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A Ground Fault Location Method Using High-Frequency Transient voltages on Transmission System

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Abstract— **Electric power systems have grown rapidly over the past fifty years. This has resulted in a large increase of the number of lines in operation and their total length. These lines experiences faults which are caused by storms, lightning, snow, freezing rain, insulation breakdown and, short circuits caused by birds and other external objects. In most cases, electrical faults manifest in mechanical damage, which must be repaired before returning the line to service. The restoration can be expedited if the location of the fault is either known or can be estimated with reasonable accuracy. As to overcome these problems this paper presents a new fault location method using high-frequency transient voltages generated by ground faults on transmission system. The method is based on the measurement from one end of the transmission line. The fault location is determined solely from the arrival time of initial waves of modal voltages at the measuring bus. The method does not need to exploit the reflected waves. The method is tested quantitatively using the Matlab 7.5 / Simulink, M-scripting for typical ground faults on a model of transmission line. The statistical results are given to demonstrate the performance of the proposed method.**

Index Terms— **Clarke Transformation, Fault Location, Simulink.**

I. INTRODUCTION

The fault analysis of a power system is required in order to provide information for the selection of switchgear, setting of relays and stability of system operation. A power system is not static but changes during operation (switching on or off of generators and transmission lines) and during planning (addition of generators and transmission lines).Faults usually occur in a power system due to either insulation failure, flashover, physical damage or human error. These faults, may either be three phase in nature involving all three phases in a symmetrical manner, or may be asymmetrical where usually only one or two phases may be involved. Faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases. Balanced three phase faults may be analyzed using an equivalent single phase circuit. With asymmetrical three phase faults, the use of symmetrical components help to reduce the complexity of the calculations as transmission lines and components are by and large symmetrical, although the fault may be asymmetrical. Fault analysis is usually carried out in per-unit quantities (similar to percentage quantities) as they give solutions which are somewhat consistent over different voltage and power ratings, and operate on values of the order of unity. Different types of faults can occur including phase faults among two or more different conductors or ground faults including one or more conductors to ground types. The dominant type of fault is ground ones. Most of them occur temporarily as a result of a flashover on the insulation due to the environmental factors such as the lightning or humidity. Temporary faults are normally characterized by the existence of non-linear arcs. Almost all known fault location algorithms were developed by assuming a linear fault arc with constant impedance. However, the simulation results showed that the non-linear physical behavior of the fault arc in air may remarkably influence the performance of all impedance measurement-based protection equipment such as distance relays and fault location equipment. This is mainly due to the impedance nonlinearity resulting from the time varying parameters of the arcs during these faults. It is therefore more proper to consider the influence of these situations in order to realize the aimed accurate performance.

A. *Fault Location Estimation Benefits Time and Effort Saving*

After the fault, the related relaying equipment enables the associated circuit breakers to denergize the faulted sections. Once the fault is cleared and the participated faulted phase(s) are declared, the adopted fault locator is enabled to detect the fault position. Then, the maintenance crews can be informed of that location in order to fix the resultant damage. Later, the line can be reenergized again after finishing the maintenance task. Since transmission line networks spread for some hundreds of kilometers in different environmental and geographical circumstances, locating these faults based on the human experience and the available information about the status of all breakers in the faulted area is not efficient and time consuming. These efforts can therefore effectively help to sectionalize the fault (declare the faulted line section) rather than to locate precisely the fault position. Thus the importance of employing dedicated fault location schemes is obvious.

B. *Assisting Future Maintenance Plans*

It is quite right that temporary faults (the most dominant fault on overhead lines) are self-cleared and hence the system continuity is not permanently affected. However, analyzing the location of these faults can help to pinpoint the wake spots on the overall transmission nets effectively. This hopefully

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assists the future plans of maintenance schedules and consequently leads to avoid further problems in the future. These strategies of preventive maintenance enable to avoid those large problems such as blackouts and help to increase the efficiency of the overall power system

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C. *Economic Factor*

All the mentioned benefits can be reviewed from the economical perspective. There is no doubt that time and effort saving, increasing the power availability and avoiding future accidents can be directly interpreted as a cost reduction or a profit increasing. This is an essential concept for competitive marketing. Thus the importance of proper fault location schemes for power system utilities is obvious.

