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Location of Fault on Power System Transmission Lines Using Travelling Wave

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***Abstract-* This research investigates the fault conditions of Enugu – Nsukka 200Km 330KV Power System Transmission Line under fault condition. This investigation is done using MATLAB/Simulink model of S – Transform. The fault distance is located using MATLAB/Simulink Travelling Wave fault locator model. The results satisfy the electrical standard network showing that at every fault incidence, there is decrease in voltage and impedance magnitude while the current magnitude is increased due to fault occurrence.**

***Indexed Terms-* Travelling Wave, Propagation Velocity, Voltage, Current**

I. INTRODUCTION

In several decades ago, there has been rapid growth in the electrical power industries all over the world. This eventually brought about installation of a large number of new transmission and distribution lines. Moreover, the deregulation of electric power has a strong and positive effect on the need for reliable and uninterrupted power supply to the end users who are very sensitive to power outage. One of the biggest problems in electrical power system is the discontinuity of power supply due to occurrence of faults [1][2][3].

In an electric power system, fault is an inevitable abnormality that occurs on the power system and results to the flow of current through unintended part, increases and decreases the current and voltage magnitudes respectively. An example is a short circuit which is a type of fault in which current bypasses the normal load. An open-circuit fault also occurs if a circuit is interrupted by some failure.

The faults of a transmission line cause disturbance and endanger the security of the entire system temporarily or permanently. To restore power after permanent fault on the lines, an accurate location and classification of the fault is highly desirable to help the maintenance crew find and repair the faulted line as quickly as possible. Therefore, detecting, classifying and locating the faults in least minimum time are the main tasks of transmission system protection.

Different techniques have been employed in recent times for the detection, classification and location these faults on power system transmission lines. Among these techniques are, signal processing, Artificial Intelligence (AI) and Travelling Wave (TW) Techniques respectively. Signal processing techniques includes Laplace Transform, Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), Stock well Transform (S-Transform) etc. Artificial Intelligence techniques for classification of faults is Artificial Neural Network Pattern Recognition Algorithm while the location of fault is performed using Travelling Wave technique.

II. METHODOLOGY

(a) Detection of Fault on the Power Line using S - Transform

Extraction of the three – phase voltage and current signals from the Matlab/Simulink model of 330kV transmission line According to [1] can be done using the three – phase voltage and current signals of the transmission line are represented by equations (1) to (6).

$$V_a = V_p \sin(\theta + \emptyset) \quad (1)$$
$$V_b = V_p \sin(\theta + \emptyset) \quad (2)$$
$$V_c = V_p \sin(\theta + \emptyset) \quad (3)$$
$$I_a = I_p \sin(\theta + \varphi) \quad (4)$$
$$I_a = I_p \sin(\theta + \varphi) \quad (5)$$

$$I_a = I_p \sin(\theta + \varphi) \quad (6)$$

$$V_p = \frac{2}{3}\left[V_a(n) + V_b(n)e^{\frac{j2\pi}{N}} + V_c(n)e^{\frac{-j2\pi}{N}}\right] \quad (7)$$

$$I_p = \frac{2}{3}\left[I_a(n) + I_b(n)e^{\frac{j2\pi}{N}} + I_c(n)e^{\frac{-j2\pi}{N}}\right] \quad (8)$$

Equation (7) and (8) is the discretization equation used for the determination of discontinuous three – phase voltage and current signal from the transmission line [1][2].

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);

$$S(\tau, f) = \int_{-\infty}^{\infty} x(t) \left\{\frac{|f|}{\alpha\sqrt{2\pi}}\right\} e^{\left(\frac{-f^2(\tau-t)^2}{2\alpha^2}\right)} . e^{(-2\pi i f t)} dt \quad (9)$$

$$S(j, n) = \sum_{m=0}^{N-1} X(m+n)\, e^{\left(\frac{-2\pi^2 m^2 \alpha^2}{n^2}\right)} . e^{(-i2\pi m j)} \quad (10)$$

Where,

$$X(m + n) \equiv X(n) \quad (11)$$

And

$$X(n) = \frac{1}{N}\sum_{k=0}^{N-1} x(k)\, e^{(-i2\pi n k)} \quad (12)$$

Where, j = 1……N – 1, n = 0, 1…N -1. But j and n indicate the time samples and frequency step respectively. X(m + n) can be obtained in a straight forward manner from equation (12) above.

