American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-11, Issue-01, pp-75-98
www.ajer.org
Research Paper Open Access

Application of S – Transform For Fault Studies on 330KV Transmission Line

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ABSTRACT:
The increasing fast extension, advancement and complexity of the modern power system require that, a highly reliable and effective power system protection scheme is installed for fast operation in protecting the transmission line at occurrence of fault. Fault diagnosis is a major area of investigation for power system and intelligent system applications. To protect the power system transmission line, fast and accurate detection, classification and location of point of these faults is imperative. Transmission line fault location requires both power system model information and field data captured at different substations. This research presents a novel Time-Frequency (S–Transform) approach for the detection, classification and location of fault in Onitsha – Alaoji 330kV power system transmission using MatLab/Simulink. This discretized technique is an expansion of Wavelet transform method and is based on a moving and scalable localizing Gaussian window. The results was compared with IEEE 14 Bus transmission line network.

***KEYWORDS**: Stockwell Transform, Transmission Line, IEEE Network, Nigerian Network, Signal Techniques.*

Date of Submission: 05-01-2022 Date of acceptance: 17-01-2022

I. INTRODUCTION

In recent years, with fast extension of the power system, the research of an automatic and reliable technique for protection system has aroused widespread attention. It is well known that transmission lines are an important part in a power system and the faults of a transmission line will cause disturbance and endanger the security of the whole system. Therefore, detecting, classifying, locating and isolating the faults in time are the main tasks of transmission system protection. When a sudden change, such as a fault or a disturbance occurs on a transmission line, a traveling wave will be generated, and it will propagate at nearly the speed of light. It is a significant amount of work to characterize and locating the transients by only using the original records. There are many techniques that can be employed for extracting and analyzing the nature of the traveling wave before and fault occurrence. Stockwell transform (S – Transform) is one of the powerful tools in extracting and analyzing the features of traveling wave, its application on fault detection is presented in this dissertation. This research describes the S – Transform technique use for detection of fault based on sampling of the fault voltage and current transients at the relay point. Normally the fault generated current and voltage transients contain long duration low frequency components and short duration high frequency components, the information contained in these signals are employed by S – Transform (S-T) for the purpose of line protection [1], [2].

II. METHODOLOGY

Block Diagram and the flowchart of the Procedure for fault detection on the Onitsha – Alaoji 330kV Transmission Line located on the Nigeria 58-Bus Network using Time – Frequency method is shown on figure 1.0 and 2.0 respectively.

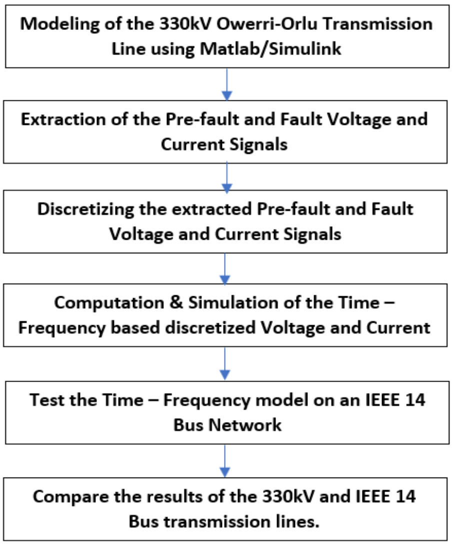

Figure 1.0: Block diagram of the methodological procedure

Flowchart of the Procedure for fault detection on the Transmission Line using Time – Frequency method

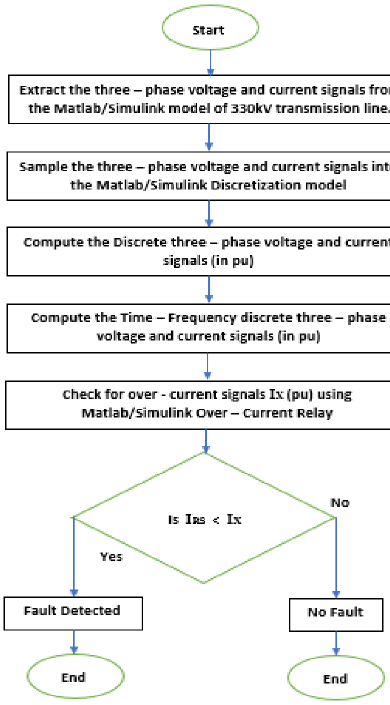

Figure 2.0: Flowchart diagram for the fault detection procedure

The figures 1.0 and 2.0 illustrate the respective methodological and implementation process of fault detection on the power system transmission line using Time – Frequency (S – Transform) technique. Here I_{RS} and I_X are relay set current and discretized S – Transform current respectively.

(I) Extraction of the three – phase voltage and current signals from the Matlab/Simulink model of 330kV transmission line

According to Sadiku and Alexandra, 2006, three – phase voltage and current signals of the transmission line are represented by equations 1.1 to 1.6.

$v_a = V_p \sin(\theta + \emptyset)$ (1.1)

$v_b = V_p \sin(\theta + \emptyset)$ (1.2)

$v_C = V_p \sin(\theta + \emptyset)$ (1.3)

$i_a = I_p \sin(\theta + \varphi)$ (1.4)

$i_b = I_p \sin(\theta + \varphi)$ (1.5)
$i_C = I_p \sin(\theta + \varphi)$ (1.6)
$V_p(n) = \frac{2}{3}[\, v_a + v_b(n)e^{\frac{j2\pi}{N}} + v_c(n)e^{\frac{-j2\pi}{N}}\,]$ (1.7)
$I_p(n) = \frac{2}{3}[\, i_a + i_b(n)e^{\frac{j2\pi}{N}} + i_c(n)e^{\frac{-j2\pi}{N}}\,]$ (1.8)
Equation (3.7) and (3.8) is the discretization equation used for the determination of discontinuous three – phase voltage and current signal from the transmission line [3].

(II) Fault detection on the power system transmission line using Time – Frequency technique.
Time – Frequency analysis technique is a powerful tool for fault detection, classification and location for protection of the transmission line. It is an invertible Time – Frequency (S – Transform) analytical technique that comprises a combination of Short Time Fourier Transform (STFT) and Wavelet Transform (WT).
Thus, a mathematical expression derived from Short Time Fourier Transform (STFT) and Wavelet Transform (WT) to solve the problem of limitations of STFT applications.
S – Transform has an advantage in the sense that, it provides multi-resolution analysis while retaining the absolute phase of each frequency.
This is one of reasons why it has been chosen in the field of electrical engineering for fault diagnosis in time series.
The following expressions is the Time – Frequency (S-Transform) for a continuous signal (voltage or current signal) x(t);
$S(\tau, f) = \int_{-\infty}^{\infty} x(t)\left\{\frac{|f|}{\alpha\sqrt{2\pi}}\right\}.e^{\left(\frac{-f^2(\tau-t)^2}{2\alpha^2}\right)}.e^{(-2\pi ift)}\,dt$(1.9)
Where f is the frequency, t is the time, τ is the parameter that controls the position of Gaussian window on the t-axis and α is a control factor of time and frequency resolution of the transform. The lower α means higher time resolution and lower frequency and vice versa.
A suitable value of α lies between the ranges of $0.2 \le \alpha \le 1$.
Considering the discrete version of the continuous S-Transform (DST) (equation 1.9), the following expression describes the DST.
$S(j, n) = \sum_{m=0}^{N-1} X(m+n).e^{\left(\frac{-2\pi^2 m^2 \alpha^2}{n^2}\right)}.e^{(i2\pi mj)}$(1.10)
Where, j = 1……N – 1, n = 0, 1…N -1.
But, j and n indicates the time samples and frequency step respectively.
X(m + n) can be obtained in a straight forward manner from equation 3.9 below.
$X(n) = \frac{1}{N}\sum_{K=0}^{N-1} x(k).e^{(i2\pi nk)}$ (1.11)
Where, n = 0, 1…, N-1
Also, the Fourier spectrum of the Gaussian window at a specific n (frequency) is called a voice Gaussian and for the frequency $f_1(n_1)$, the voice can be obtained as;
$S(j, n_1) = A(j, n_1).e^{(j\phi(j,n_1))}$ (1.12)
Where the pick value of the voice is
$\max\big(S(j, n_1)\big) = \max\,(A(j, n_1))$ (1.13)
And
$\phi(j, n_1) = \mathrm{atan}\left\{\frac{\mathrm{imag}\,(S(j,n_1))}{\mathrm{real}\,(S(j,n_1))}\right\}$ (1.14)
Then, the energy E of the signal is obtained from S – Transform as
$E = \{\mathrm{abs}(S(j, n_1))\}^2$ (1.15)
The energy signal obtained from S - Transform is used to detect and classify the fault on the transmission line [4].

