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A DWT AND PATTERN RECOGNITION APPROACH FOR FAULT DETECTION AND CLASSIFICATION IN TRANSMISSION NETWORKS

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ABSTRACT

The reliable and efficient operation of high-voltage transmission lines is essential for ensuring the stability and quality of electrical power distribution. To address this concern, this research paper presents an in-depth study on the application of wavelet transform for detecting and classifying faults in high-voltage transmission lines. Fault detection and classification are crucial tasks in the maintenance and operation of power systems to minimize downtime and ensure the safety of personnel and equipment. The wavelet transform has proven to be a powerful tool for analyzing transient signals in electrical systems, making it a valuable technique for fault detection and classification. This paper provides a comprehensive review of wavelet transform theory, its application to fault detection, and classification algorithms. Additionally, it discusses various case studies and practical implementations, highlighting the advantages and limitations of wavelet-based techniques. The results demonstrate the effectiveness of wavelet transform in enhancing the reliability and efficiency of high-voltage transmission line monitoring and maintenance.

Keywords: *High-Voltage Transmission Lines, Wavelet Transform, Faults, Power Systems*

1. INTRODUCTION

Modern power systems are rapidly expanding, with additional generators, transformers, and a wide network. A high level of reliability is essential for system operation. To protect the system from damage caused by abnormal conditions induced by faults, reliable protective devices such as relays and circuit breakers are required. Transmission lines are vital components of the power system because they transport electricity across great distances. As a result, the study of fault analysis on transmission lines is critical. Over current, over voltage, and distance relays are examples of conventional relays used for transmission line protection. Because of the huge power system, traditional fault detection and classification methods are unreliable [1] – [3].

High-voltage transmission lines play a pivotal role in the power grid, ensuring the efficient distribution of electrical energy over long distances. However, these lines are susceptible to various faults and disturbances, such as short circuits, insulation breakdowns, and line faults, which can disrupt power supply, damage equipment, and pose risks to personnel safety. Detecting and classifying these faults promptly is essential for minimizing downtime, reducing repair costs, and maintaining the integrity of the power grid. Digital relays have been created in recent years to address the issues caused by conventional relays. For fault detection and classification, digital relays require a fast and accurate algorithm. As a result, an effective method of fault classification serves as the foundation for developing an efficient and accurate relay algorithm. This thesis provides an effective method based on wavelet transformations for detecting and classifying transmission and distribution line faults. This paper explores the application of wavelet transform, a powerful signal processing tool, for fault detection and classification in high-voltage transmission lines [4]- [7].

Wavelet multi resolution analysis is proven to be the best method for extracting information from transient fault signals in this thesis. Because second and third order harmonics are dominant in the fault signals, they are chosen for analysis (d6 coefficients) and Db4 as mother wavelet. The summation of detail coefficients for the sixth level is retrieved from the current signal using the wavelet MRA approach. The presence of a problem in a specific phase is recognised using the amplitude of detail coefficient summations. For the categorization of transmission line defects, a generalised approach based on wavelets has been validated. The most essential aspect of this approach is that it is not affected by fault location, impedance, or inception angle [8] – [12].

2. WAVELET TRANSFORM THEORY

Wavelet transform is a mathematical technique that decomposes a signal into its constituent wavelets, allowing both time and frequency information to be simultaneously analyzed. This characteristic makes wavelet transform well-suited for analyzing transient signals commonly associated with electrical faults. The paper provides an overview of the fundamental principles of wavelet transform, including the continuous wavelet transform (CWT) and the discrete wavelet transform (DWT). It also discusses the selection of appropriate wavelets and decomposition levels for fault analysis [13] – [14].

The fault current signals are non-stationary in nature. Therefore, conventional Fourier transform and short time Fourier transforms are inadequate to deal with such signals. The Wavelet theory and its applications are rapidly developing fields in applied mathematics and signal analysis. The wavelet transform is a tool that divides up data into different frequency components, and then evaluates each component with a resolution matched to its scale. The wavelet transform is useful in analysing the transient phenomena associated with transmission-line faults and/or switching operations. Wavelet analysis is the breaking up of a signal into shifted and scaled version of the original (or mother) wavelet. Scaling a wavelet means stretching (or compressing) it. Shifting a wavelet simply means delaying its onset [15].