D. *Classification of Developed Fault Location Methods*

Generally speaking, fault location methods can be classified into two basic groups, travelling wave-based schemes and impedance measurement-based ones as shown in Figure.1 Travelling wave schemes can be used either with injecting a certain travelling wave from the locator position or with analyzing the generated transients due to the fault occurrence.

Impedance measurement schemes are classified whether they depend on the data from one or both line ends. Each category can be then classified according to the considered line model during the derivation method using either simpler (lumped) models or detailed (distributed parameters) ones.

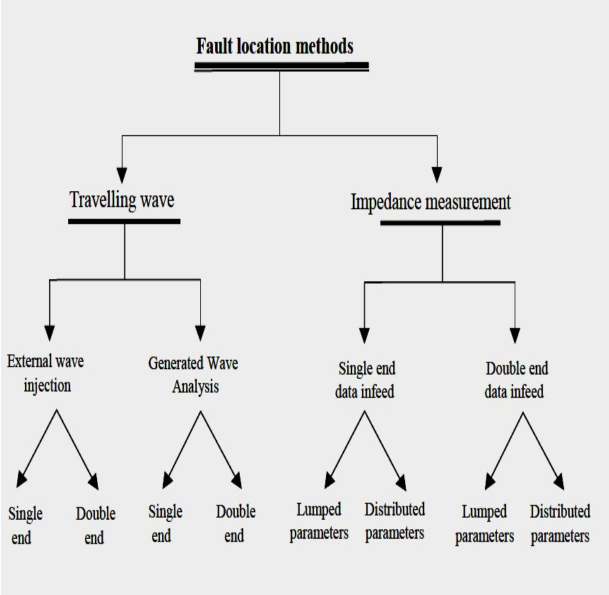

Figure 1: Classification of fault location methods

E. *Wavelet Transform for Identification of Fault Location*

Fault location estimation is very important issue in power system engineering in order to clear faults quickly and restore power supply as soon as possible with minimum interruption. Wavelet transform is one of the efficient tools for analyzing non stationary signals such as transients, and has been widely applied to solve numerous problems in power systems. This paper presents a recent fault location method based on the double terminal methods of travelling wave using CWT which has much better resolution for locating a transient event in time-domain. Matlab simulation results show the new method is a good and powerful tool to estimate the disrupts location on the transmission line when fault occur.

In the past, several methods have been used for estimating fault location with different techniques such as line impedance based numerical method, travelling wave methods and Fourier analysis (Elhaffar and Lehtonen, 2004).

Fourier transform are used to abstract fundamental frequency component but it has been shown that Fourier transform based analysis sometimes are not exactly enough. 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 frequency.

The location of fault using wavelet transform was initially proposed by [**2**]. Recently, several techniques have been employed to determine the fault location in underground cable such as age cable (Tag El Din *et al* 2005); bridge technique (Bascom and Von Dollen, 1994), Murry loop pulse radar (Bascom and Von Dollen, 1994) and traveling wave (Potivejkul *et al* 2000), (Wiggins *et al* 1994), (Choi *et al* 2005) but each technique has different solutions. The ability of wavelets to focus on a short time interval for high frequency components improves the analysis of signals, particularly in the presence of transient components (Robertson *et al* 1996), (Chaari *et al* 1996), (Koglin *et al* 1999).

In Paper [**4**] used the technique that is suitable for estimating locations of shunt faults. The estimates are reasonably accurate even if the fault resistance is substantial and the transmission line is connected to energy sources at both terminals. The technique uses post fault fundamental frequency voltages and currents measured at the line terminals.

In [**6**] composite correlation output is used to recognize the reflection from the fault and distinguish it from other reflections from points behind the fault.

A new technique for single-ended location of resistive earth faults on transmission lines is presented [**5**].the algorithm developed has inherent insensitivity to setting errors in the remote source impedance value. The remote source impedance often varies significantly under operational conditions. The paper shows the theoretical development of the algorithm, together with a detailed consideration of the hardware aspects. Results are presented for a standard 400 kV transmission line application study.

In [**9**] Presented accurate fault location on distribution overhead lines and underground cables. **A** specially designed fault locator unit is used to capture the high frequency voltage transient signal generated by faults on the distribution line/cable.

II. FORMULATION OF THE PROBLEM

Consider a three-phase transmission line with a length of L connected between buses A and B as shown in Figure. 2. The measuring system is located at bus A. If a ground fault F occurs at a distance d from the measuring bus A, then an abrupt wave will appear at the fault point. This wave will travel in both directions and will continue to bounce back and forth between the fault point and the two terminal buses until the post fault steady state is reached. In three phase transmission lines, the travelling waves are mutually coupled and therefore a single travelling wave velocity does not exist.