(III) Modeling the Discretization Equation
Equations 1.7 and 1.8 are modeled using MATLAB/SIMULINK block to obtain Figures 3.0 and 4.0.
However, the input ports figures 3.0 and 4.0 are connected to output signal port of the voltage – current Matlab/Simulink measurement block to extract the continuous phase voltage and current signals as input signals into the system. They processes the signals in-line their modeled mathematical derivations to obtain the discontinuous output voltage (Vp) and current (Ip) as their discrete version.

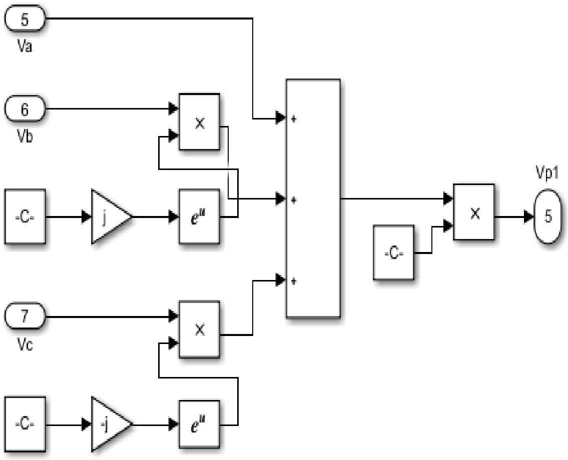

Figure 3.0: Discrete Voltage Simulink Block

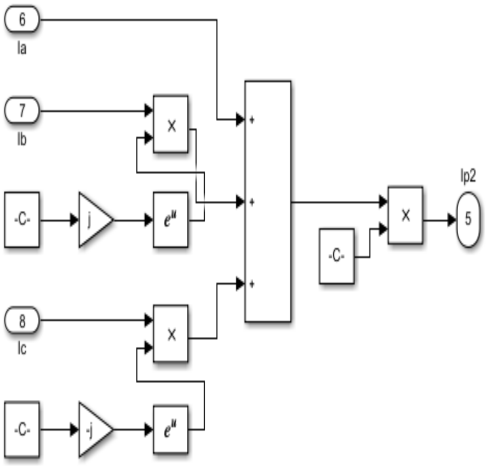

Figure 4.0: Discrete Current Simulink Block

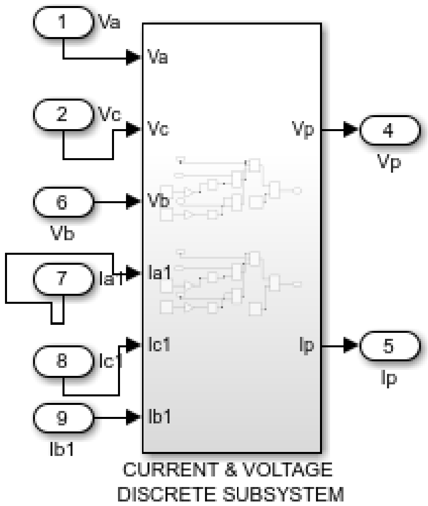

Figure 5.0: Voltage and Current Subsystem

Figure 5.0 is the Matlab/Simulink subsystem of figures 3.0 and 4.0.

(IV) Modeling the Discretized Time – Frequency Equation

Figures 6.0 and 7.0 are the Matlab/Simulink models of equation 1.10 for voltage and current signals respectively. The input port of figure 6.0 is connected to the output port of figure 3.0, while the input port of figure 7.0 is connected to the output port of figure 4.0 for extraction of the discretized voltage and current signals respectively.

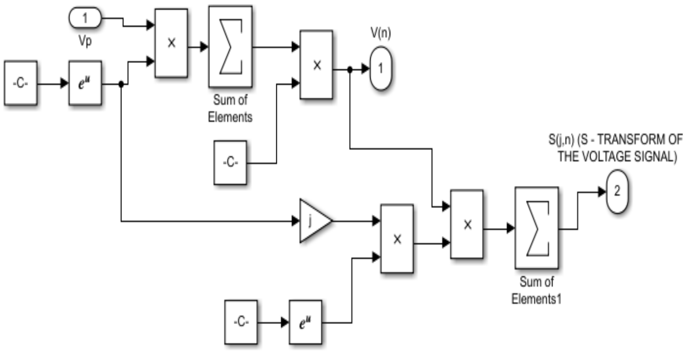

Figure 6.0: Discrete S -Transform Computation Model for Voltage Signal

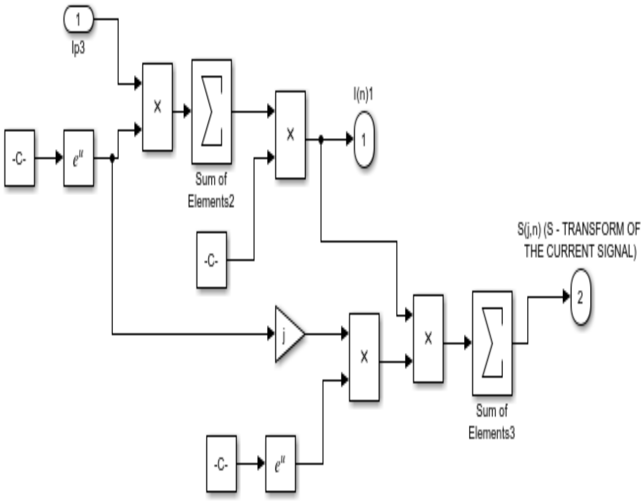

Figure 7.0: Discrete S -Transform Computation Model for Current Signal

(V) Computation of the Discrete Energy Signal of the three-phase voltage and current

The discrete energy signal of the voltage and current signals is the signal that show the magnitude, severity, frequency of fault occurred on the line.

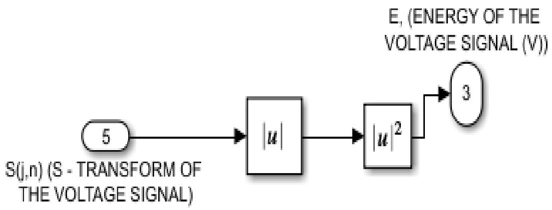

Figure 8.0: Discrete S -Transform Energy Signal Computation Model for Voltage and Current Signal

The magnitude of the energy signal of voltage can only be greater than that of current when there is no fault on the network. If the magnitude of the energy signal output of voltage is greater than that of current after fault simulations, it shows that the energy equation of 1.15 is wrong. However, the magnitude of energy signal of voltage is expected to be less than that of current when fault occurs on the network. This is because, according the standard electric circuit or network theories, when fault occurs on an electric circuit, the voltage magnitude decreases while the current increases, hence magnitude of energy signal of current during faulty condition is greater than that of voltage [4], [5].

(VI) Computation of the discrete three – phase voltage and current signals
The computation of the discrete three – phase pre-fault and fault voltage and current signals is achieved using figures 3.9 and 3.10 respectively. Their values computed are shown in table 4.3 and 4.4 respectively.

(VII) Compute the Time – Frequency discrete three – phase voltage and current signals
Time – Frequency discrete three – phase pre-fault and fault voltage and current signal for single phase to ground, double phase to ground, phase to phase and three – phase faults are computed using figures 3.0 and 4.0. Their values are shown on table 1.0 and 2.0 respectively.
Also, figure 8.0 which represent the computation model for computing the energy signal of the voltage and current of the transmission line for pre-fault and fault conditions. The energy signal equation 1.15 represents the fault signal of parameter and carries fault frequency component of the parameter [5] [6].