3. FAULT DETECTION AND CLASSIFICATION USING WAVELET TRANSFORM

This section focuses on the application of wavelet transform for fault detection in high-voltage transmission lines. It discusses the reprocessing of electrical signals, decomposition using wavelet transform, and the identification of fault-induced transient features. Various signal processing techniques and algorithms, such as thresholding and feature extraction, are explored for detecting the presence of faults.

Once a fault is detected, the next step is to classify the type of fault accurately. This section delves into the methodologies and algorithms used for fault classification using wavelet transform. Different fault types, such as line faults, short circuits, and insulation breakdowns, are discussed, along with the distinctive features in wavelet-transformed signals that aid in their classification.

3.1 The Discrete Wavelet Transform (Dwt)

The continuous wavelet transform (CWT) has a digitally implementable counterpart known as the DWT, which is analogous to the relationship between the continuous Fourier transform (FT) and the Discrete Fourier Transform (DFT). The Discrete Wavelet Transform (DWT) was introduced to tackle the previous difficulties. Taking samples on the non-uniform grid defined by is the most natural technique to sample the time-scale plane.

$$DWTX(m,n;Y) = \sum_{-\infty}^{+\infty} x(u)\, y_{m,n}(u) \qquad (1)$$

The two sequences {g0 [k]}, {g1 [k]} such that

$$\varphi (t) = g0\,[k]\varphi(2t-k) \qquad (2)$$

$$\psi(t) = g1\,[k]\varphi(2t-k) \qquad (3)$$

In general, for any j Z the relations between Vj and Wj with Wj+1

$$\varphi(2jt) = g0\,[k]\varphi(2j+1\,t-k) \qquad (4)$$

$$\psi(2jt) = g1\ [k]\varphi(2j + 1\ t - k) \quad (5)$$

$$\varphi(\omega) = G0(z)\ \varphi(\omega) \quad (6)$$

$$\psi(\omega) = G1(z)\ \psi\ (\omega) \quad (7)$$

Wavelet turns amplitude versus time signals into scale vs time signals. A wavelet is a waveform with a finite duration and an average value of zero. Multi resolution analysis is used to implement the discrete wavelet transform. A signal can be divided into a smooth approximation and a detail using MRA. The process is repeated until the approximation is further split into an approximation and a detail. The signal is decomposed by consecutive high pass and low pass filtering of the time domain signal. Levels are the sequential steps of decomposition, and the above process is known as sub band coding. Subband information can be used to classify faults.

To lessen the computing strain, the sample frequency should not be too high, but it should be sufficient to collect fault information. More simulations were run using MATLAB/ SIMULINK by randomly changing the point of failure on the gearbox line. The wavelet transform is used to assess the generated current signal in each situation. The sample frequency is set at 12.5 kHz. The Daubechies wavelet Db4 is utilised as the mother wavelet because it performs well in power system fault investigation. The frequency components corresponding to the second and third harmonics are given by the detail coefficients of the fault current signal at the sixth level (d6). On this basis, the summation of the 6th level detail coefficients of the three phase currents Ia, Ib, and Ic is employed for fault identification and classification in the transmission line.

3.2 Fault Detection and Classification Algorithm

Fault signals are generated in transmission lines while taking into account various parameters such as fault inception angles, fault resistance, fault resistance, and ground resistance, using DWT as a feature extraction tool, which has been widely used by researchers for fault detection due to its inherent characteristics to overcome the effects of noise in fault detection and understating information in both time and frequency domain. The following steps and flow chart, displayed in Figure 1, explain the methods employed in this work.

4. CASE STUDIES AND SIMULATION MODEL FOR TRANSMISSION LINE FAULT ANALYSIS

To demonstrate the practicality and effectiveness of wavelet-based fault detection and classification, this section presents case studies and real-world implementations. These examples highlight successful applications of wavelet transform in detecting and classifying faults in high-voltage transmission lines. A 3 phase transmission line rated 400kV and length of line is 300km has been considered for the case study. The circuit diagram of the transmission line fault analysis is shown in figure2. The fault analysis of transmission lines involves transient phenomena. Therefore, the positive, negative and zero sequence parameters of the source as well as transmission lines are necessary. The various line parameters pertaining to source as well as transmission line are shown in table 1. An active load of 500MW and a reactive load of 20MVAR (inductive) are used for the analysis.