(b) Modelling the Discretization Equation

Equations 7 and 8 are modelled using MATLAB/SIMULINK block to obtain Figures 1 and 2. However, the input ports figure 1 and 2 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 process the signals in-line their modelled mathematical derivations to obtain the discontinuous output voltage (Vp) and current (Ip) as their discrete version.

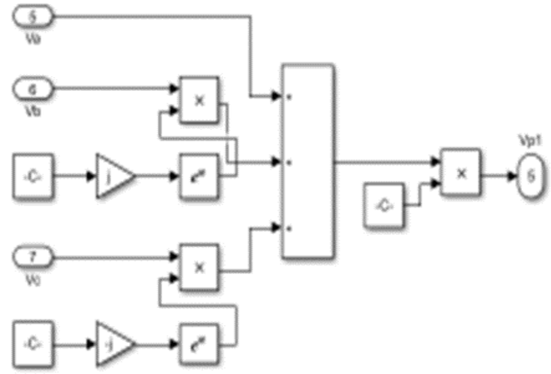

Figure 1: Discrete Voltage Simulink Block

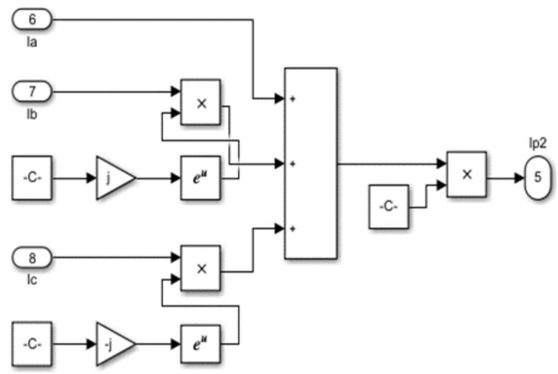

Figure 2: Discrete Current Simulink Block

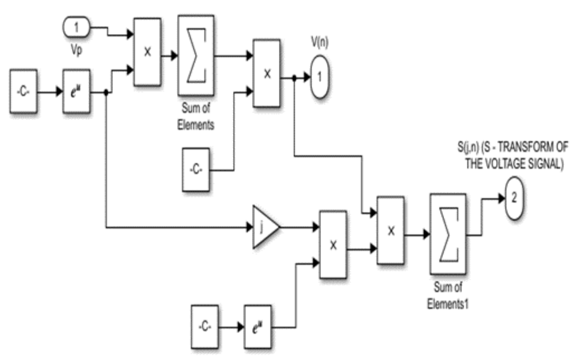

Figure 3: Discrete S -Transform Computation Model for Voltage Signal

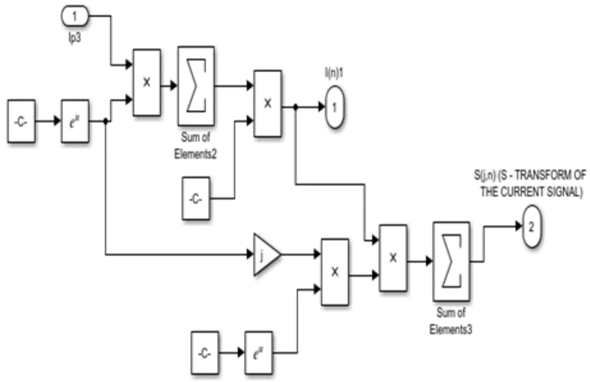

Figure 4: Discrete S -Transform Computation Model for Current Signal

(c) Location of Fault on the Power Lines using Travelling Wave

Velocity $v = \sqrt{\frac{1}{LC}}$ (13)

But

Relay impedance $Z_r = \frac{V^2}{I^2} = \frac{L}{C}$ (14)

Inductance $L = \frac{V^2 C}{I^2}$ (15)

Capacitance $C = \frac{I^2 L}{V^2}$ (16)

Therefore,

velocity $v = \sqrt{\frac{1}{\left(\frac{V^2 C}{I^2}\right) \times \left(\frac{I^2 L}{V^2}\right)}}$ (17)

The arrival times of the traveling waves on both ends of the line are compared and the fault location x is calculated according to the following formula:

$x = \frac{(D + (\tau_l - \tau_r)\, v)}{2}$ (18)

Where,

D = Total length of the line

τ_l = Departure time at the remote end

τ_r = Arrival time at the local end

v = Propagation velocity

Equation (18) is modelled using MATLAB/SIMULINK for location of any type of fault on the transmission line. Figure 10 and 11 are propagation velocity and fault location models [4][5].