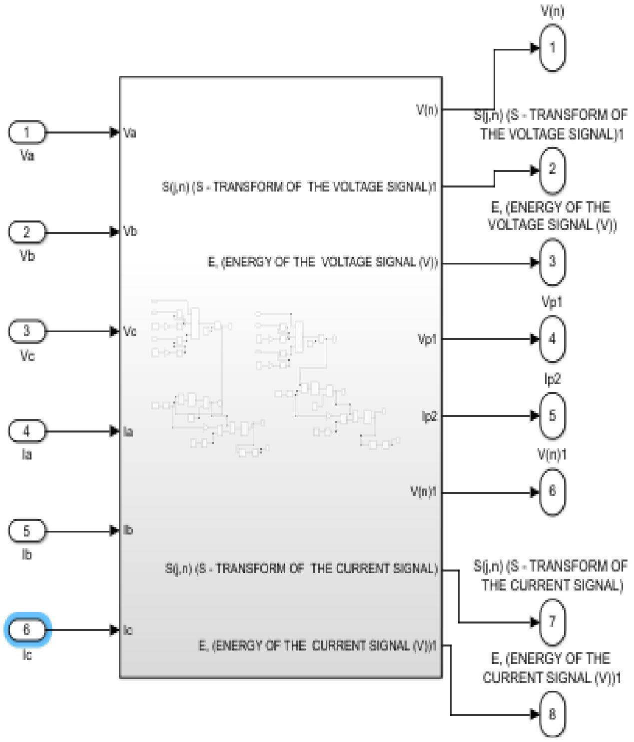

Figure 9.0: Complete Discrete S -Transform Model for the Computation Voltage and Current Signal Conditions

Figure 9.0 is a subsystem containing the Matlab/Simulink model for computing discrete values of pre-fault and fault voltage and current. It also contains the S – Transform fault detection and Energy models for voltage and current signals.
The inputs of the S – Transform fault detection model is connected to the matlab/Simulink voltage – current measurement block for the extract of the phase voltage and current signals. Each of the models in the S – Transform fault detection system is linked to the input signals. They compute their voltage and current signal values and gives results. Their results are tabulated accordingly in chapter four.

(VIII) RESULTS AND DISCUSSIONS
Results obtained through simulation of the Nigeria 58 – Bus Network with Onitsha – Alaoji 330KV transmission line as a case study.
This chapter discusses the result obtained using the methodology in chapter three. The following results were obtained when the complete system of Time -Frequency (S – Transform) model is simulated.

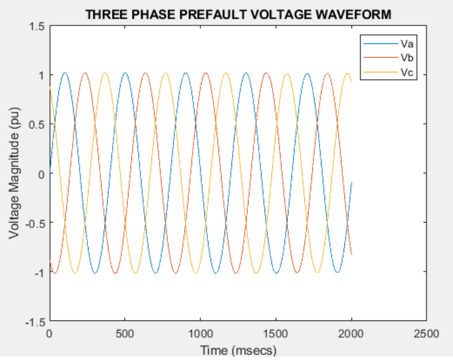

Figure 10: Three Phase Pre-fault Voltage Waveform

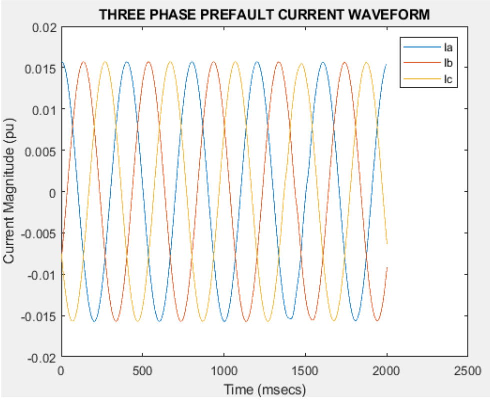

Figure 11: Three Phase Pre-fault Current Waveform

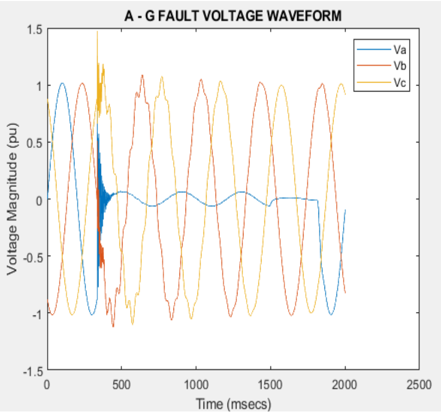

Figure 12: Three Phase A – G fault Voltage Waveform

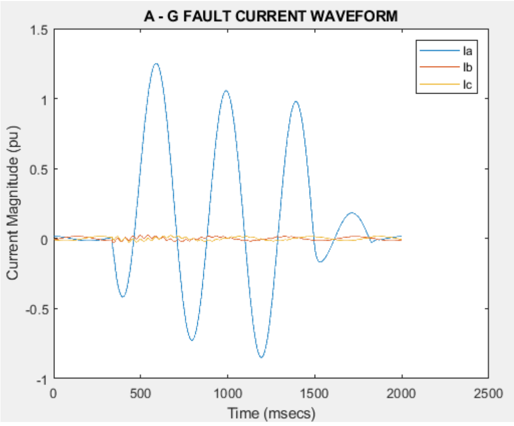

Figure 13: Three Phase A – G fault Current Waveform

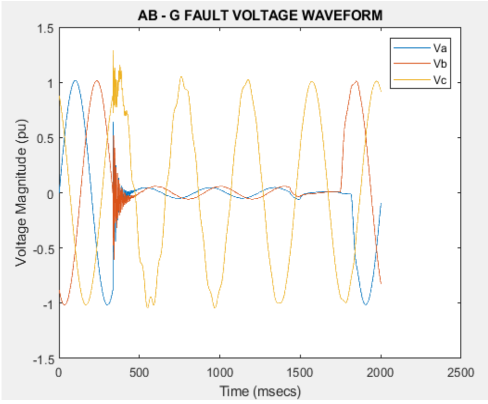

Figure 14: Three Phase AB – G fault Voltage Waveform

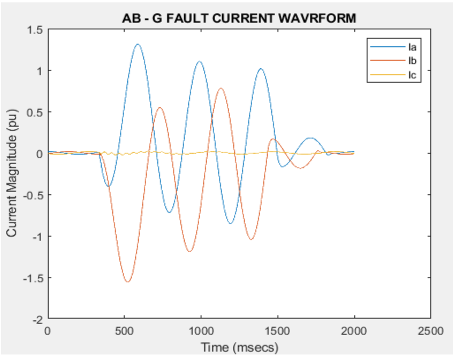

Figure 15: Three Phase AB – G fault Current Waveform

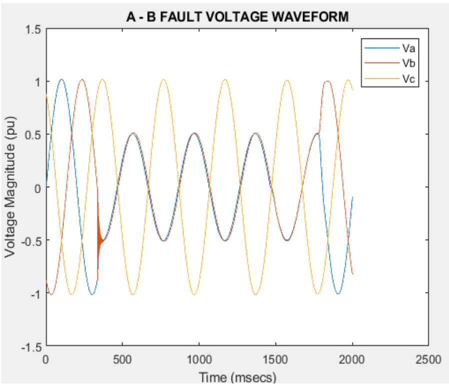

Figure 16: Three Phase A – B fault Voltage Waveform

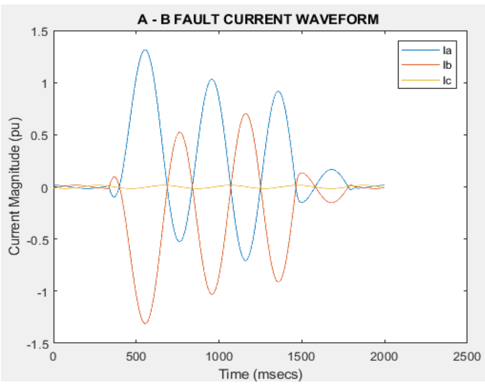

Figure 17: Three Phase A – B fault Current Waveform

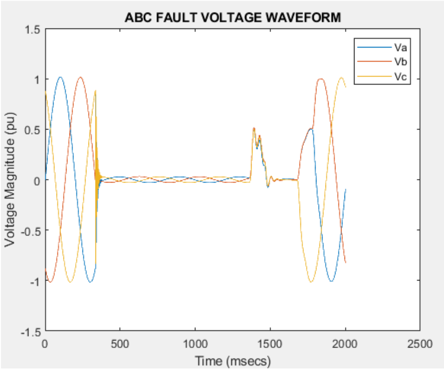

Figure 18: Three Phase ABC fault Voltage Waveform

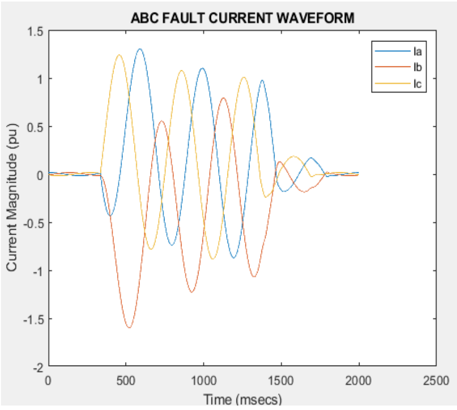

Figure 19: Three Phase ABC fault Current Waveform

The faults that occurred on the transmission line were occurred and cleared at same time (480msecs) and (1800msecs) respectively, except at three phase (ABC) fault when at 1480msecs the voltage magnitudes of the lines increased from 0.0 to 0.5 and decreased back to 0.00 at 1500msecs.