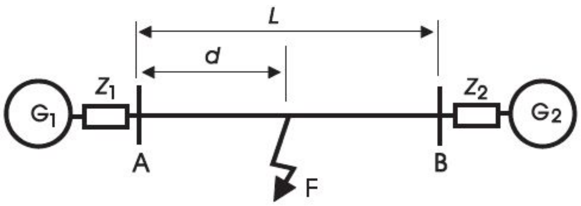

Figure 2: Transmission line consider for analysis

A. *Clarke Transformation*

Clark transformation is a well-known de-coupling method for three phase line parameters. The stationary two phase variables of the Clark transform are denoted as “alpha” and “beta”. A third one is denoted as zero-sequence component. The phase domain voltages (V_A, V_B, V_C) are converted into their modal voltages by means of the commonly known Clarke Transformation. This transformation is generally used for transposed lines and is given by

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{bmatrix}\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix}$$

Where V_0 is the voltage of the ground mode, while V_α and V_β are the voltages of aerial mode.

B. *Mathematical Clarke Transform.*

The mathematical transformation called Clarke transform modifies a three phase system to a two-phase orthogonal system

$V_{0}=\frac{1}{3}(V_A+V_B+V_c\ )$

$V_\alpha=\frac{1}{3}\ (2(V_A-2V_B+V_c)$

$V_\beta=\frac{1}{3}\ (0\,V_A+\sqrt{3}V_B-\sqrt{3}V_c)$

These three converted voltages are called modal voltages and are used to find fault location with 50 km created fault as reference value. These values is being converted by matlab model to find ground mode voltage and aerial mode voltage.

III. MEASURING AND REAL SYSTEM

The generated voltages in the transmission system are assumed balanced prior to the fault, so that they consist only of the positive sequence component E_f(pre-fault voltage). This is in fact the Thevenin’s equivalent at the point of the fault prior to the occurrence of the fault.

$Va_0 = 0 – Z_0 *Ia_0$
$Va_1 = E_f – Z_1 *Ia_1$
$Va_2 =0 – Z_2 *Ia_2$

This may be written in matrix form as follows-

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_f \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 \\ Z_1 \\ Z_2 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

These may be expressed in network form as shown in the Figure 3

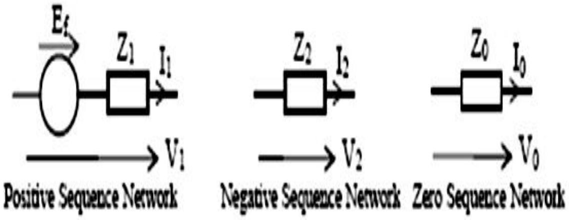

Figure 3: Sequence networks representing three phase fault

A. *True and Estimated Distance*

When a ground fault occurs, both aerial and ground modes of transient voltages appear. The voltage waves of aerial and ground modes travel equal distance from the fault location to the measuring bus A in figure 2, hence

$$d = v_\alpha t_1 = v_o t_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where v_α and v_o are, respectively, the velocity of aerial (α) and ground modes, while t_1 and t_2 are the arrival time of initial waves of aerial and ground modes, respectively. The difference in time-of-arrival (DTOA) between the ground and aerial modes is defined as

$$\Delta t = t_1 - t_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Using (2) and (3), the estimate of fault location $\hat{d}$ can be obtained as follows

$$v_\alpha t_1 = v_0(t_1 + \Delta t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$t_1 = \frac{d}{v_\alpha} = \frac{v_0}{v_\alpha - v_0}\Delta t \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$\hat{d} = \left(\frac{v_0 v_\alpha}{v_\alpha - v_0}\right)\Delta t \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Here the value $\hat{d}$ is called estimate fault location value and t_2-t_1 is the arrival time difference of aerial and ground mode voltages.