Figure 3 depicts the simulation model for the transmission line fed from one end, which is based on MATLAB and SIMULINK. The first block in the simulation model represents a three phase equivalent source with 500MVA and 400KV. The next block (mutual inductance Z1-Z0) depicts the source's positive, negative, and zero sequence impedances. During the simulation, the voltage and current measurement block records all voltages and currents. The two transmission line blocks are based on distributed parameter representation. Any form of fault can occur between the two transmission line blocks (3 phase fault block). This block offers fault inception angle and fault resistance for all fault types. The last block represents a three-phase load made up of resistance and inductance.

The fault may appear at any instant of time, and thus voltage or current ranging from 0 to 360 degrees. The angle at which fault occurs is called fault inception angle and it effects the amplitude of fault current. The fault distance changes then corresponding line impedance changes which is going change the fault current. Fault resistance also affects the fault current. Fault resistance increases fault current decreases. Different types of power system faults are created using simulation model as shown, at different fault distances having different fault inception angles with different fault resistance. The wave forms are shown below figures 4-7.

Based on the sampling rate the signal is divided into 12 decomposition levels. Among different levels only 6th level is consider for analysis because the frequency corresponding to this level is covering 2nd and 3rd harmonics which are dominant in the fault conditions. Based on 6th level detail coefficients, an efficient algorithm proposed.

In a power system, transmission line faults are typically categorised as L-G, L-L-G, L-L, and L-L-L. Let Sa, Sb, and Sc represent the coefficients derived by adding the 6th level wavelet detail coefficients for currents in phases A,B, and C. When the algebraic sum of Sa, Sb, and Sc is zero, the answer can be L-L-L or L-L. To distinguish these two, the sum of any two phases is zero, and the remaining healthy coefficient is very small in the L-L fault. If the algebraic total is not equal to zero, it must be L-G or L-L-G. It is an L-G defect if the absolute values of any two coefficients are equal and substantially smaller than the absolute values of the other coefficients. It is an L-L-G if the absolute value of any two coefficients is not equal to zero and is always substantially greater than the absolute value of the remaining coefficients.

The tabulated results demonstrate the efficacy of the fault classification method utilising db4 wavelet for various fault locations, fault resistances, and FIA, and the algorithm was validated.

From the Tables 1 and 2, the summation coefficients in any two phases are equal and the third healthy phase value is very less compared to two faulty phases.

The summation of detail coefficients of all three phases sum is not equal to zero for L-G and L-L-G, which is used to discriminate L-G, L-L-G from L-L and L-L-L. From tables 5 and 6, Faulty phase summation value is very high compared to healthy phases. Healthy phase summation values are almost equal.

From the tables 3 and 4, the summation of detail coefficients of three phases sum is zero but all three phase summation values are different, in L-L fault two phases have a same value, which is used to discriminate L-L from L-L-L.

From tables 7 and 8, the summation of detail coefficients sum is not equal to zero and all three phases have different summation values (summation coefficients of any two phases is not equal), which is used to discriminate L-G from L-L-G.

5. CONCLUSION

This research paper provides a comprehensive exploration of the application of wavelet transform for fault detection and classification in high-voltage transmission lines. The paper emphasizes the significance of prompt and accurate fault detection in maintaining the reliability and safety of power systems. Wavelet transform offers a robust approach to analyze transient signals and extract essential features for fault detection and classification. The presented case studies and practical implementations underscore the effectiveness of wavelet-based techniques in real-world scenarios. However, it is essential to recognize their limitations and consider them in the context of specific applications. As power systems continue to evolve, wavelet transform remains a valuable tool for enhancing the monitoring and maintenance of high-voltage transmission lines.