Table 1: Three phase Pre-fault and fault Voltage and Current for the symmetrical and unsymmetrical faults

S/N	V_a	V_b	V_c	I_a	I_b	I_c	Fault Conditions
1	1.0000	1.0000	1.0000	0.0150	0.0150	0.0150	No Fault
2	0.0001	1.0000	1.5000	1.2800	0.0150	0.0150	A – G
3	0.0010	0.0110	1.2500	1.3800	-1.5000	0.0000	AB – G
4	0.5000	0.5000	1.0000	1.3500	-1.3800	0.0000	A – B
5	0.0000	0.0000	0.0000	1.3500	-1.5000	1.1500	ABC

Table 1.0 shows the pre-fault, fault voltage and current magnitude of the case study transmission line obtain when the line is simulated for No fault, A – G, AB – G, A – B and ABC fault conditions.
Figures 20 to 29 represent the pre-fault voltage waveform of No fault, A – G, AB – G, A – B and ABC fault conditions.

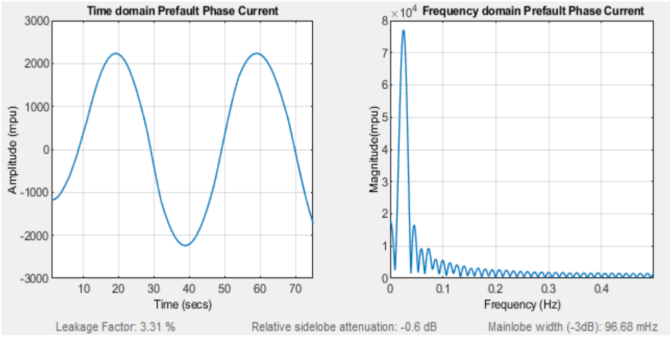

Figure 20: Time and Frequency Domain Onitsha – Alaoji 330kV Transmission Line Pre-fault Current Waveform

Signal processing method is divided into time domain, frequency domain and time-frequency domain methods. In terms of frequency, low frequencies (high scales) whereas high frequencies (low scales) correspond to a detailed information of a hidden pattern in the signal (that usually lasts a relatively short time). At higher frequency we have low and poor frequency resolution or window or short time interval and large time resolution, but at lower frequency we have high and better frequency resolution or window or large time interval and lower time resolution [8]

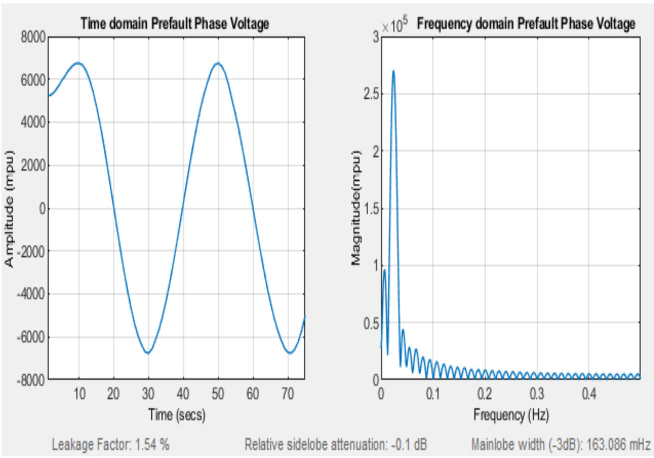

Figure 21: Time and Frequency Domain Onitsha – Alaoji Transmission Line Pre-fault Voltage Waveform

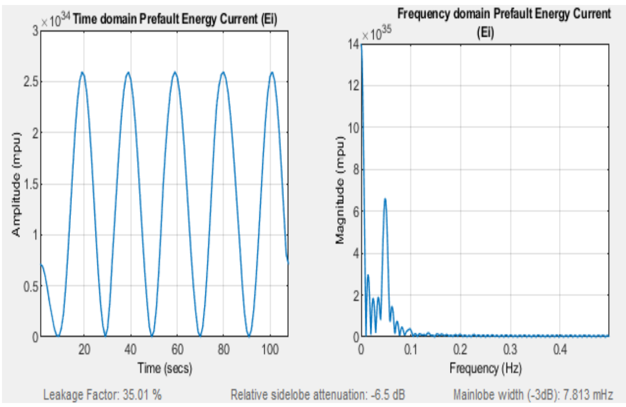

Figure 22: Time and Frequency Domain Onitsha – Alaoji Transmission Line Pre-fault Energy of Current Waveform

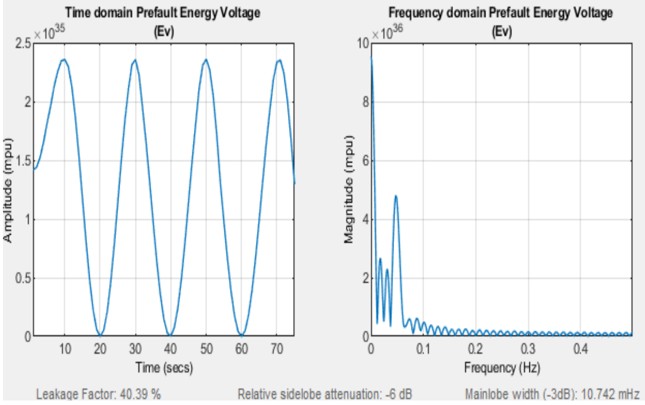

Figure 23: Time and Frequency Domain Onitsha – Alaoji Transmission Line Pre-fault Energy of Voltage Waveform

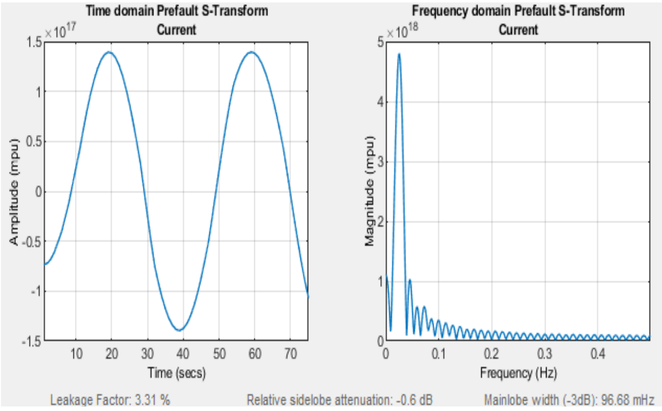

Figure 24: Time and Frequency Domain Onitsha – Alaoji Transmission Line Pre-fault S-Transform Current Waveform

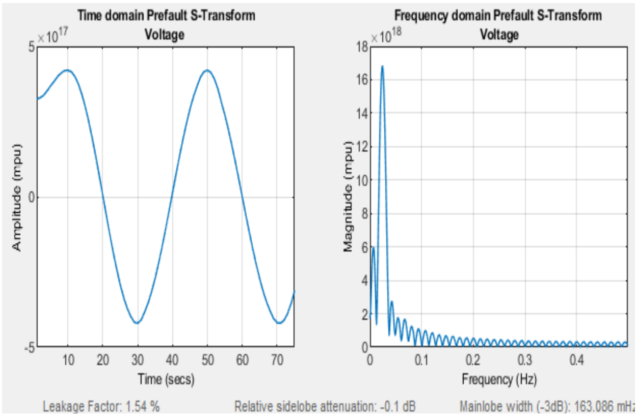

Figure 25: Time and Frequency Domain Onitsha – Alaoji Transmission Line Pre-fault S-Transform Voltage Waveform

Table 2: Time & Frequency Domain Pre-fault Voltage and Current Computation at No Fault Condition

S/N	S – Transform Parameters	Time – Domain (mpu)	Frequency – Domain (mpu)
1	V_P	6300	2.80e5
2	I_P	2100	7.80e4
3	E_V	2.30e35	10.00e36
4	E_I	2.60e34	14.00e35
5	S-T_V	4.80e17	16.20e18
6	S-T_I	1.40e17	4.80e18

Signals in time – domain (T) are dependent on time interval taken for such signals to occur. But frequency - domain (s) is dependent on number of spectrum and its magnitude.
According to Mohammed (2013), time and frequency domain signals are the most signals in practice and that in many applications of signal processing, the frequency content of the signals contains the most relevant and discrete information. Thus various mathematical transform are used to analyses those signal processes. The transmission line contains the high frequency of current and voltage waves including other parameters like reactance, resistance, capacitance, admittance and conductance which are all used for analyses of the waveform.

