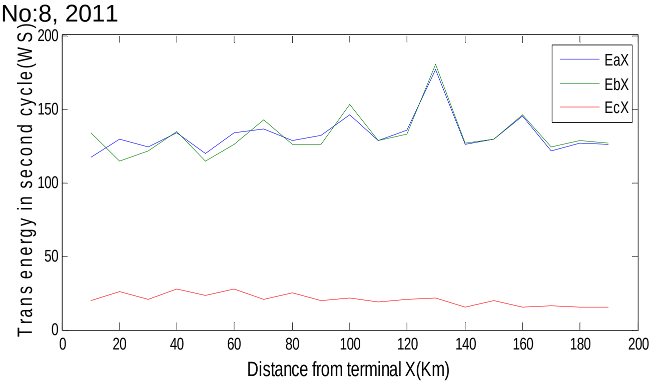

Fig. 14 Transient energy at X in the second cycle(when LLG fault occurs)

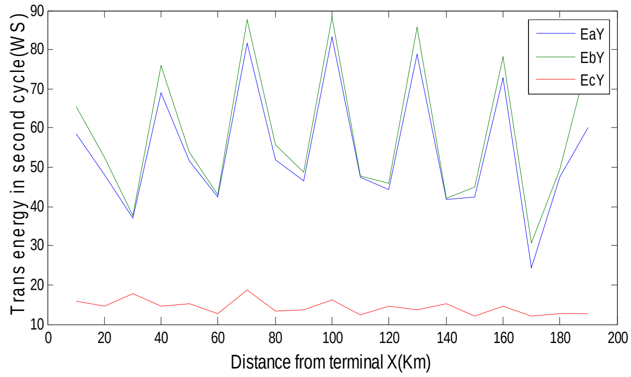

Fig. 15 Transient energy at Y in the second cycle(when LLG fault occurs)

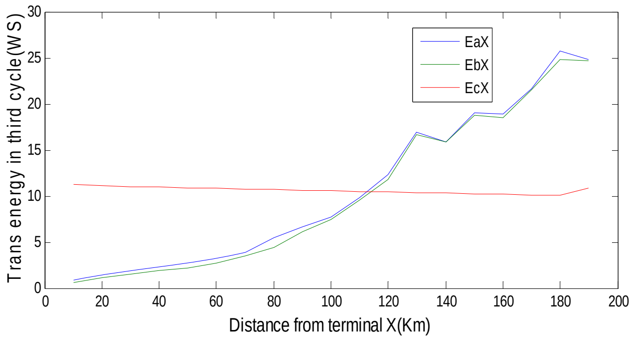

Fig. 16 Transient energy at X in the third cycle(when LLG fault occurs)

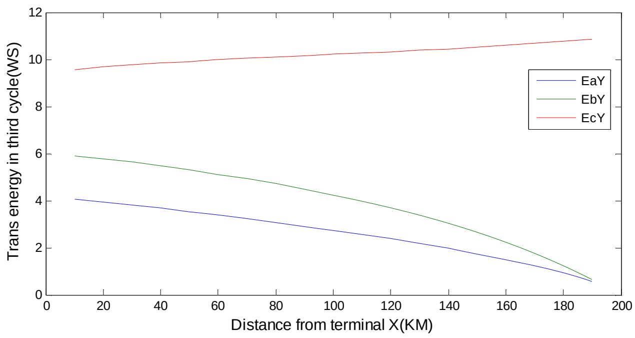

Fig. 17 Transient energy at Y in the third cycle (when LLG fault occurs)

C. Three-pase to Ground (LLLG) Faults:

The data was analyzed for triple line to ground fault and corresponding results are shown in Figs. 18-21. Transient energy in the faulted cycle increases for all the three phases, but are different due to different inception angles at different lines. Post fault results show that the values decrease and are less than pre-fault values as was the case with other ground faults.