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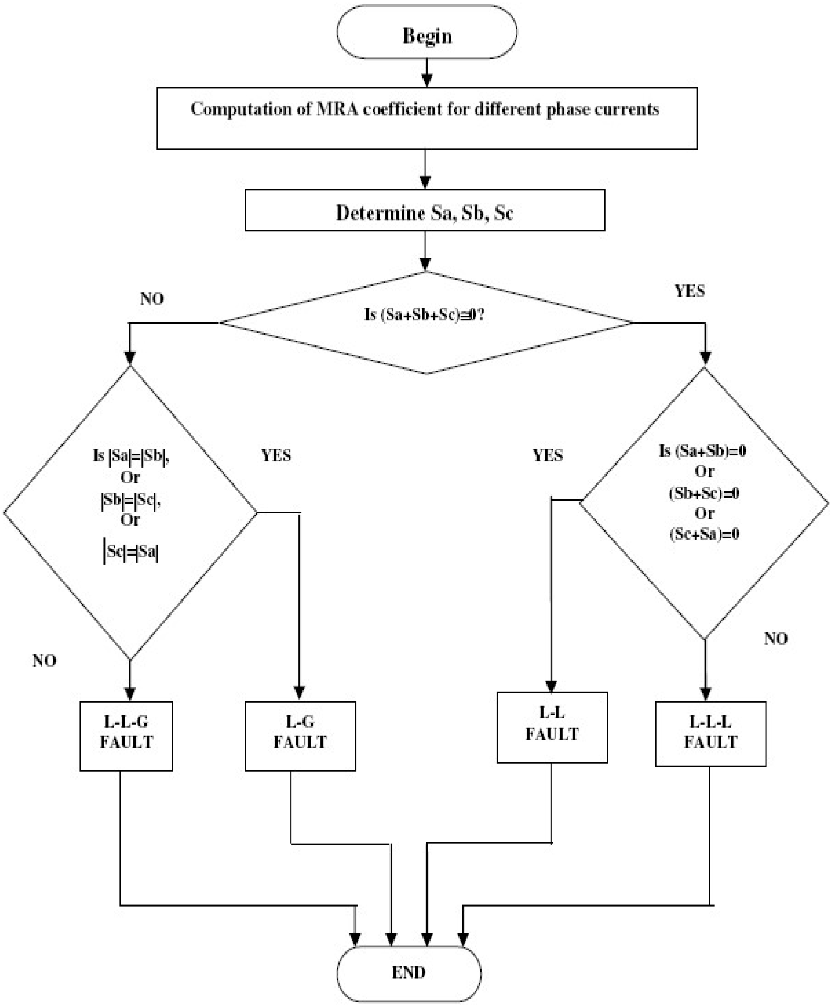

Figure 1. Algorithm for Transmission line fault classification

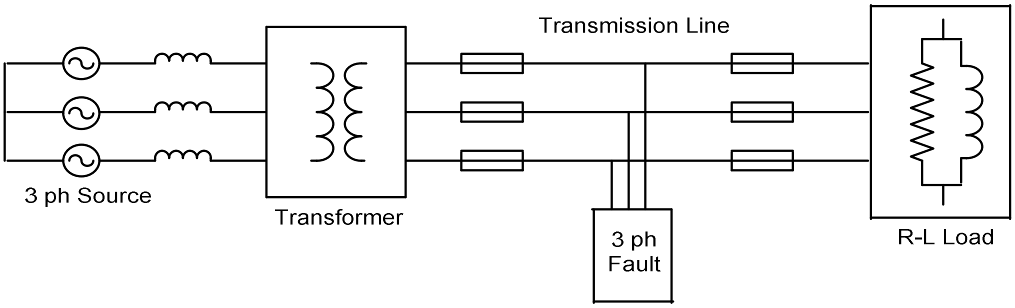

Figure 2. Circuit For Transmission Line Fault Analysis

Table 1. Sequence Parameters Of Source And Line

Source parameters (Impedance Ω)	Positive, negative sequence	0.45+j5
	Zero sequence	0.675+j7.5
Line Inductance (mH/km)	Positive, negative sequence	0.95
	Zero sequence	3.25
Line capacitance (µF/km)	Positive, negative sequence	0.0124
	Zero sequence	0.0084
Line resistance (Ω/km)	Positive, negative sequence	0.0234
	Zero sequence	0.3885