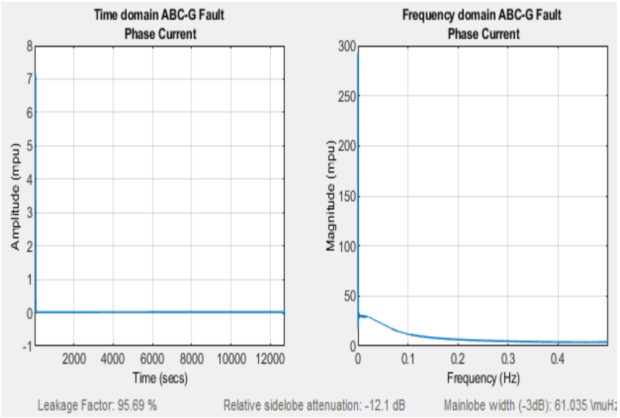

Figure 26: Time and Frequency Domain Onitsha – Alaoji Transmission Line ABC-G Fault Current Waveform

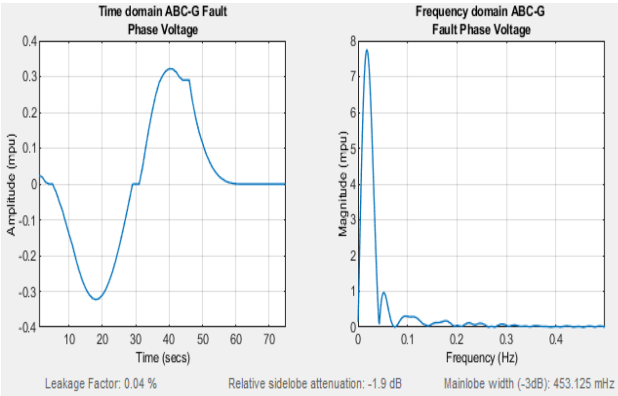

Figure 27: Time and Frequency Domain Onitsha – Alaoji Transmission Line ABC-G Fault Voltage Waveform

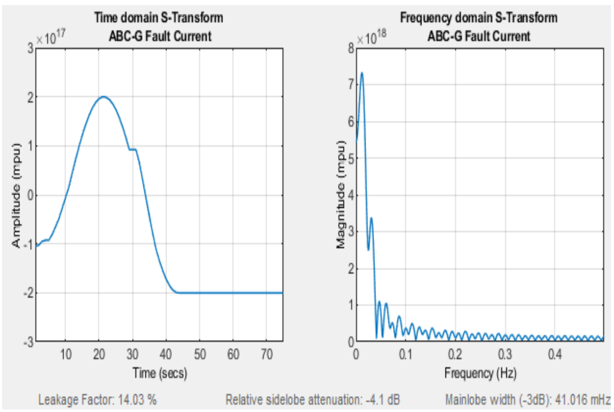

Figure 28: Time and Frequency Domain Onitsha – Alaoji Transmission Line S – Transform ABC-G Fault Current Waveform

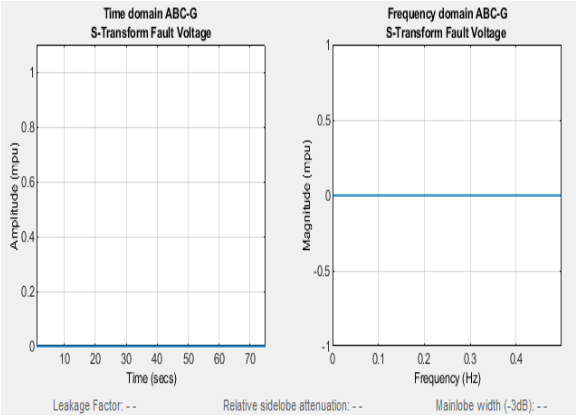

Figure 29: Time and Frequency Domain Onitsha – Alaoji Transmission Line S – Transform ABC-G Fault Voltage Waveform

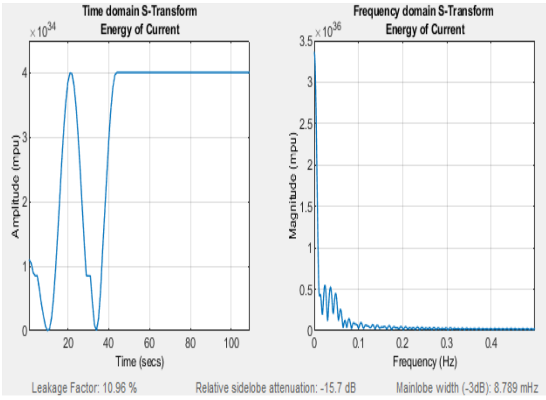

Figure 30: Time and Frequency Domain Onitsha – Alaoji Transmission Line S – Transform Energy of Fault Current Waveform

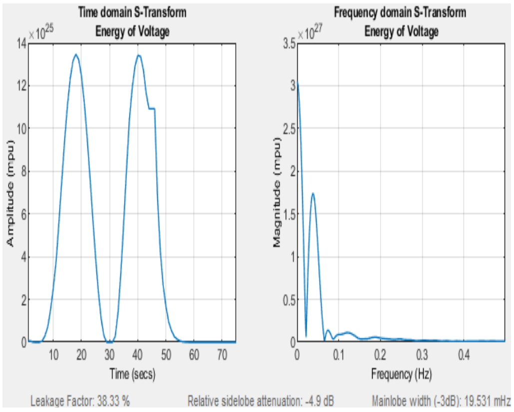

Figure 31: Time and Frequency Domain Onitsha – Alaoji Transmission Line S – Transform Energy of Fault Voltage Waveform

Table 3: Time & Frequency Domain fault Voltage and Current Computation at Three Phase (ABC) Fault Condition

S/N	S – Transform Parameters	Time – Domain (mpu)	Frequency – Domain (mpu)
1	V_p	0.30	7.80
2	I_p	7.00	300.00
3	E_V	13.50e25	3.00e27
4	E_I	4.00e34	3.50e36
5	S-T_V	0.00	0.00
6	S-T_I	2.00e17	7.20e18

(V) Comparative Analysis between the Results of the Application of the Nigeria 58-Bus Case Study Model & IEEE 14 – Bus System Network

In this section, comparison between the results of the simulation of the Onitsha – Alaoji 330 kV case study transmission line and the IEEE 14 - Bus transmission line is performed.