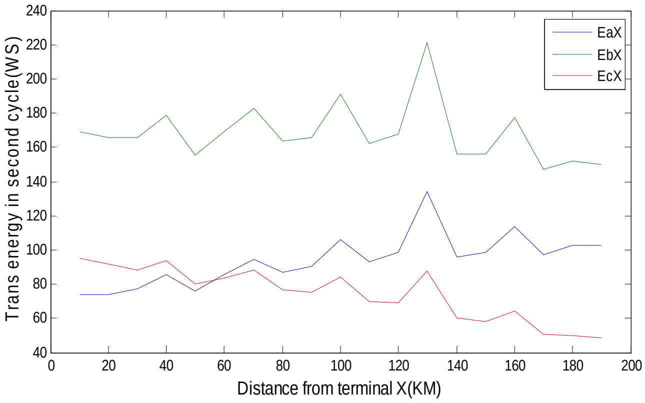

Fig. 18 Transient energy at X in the second cycle (when LLLG fault occurs)

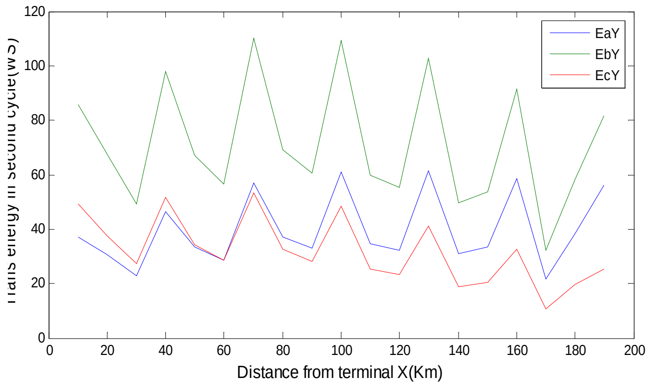

Fig. 19 Transient energy at Y in the second cycle(when LLLG fault occured)

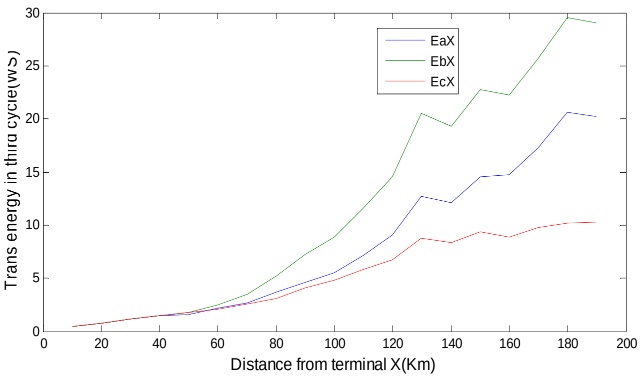

Fig. 20 Transient energy at X in the third cycle (when LLLG fault occurred)

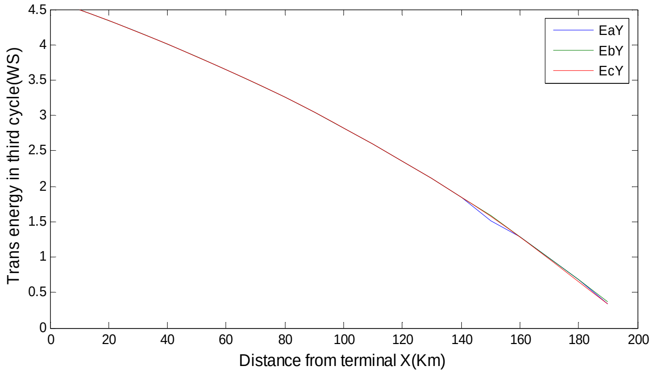

Fig. 21 Transient energy at Y in the third cycle (when LLLG fault occurred)

II. CONCLUSIONS

The occurance of faults in the transmission line produces transients. The transient developed contains harmonics and also possesses energy which die out as the transients disappear. The nature of transients developed after the initiation of fault depends on fault resistance, fault inception angle, line parameters, type of fault and its location. The pattern of transient energy also changes with change of pattern in transient voltages at the two ends of the transmission line and is observed to be different before and after the fault. It increases during the fault and more severe the fault is, the more is the value of transient energy. It can also be stated that the relation between the location, the type of fault etc. is a nonlinear function of the transient energy developed during the fault. Artificial intelligence methods as artificial neural network or fuzzy logic system can be used to classify and locate fault with the help of these transient energy patterns obtained in different cases.

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