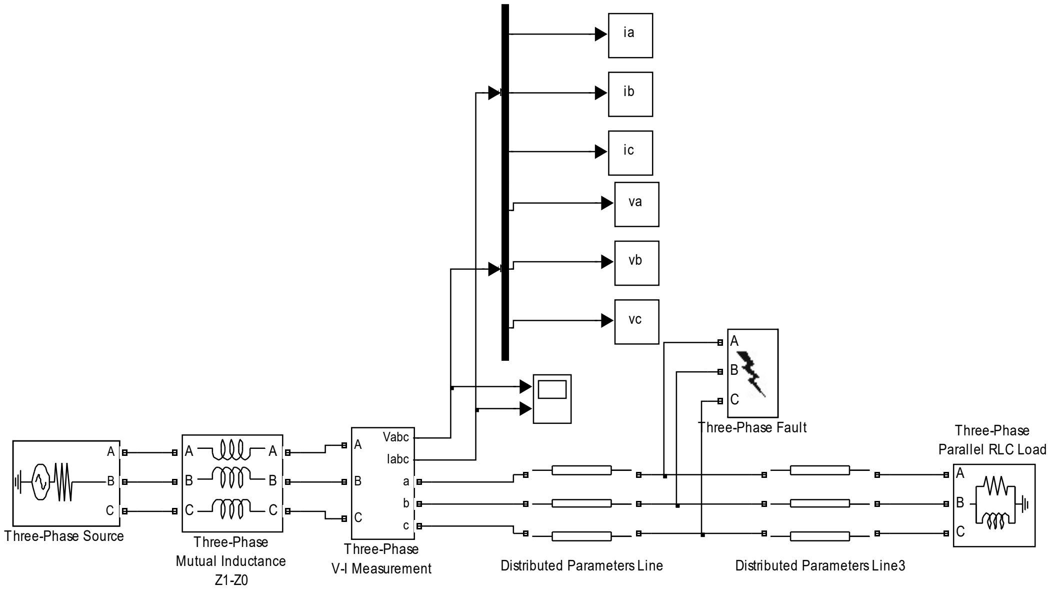

Figure 3. Simulink Model For Transmission Line Fault Analysis

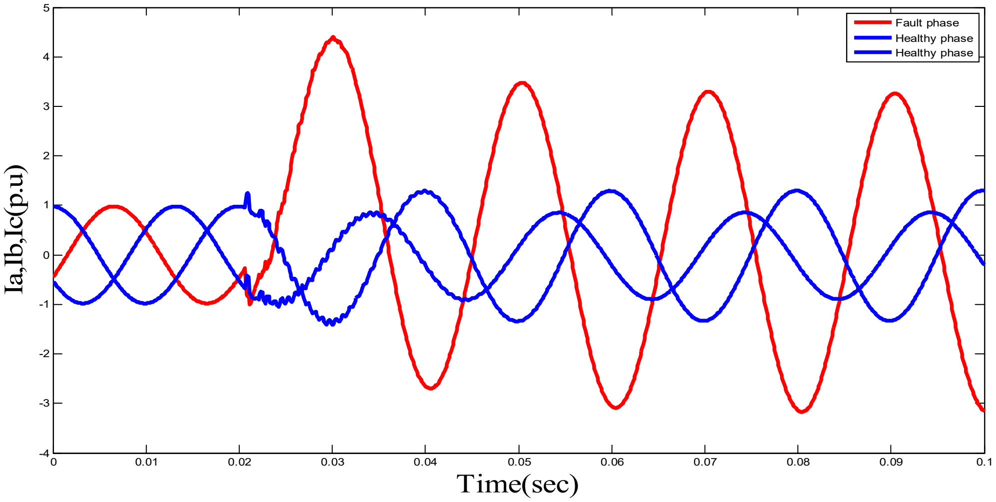

Figure 4. Ia, Ib, Ic For AG Fault At D==200Km, FIA=0, Rf=0.001Ω

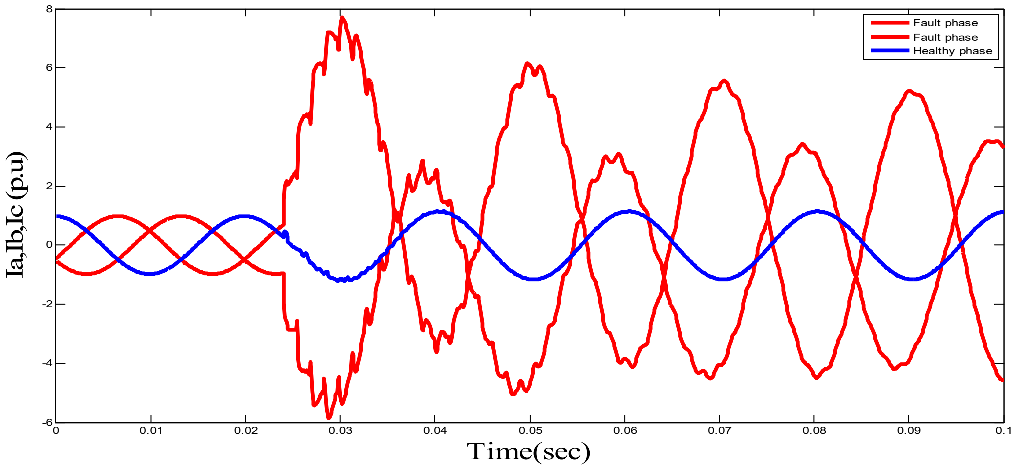

Figure 5. Ia, Ib, Ic For ABG Fault At D==200Km, FIA=60, Rf=1Ω