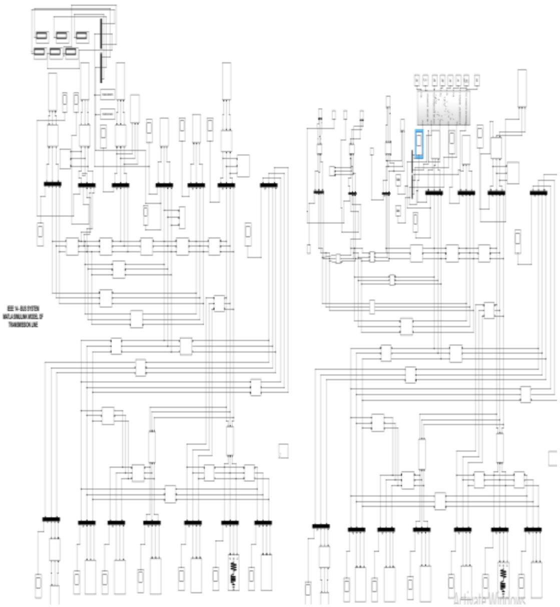

Figure 32: IEEE 14 – Bus System Network Transmission Line

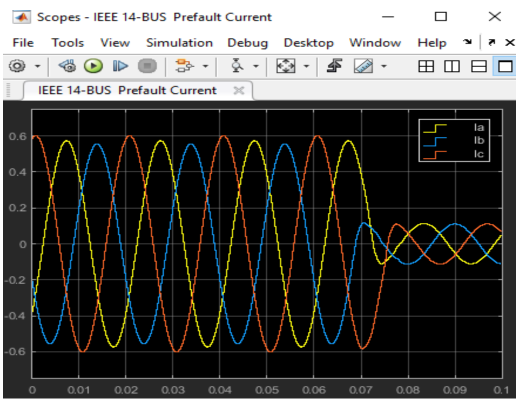

Figure 33: IEEE 14-Bus Three Phase Pre-Fault Current Waveform

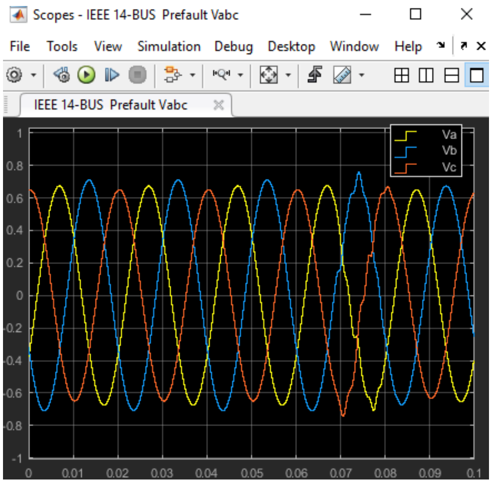

Figure 34: IEEE 14-Bus Three Phase Pre-Fault Voltage Waveform

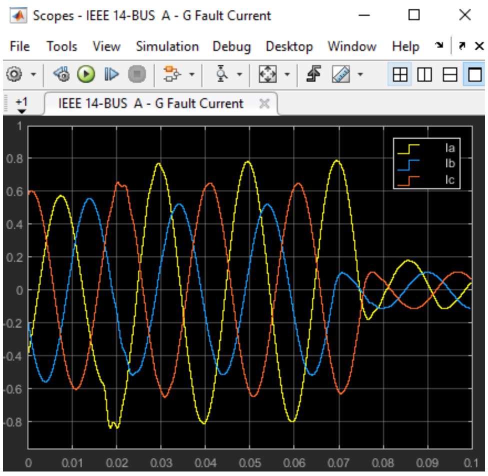

Figure 35: IEEE Single Line Three Phase A – G fault Current Waveform

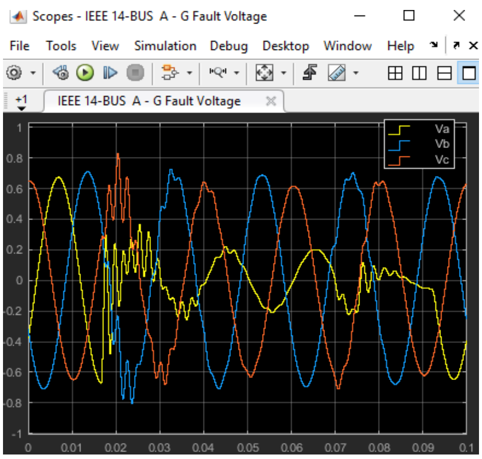

Figure 36: IEEE Single Line Three Phase A – G fault Voltage Waveform

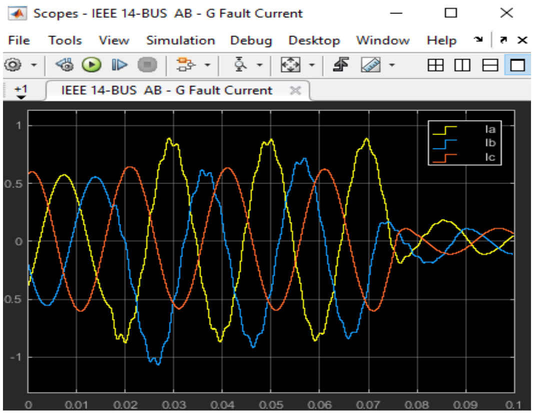

Figure 37: IEEE Single Line Three Phase AB – G fault Current Waveform

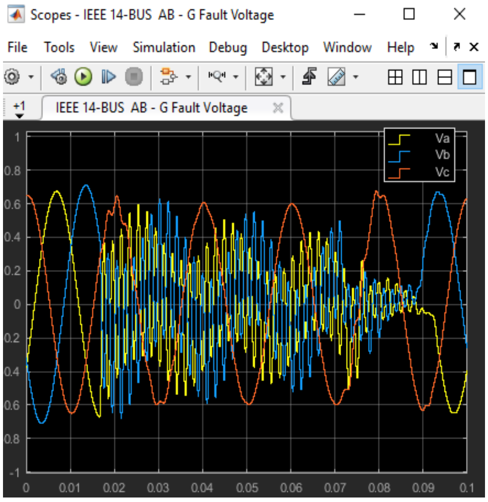

Figure 39: IEEE Single Line Three Phase AB – G fault Voltage Waveform

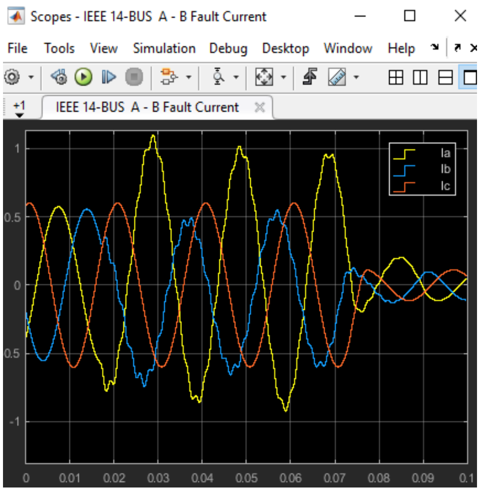

Figure 40: IEEE Single Line Three Phase A - B fault Current Waveform

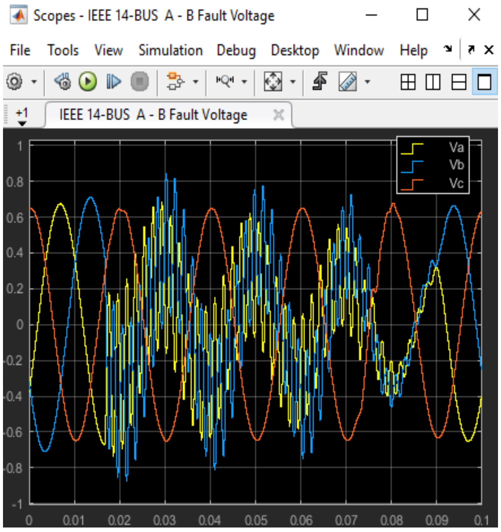

Figure 41: IEEE Single Line Three Phase A - B fault Voltage Waveform

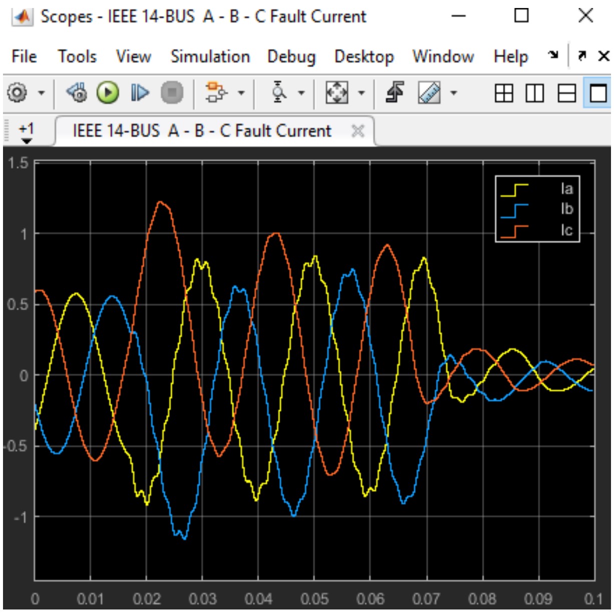

Figure 42: IEEE Single Line Three Phase ABC fault Current Waveform

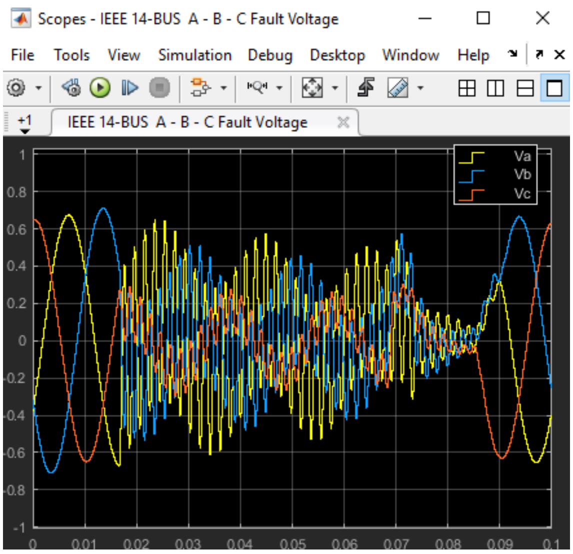

Figure 43: IEEE Single Line Three Phase ABC fault Voltage Waveform

Table 4: IEEE 14 – Bus System Three phase Pre-fault and fault Voltage and Current for the symmetrical and unsymmetrical faults

S/N	V_a	V_b	V_c	I_a	I_b	I_c	Fault Conditions
1	0.6200	0.7000	0.6200	0.5800	0.5700	0.6000	No Fault
2	0.1500	0.7000	0.8000	0.8200	0.5700	0.6100	A – G
3	0.6000	0.6000	0.6200	0.9000	1.2000	0.6000	AB – G
4	0.6200	0.8000	0.6200	1.3000	0.6000	0.5300	A – B
5	0.6000	0.5000	0.2300	0.5500	0.5400	1.3800	ABC