B. *Real System*

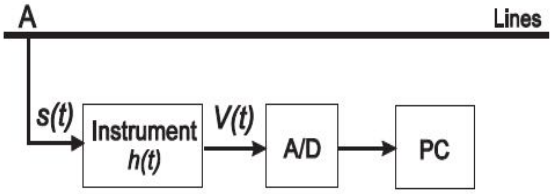

Figure 4: Block diagram of the fault locator measuring system

A simplified block diagram of fault locator measuring system is shown in Figure. 4. The instrument is coupled to the bus A by means of an HV capacitor. The instrument contains a band pass filter and a high gain amplifier which is followed by an A/D converter and a microcomputer (PC) for signal processing [7]. The measured high frequency transient voltage can be expressed as

$$V(t) = h(t) \circ s(t) = \sum h(\xi)\, s(t-\xi) \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Where $h(t)$ is the impulse response of the instrument, $s(t)$ is the received voltage signal, and denotes the linear convolution operation. The measured signal is then digitized by the A/D converter. The recorded signals processing.

IV. MODEL AND SYSTEM PARAMETER

Ground fault location method using high-frequency transient voltages has been presented. The proposed method estimates the fault location solely from the arrival time of initial waves of modal voltages at one end of the transmission line. Ground faults with additive noise were generated at various locations. The statistical results for different fault locations demonstrate that the proposed method can accurately pinpoint the location of faults on a transmission line.

A. Simulation Model

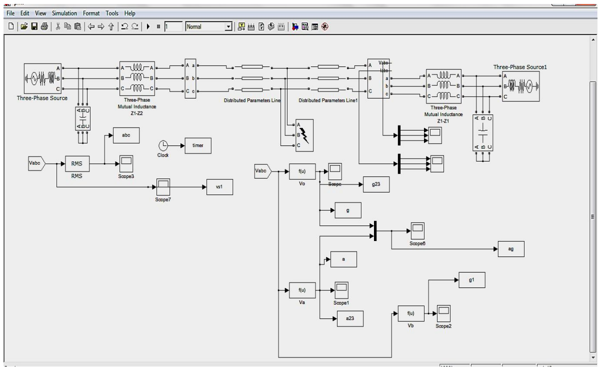

Figure 5: Transmission line model for 25th km

Estimation of distance is possible only after running the above Figure 5 with M-script this is for only 25th km. If supposed to calculate other two distance and comparing with the true distance the same model needs some changes in the variable part to overcome the error in M-script this paper is for one trial.

System Parameters

The transmission line is represented as a distributed parameter model so that the travelling wave effects will be apparent. The transmission line model is assumed to be fully transposed. The chosen tower configuration yields modal propagation velocities of $v_\alpha = 2.92\times10^8$ m/s and $v_o = 2.53\times10^8$ m/s. The length of transmission line is L = 100 km. The impedances of infinite source G1 are $Z1 = Z2 = 0.184+j1.042\Omega$ and $Z0 = 0.193+j1.094\Omega$ while the impedances of G2 are $Z1 = Z2 = 0.138+j0.781\Omega$ and $Z0 = 0.175+j0.989\Omega$ [1] A bus bar capacitance has to be included in the model in order to represent better high-frequency properties of the line. A typical bus bar capacitance of 0.1 µF is assumed at both buses. The fault resistance is 10 Ω for all types of faults. The instrument of fault locator measuring system is modelled by an 8-th order IIR filter with a bandwidth of 100 kHz to 2 MHz and 3 dB attenuation at cut-off frequency. The A/D converter has a sampling time of 150 ns (or 6.7 MHz). The noise is assumed to be Gaussian with the signal-to-noise ratio (SNR) of 10 dB for all simulations.

These parameter have been considered for 50th km but the paper is explains statistical results of standard deviation and average error hence required to consider other two trial of faults such as 50th km and 75th km in single end method of 100km transmission line.

V. RESULTS

In this paper for getting statistical results minimum 3 trial is required the proposed fault trails are 25th, 50th and 75th km. Initially it begins with 25th km model and M script. , Ground faults at 25th km before applying Clark's transformation three phase voltages waveform is shown in figure 6. Other two follow the same procedure but average error values and standard deviation get differs from each other.

In order to implement the travelling wave method in three phase system, the Phase domain voltages (V_A, V_B, *and* V_C) are converted into their modal voltages by means of the commonly known Clarke Transformation.