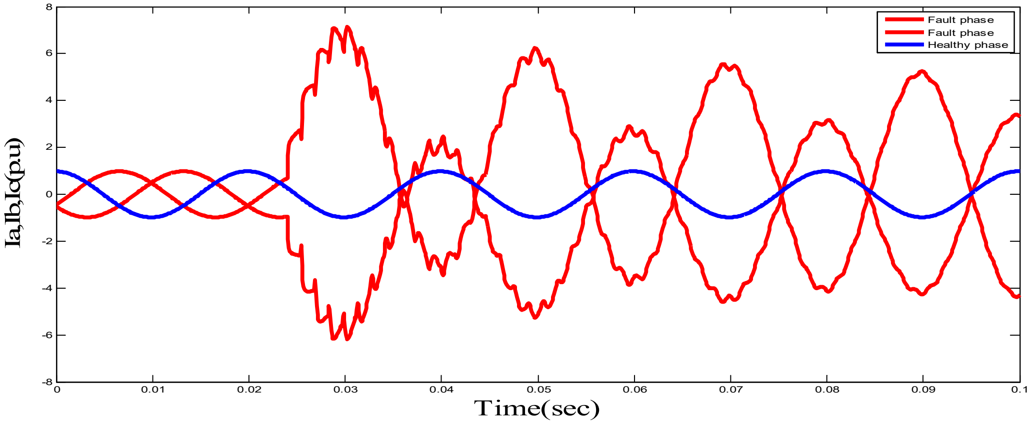

Figure 6. Ia, Ib, Ic For AB Fault At D==200Km, FIA=60, Rf=0.001Ω

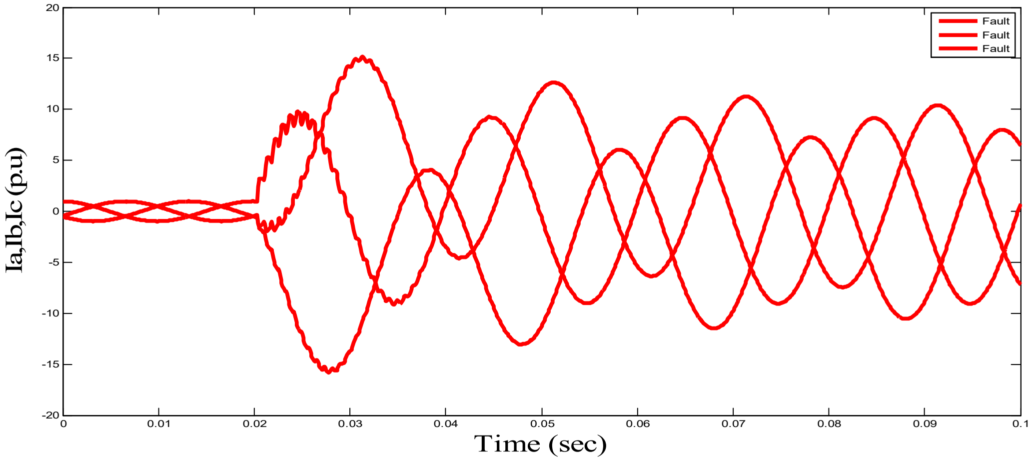

Figure 7. Ia, Ib, Ic For ABC Fault At D==100Km, FIA=0, Rf=0.001Ω

Table 1. L-L Fault With Different Fault Distances The Values Of Sa, Sb, Sc With FIA=0°