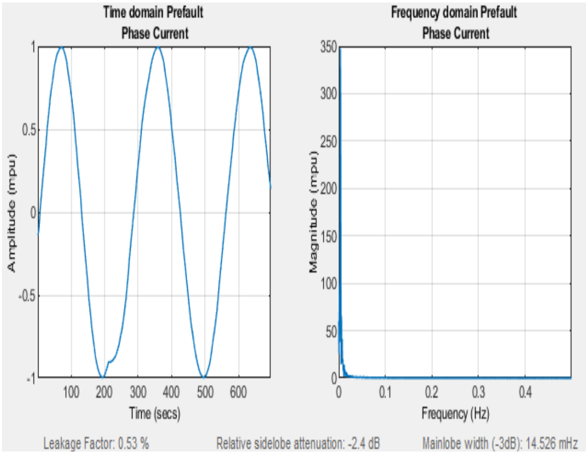

Figure 44: Three Phase ABC fault Current Waveform

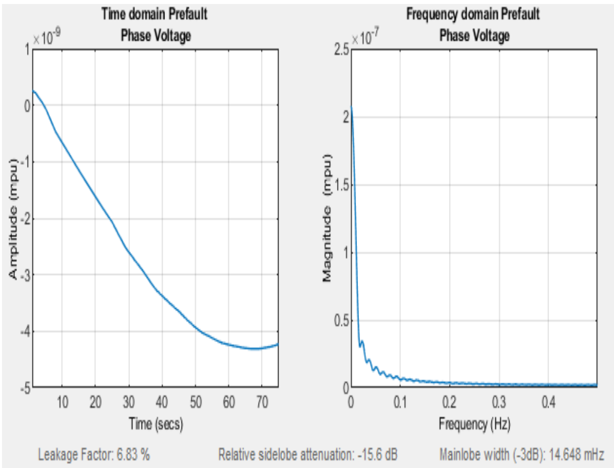

Figure 45: Three Phase ABC fault Current Waveform

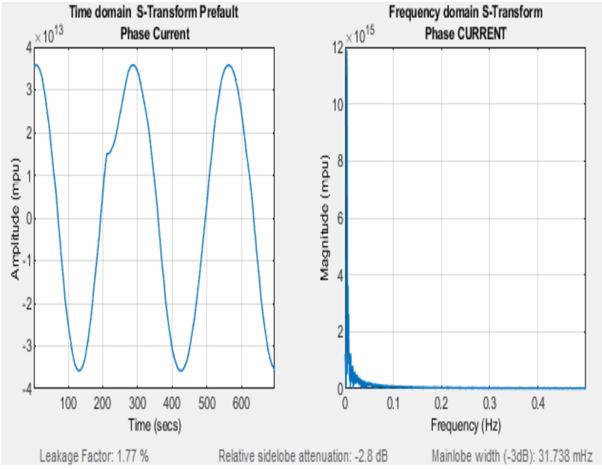

Figure 46: Three Phase ABC fault Current Waveform

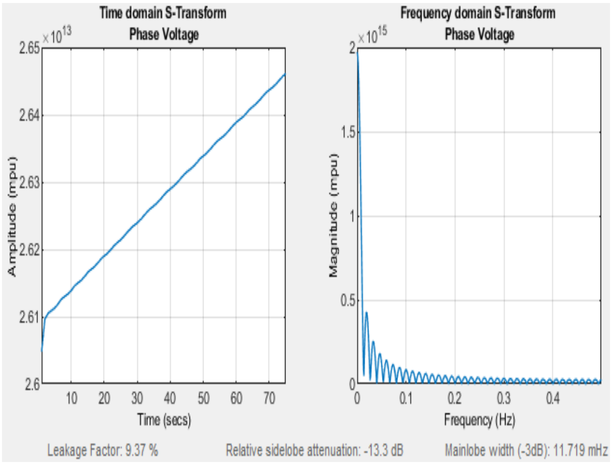

Figure 47: Three Phase ABC fault Current Waveform

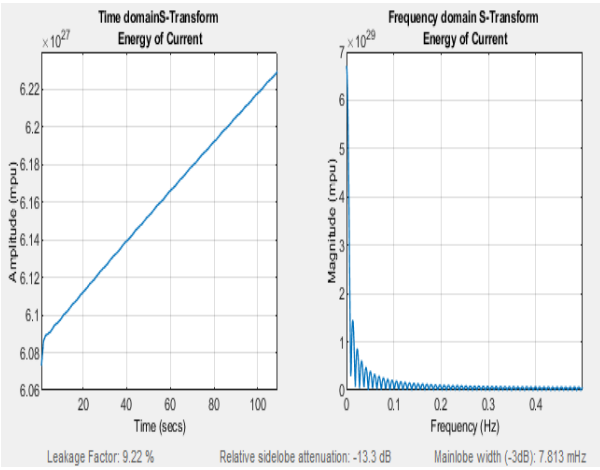

Figure 48: Three Phase ABC fault Current Waveform

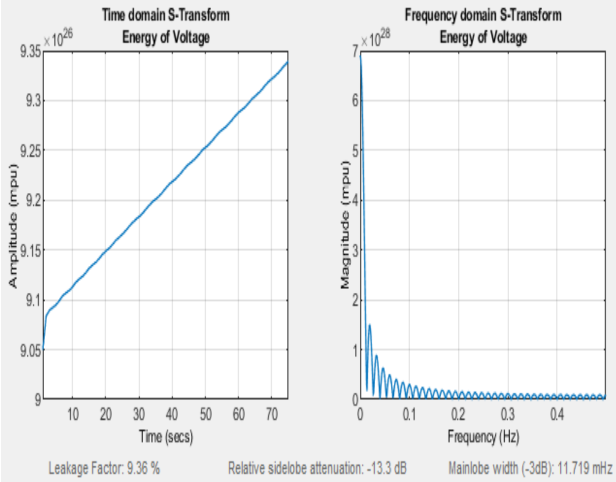

Figure 49: Three Phase ABC fault Current Waveform

Table 5: IEEE 14 - Bus Network Time & Frequency Domain Pre-fault Voltage and Current Computation at No Fault Condition

S/N	S – Transform Parameters	Time – Domain (mpu)	Frequency – Domain (mpu)
1	V_P	1.00	350
2	I_P	0.2e-9	2.00e-7
3	E_V	9.33e26	7.00e28
4	E_I	6.22e27	6.80e29
5	$S\text{-}T_V$	2.645e13	2.00e15
6	$S\text{-}T_I$	3.50e13	12.00e15