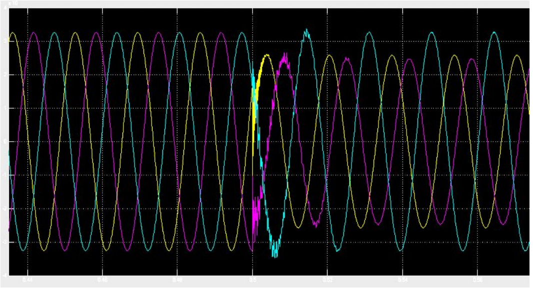

Figure 6: Three phase voltages (V_{abc})

The method often has problems of distinguishing between the waves reflected from the fault and from the remote end of the transmission line it's been overcome by applying modal voltages.

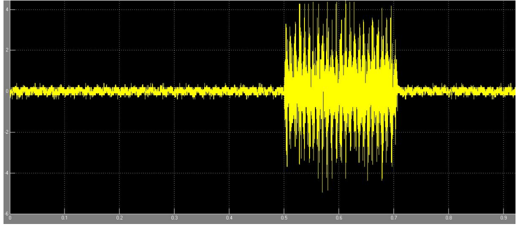

Figure 7: Model voltages

To get only the arrival time of initial arriving waves and for easy analysis of waveform modal voltages is used as shown in above figure 7. After applying Clark transformation aerial mode voltage and ground mode voltages are available from modal voltages shown in figure 8 & 9 respectively.

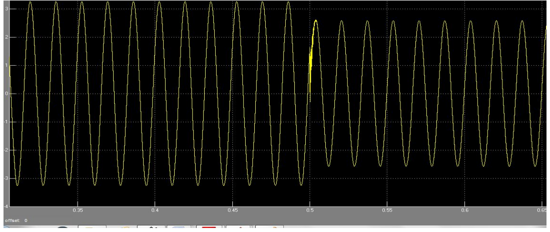

Figure 8: Aerial mode voltage

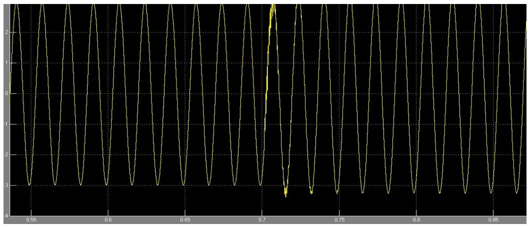

Figure 9: Ground mode voltage

A. M-Script Results

The location accuracy depends not only on the fault location, but also on the sampling rate selected. Table 1 shown the error and its standard deviation (inside the bracket) with respect to the sampling rate for the fault at d = 50 km.

Table 1

Error and standard deviation (in Km) with respect to the sampling rate

Fault Type	Sampling Rate(MHz)				
	6.7	2.2	1.3	1.0	0.67
SLG	0.36(.043)	1.44(1.85)	2.61(3.43)	3.89(4.70)	6.7(8.64)
LLG	0.60(0.49)	1.67(2.05)	3.29(4.17)	4.80(6.07)	7.90(9.1)

The performance of the proposed method has been evaluated quantitatively through a computer simulation. The statistical results for different fault locations demonstrate that the proposed method can accurately pinpoint the location of faults on a transmission line

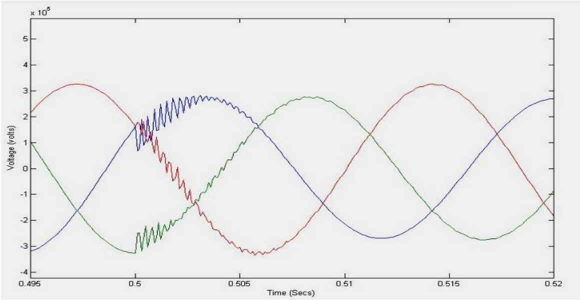

Figure 10: Three phase voltages

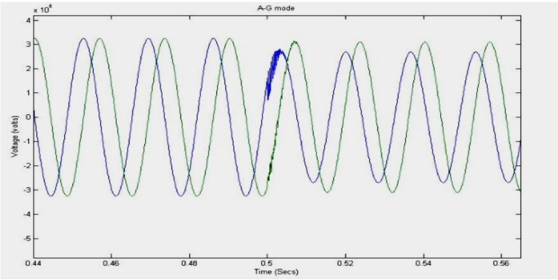

Figure 11: Aerial and ground mode voltages

B. *Statistical Results*

Simulink results shown in figure 12 clearly mentions that true location is linear to expected mean location for LLG faults for three different trials and theoretical graph shown in figure 14 resembles the result that was obtained through simulation.