	10(km)	30 (km)	50(km)	70(km)	90(km)	100(km)	150(km)	200(km)
Sa	5.5206	3.6877	2.8239	2.3508	2.0473	1.9327	1.5714	1.3852
Sb	-5.5007	-3.6679	-2.8041	-2.331	-2.0275	-1.9129	-1.5514	-1.3652
Sc	-0.0199	-0.0197	-0.0197	-0.0198	-0.0198	-0.0198	-0.0199	-0.0199

Table 2. L-L fault with different fault distances the values of Sa, Sb, Sc with IA=30°

	10(km)	30 (km)	50(km)	70(km)	90(km)	100(km)	150(km)	200(km)
Sa	5.5213	3.6713	2.8134	2.3421	2.0409	1.9289	1.5735	1.3234
Sb	-5.5014	-3.6515	-2.7934	-2.3223	-2.0211	-1.909	-1.5535	-1.3034
Sc	-0.0199	-0.0197	-0.0196	-0.0198	-0.0198	-0.0198	-0.0199	-0.0199

Table 3. L-L-L fault with different fault distances the values of Sa, Sb, Sc with FIA=0°

	10(km)	30 (km)	50(km)	70(km)	90(km)	100(km)	150(km)	200(km)
Sa	24.1143	14.0759	10.0703	7.9054	6.5395	6.0234	4.4194	3.5874
Sb	12.4673	6.7206	4.4424	3.2236	2.4647	2.1783	1.2965	0.8346
Sc	-36.581	-20.796	-14.512	-11.129	-9.0041	-8.2017	-5.7159	-4.422

Table 4. L-L-L fault with different fault distances the values of Sa, Sb, Sc with FIA=30°

	10(km)	30 (km)	50(km)	70(km)	90(km)	100(km)	150(km)	200(km)
Sa	24.1687	14.0944	10.0878	7.9146	6.5491	6.0374	4.4083	3.5518
Sb	12.9371	6.7765	4.4803	3.2455	2.4917	2.198	1.2794	0.9275
Sc	-37.105	-20.876	-14.568	-11.16	-9.0409	-8.2354	-5.6877	-4.4793

Table 5. L-G fault with different fault distances the values of Sa, Sb, Sc with FIA= 0°

	10(km)	30 (km)	50(km)	70(km)	90(km)	100(km)	150(km)	200(km)
Sa	15.0673	7.3082	4.9285	3.7782	3.0993	2.8547	2.1021	1.7146
Sb	-0.0126	0.0073	0.0132	0.0156	0.0168	0.0171	0.0174	0.0193
Sc	-0.0978	-0.0776	-0.0717	-0.0694	-0.0682	-0.068	-0.0678	-0.0695

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Table 6. L-G fault with different fault distances the values of Sa, Sb, Sc with FIA=60°

	10(km)	30 (km)	50(km)	70(km)	90(km)	100(km)	150(km)	200(km)
Sa	15.0457	7.2938	4.919	3.771	3.0936	2.8493	2.098	1.7101
Sb	-0.0108	0.0072	0.0131	0.0155	0.0165	0.0168	0.0169	0.0182
Sc	-0.0959	-0.0778	-0.0719	-0.0695	-0.0685	-0.0683	-0.0682	-0.067

TABLE 7. L-L-G FAULT WITH DIFFERENT FAULT DISTANCES THE VALUES OF SA, SB, SC WITH FIA=0º

	10(km)	30 (km)	50(km)	70(km)	90(km)	100(km)	150(km)	200(km)
Sa	16.1456	8.4744	5.9805	4.7147	3.943	3.6592	2.7751	2.3212
Sb	3.9181	1.1191	0.3525	0.0331	-0.1318	-0.1857	-0.3454	-0.4294
Sc	-0.1453	-0.1655	-0.1748	-0.1819	-0.1881	-0.1912	-0.2064	-0.2219

Table 8. L-L-G fault with different fault distances the values of Sa, Sb, Sc with FIA=60º

	10(km)	30 (km)	50(km)	70(km)	90(km)	100(km)	150(km)	200(km)
Sa	15.5731	8.3536	5.8965	4.6615	3.906	3.6127	2.7655	2.1906
Sb	4.5378	1.2399	0.4332	0.0824	-0.0988	-0.1435	-0.3402	-0.3041
Sc	-0.1456	-0.1657	-0.1748	-0.1819	-0.1883	-0.1914	-0.2067	-0.2224