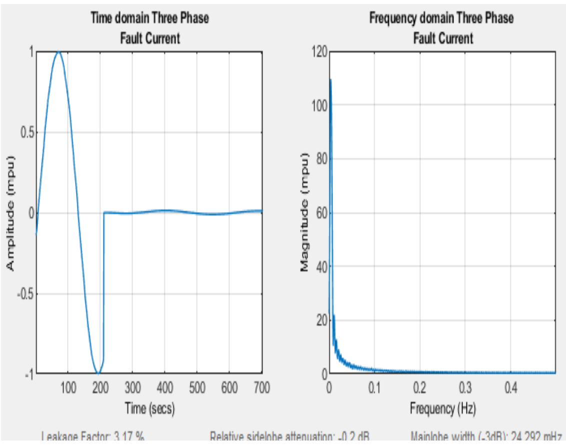

Figure 50: Three Phase ABC fault Current Waveform

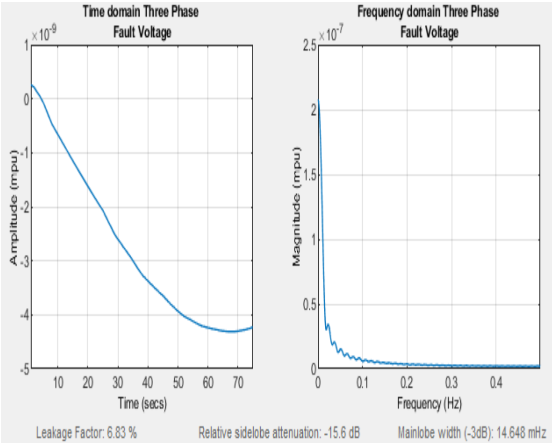

Figure 51: Three Phase ABC fault Current Waveform

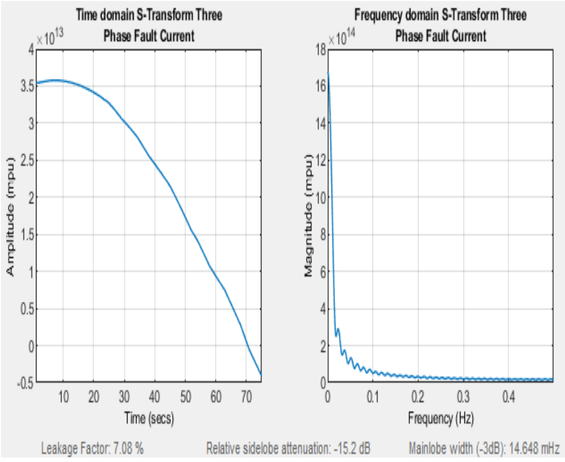

Figure 52: Three Phase ABC fault Current Waveform

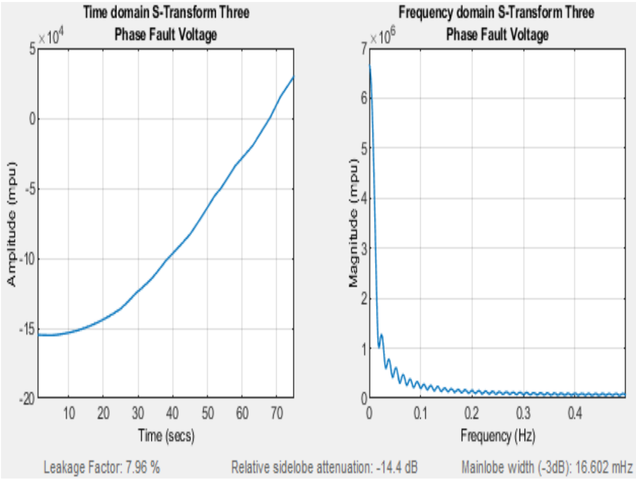

Figure 53: Three Phase ABC fault Current Waveform

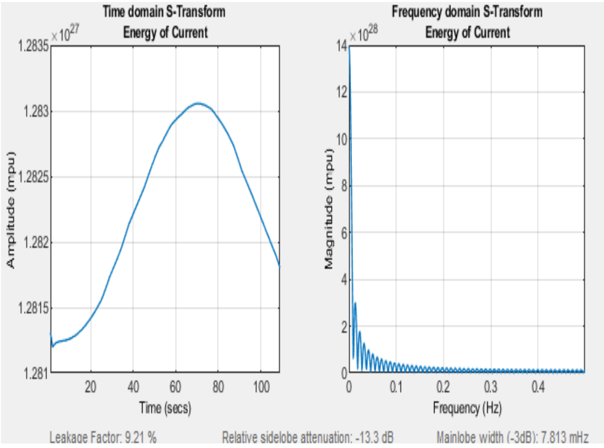

Figure 54: Three Phase ABC fault Current Waveform

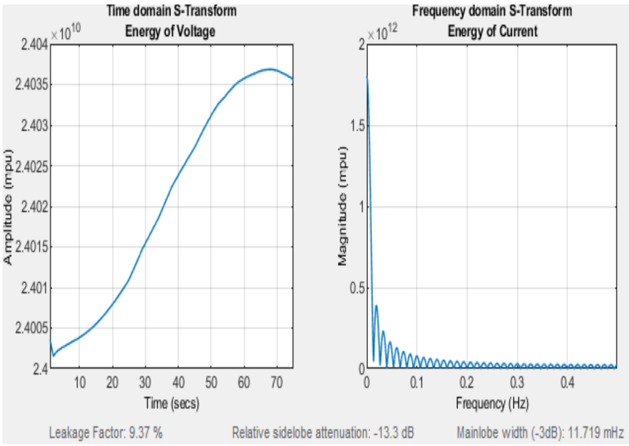

Figure 55: Three Phase ABC fault Current Waveform

Table 6: Time & Frequency Domain Fault Voltage and Current Computation at Three Phase Fault Condition

S/N	S – Transform Parameters	Time – Domain (mpu)	Frequency – Domain (mpu)
1	V_P	0.10e-9	2.00e-7
2	I_P	1.00	110
3	E_V	2.4035e10	1.00e12
4	E_I	1.283e27	14.00e28
5	S-T_V	0.40e4	6.50e6
6	S-T_I	3.50e13	16.00e14

The large magnitude of S – Transform Energy component E_v or E_i is due to fault on the line and explains the greater effect of fault or severity of fault on the transmission line equipment.
Comparing the energy obtained from the Nigerian line and that of IEEE, the energy of the IEEE components is larger than that of Nigerian Network.

Table 7: Comparative Result of Time & Frequency Domain Pre-fault Voltage and Current Computation for Nigerian 58 – Bus and IEEE 14 – Bus Networks Respectively

S/N	S – Transform Parameters	Time – Domain (mpu)		Frequency – Domain (mpu)	
		Nigeria - P_T	IEEE - P_T	Nigeria - P_F	IEEE - P_F
1	Vp	6300	1.00	2.80e5	350
2	Ip	2100	0.2e-9	7.80e4	2.00e-7
3	Ev	2.30e35	9.33e26	10.00e36	7.00e28
4	Ei	2.60e34	6.22e27	14.00e35	6.80e29
5	S-Tv	4.80e17	2.645e13	16.20e18	2.00e15
6	S-Ti	1.40e17	3.50e13	4.80e18	12.00e15

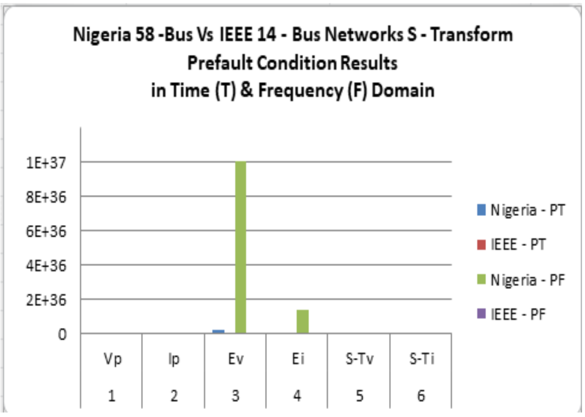

Figure 56: Histogram showing the Difference in Pre-fault Voltage & Current Magnitude for Nigeria 58 Bus and IEEE 14 – Bus Networks

Considering table 7 and figure 56, it is observed that, the magnitude of energy of pre-fault voltage for Nigeria network is larger than that of current in the same Nigeria network in time and frequency domain. But, for the IEEE network, the energy of the current magnitude is larger than that of the voltage in the same time and frequency domain.

Table 8: Comparative Result of Time & Frequency Domain Fault Voltage and Current Computation for Nigerian 58 – Bus and IEEE 14 – Bus Networks Respectively

S/N	S – Transform Parameters	Time – Domain (mpu)		Frequency – Domain (mpu)	
		Nigeria	IEEE	Nigeria	IEEE
1	Vp	0.30	0.10e-9	7.80	2.00e-7
2	Ip	7.00	1.00	300.00	110
3	Ev	13.50e25	2.4035e10	3.00e27	1.00e12
4	Ei	4.00e34	1.283e27	3.50e36	14.00e28
5	S-Tv	0.00	0.40e4	0.00	6.50e6
6	S-Ti	2.00e17	3.50e13	7.20e18	16.00e14

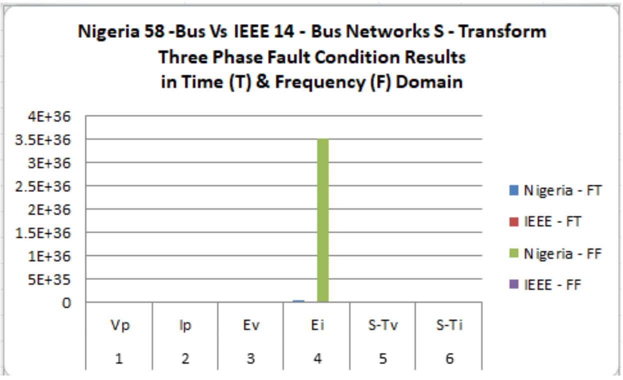

Figure 57: Histogram showing the Difference in Three Phase Fault Voltage & Current Magnitude for Nigeria 58 Bus and IEEE 14 – Bus Networks

Considering table 8 and figure 57, it is observed that, the magnitude of phase current, energy of three phase fault current and S – Transform of current signals for Nigeria and the IEEE networks are all far larger or greater than that of voltage in the both networks in time and frequency domain.

This means that, the Nigeria 58 – Bus Network containing the case study Onitsha – Alaoji 330KV transmission line connected to the S – Transform fault detection model is well modeled and was able to detect, give accurate and correct results corresponding to the standard electric circuit characteristics [9].

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