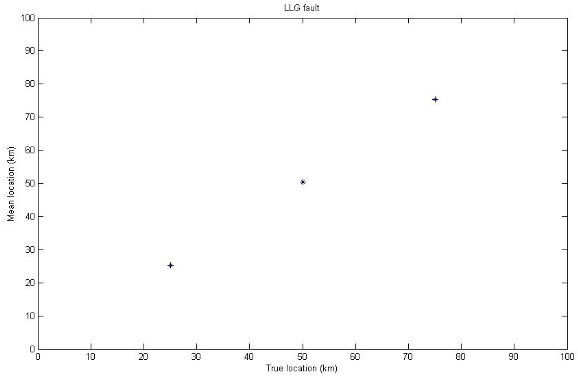

Figure 12: statistical results for LLG faults

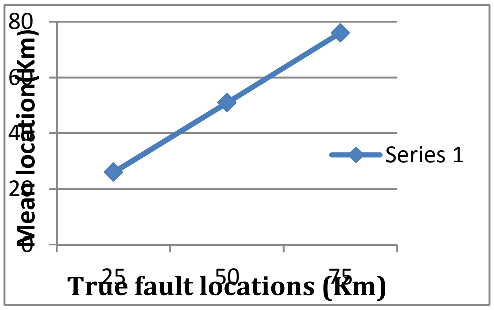

Figure 13: statistical results for SLG faults

Standard Deviation from mean value is 0.3 as shown in figure 14, which implies that using the proposed system fault is detected that happens in 25th Km there might be small deviation of +0.3Km from the actual point.

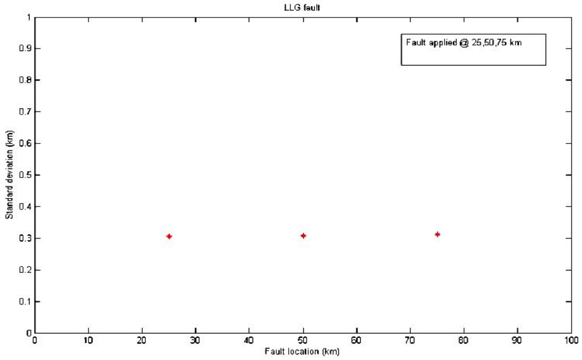

Figure14: standard deviation from mean for LLG faults

1) Average Error

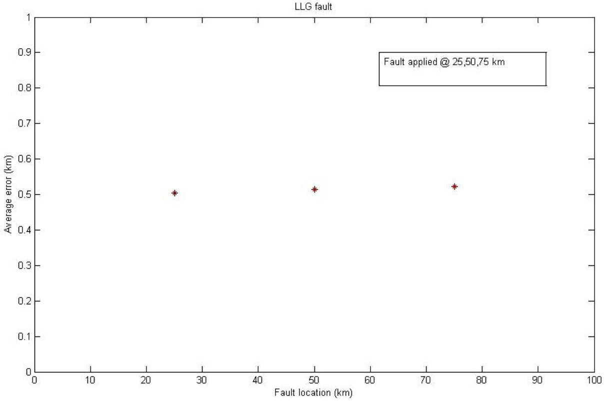

Figure 15: Results for average error

Average error from simulation is obtained nearly of 0.5µm for all three different testing points implies the efficiency of 99.99% All the above results are for LLG faults and there is no much difference between LLG and SLG fault. If proposed system is simulated for SLG faults only fraction of difference will be able to find out.

CONCLUSION

A ground fault location method using high-frequency transient voltages has been presented. The proposed method estimates the fault location solely from the arrival time of initial waves of modal voltages at one end of the transmission line. The method does not need to exploit the reflected waves so that the problem of distinguishing between the travelling waves reflected from the fault and from the remote end of the line can be avoided. The performance of the proposed method has been evaluated quantitatively through a computer simulation. Ground faults with additive noise were generated at various locations. The statistical results for different fault locations demonstrate that the proposed method can accurately pinpoint the location of faults on a transmission line. This is indicated by the low average error and the high correlation between the true and mean locations. Similar to other travelling wave methods, some requirements must be considered when the proposed method will be applied to the in-service transmission system. Since the estimate of fault location uses modal propagation velocities, therefore these velocities must be known and well calibrated beforehand. Another requirement is the fault locator measuring system must have large frequency bandwidth, preferably in the frequency range of 1 to 10 MHz. Both factors above are crucial and greatly affect the accuracy of fault location.

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