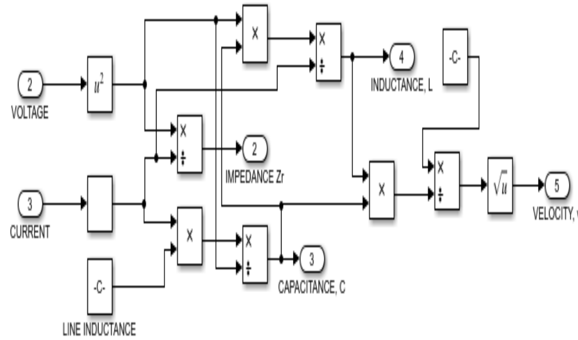

Figure 10: Traveling Wave Propagation Velocity Model

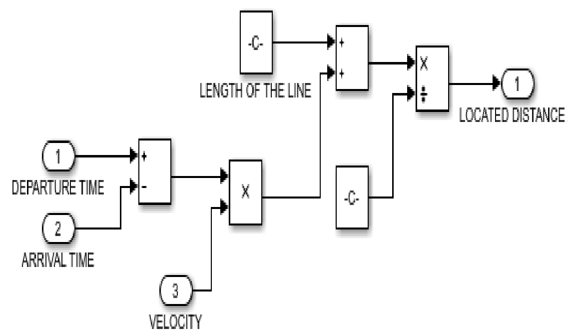

Figure 11: Traveling Wave Fault Location Model

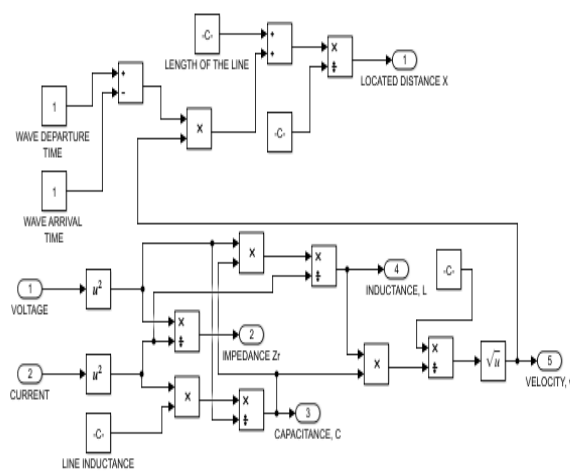

Figure 12: Traveling Wave Fault Location Model

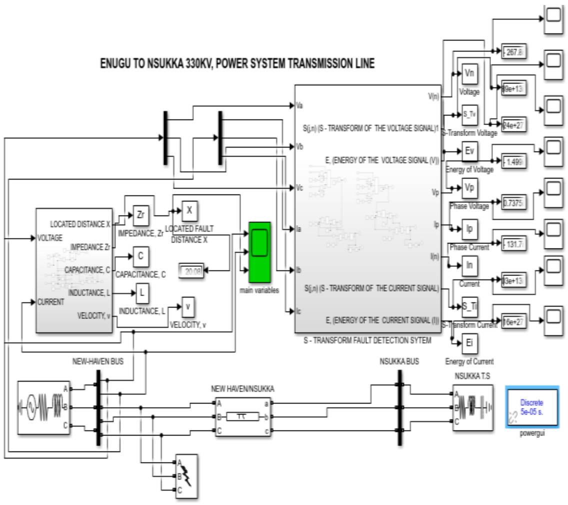

Figure 13: Typical Enugu-Nsukka Power Line MATLAB/Simulink Fault Diagnosis Model

III. RESULTS AND ANALYSIS

(i) Pre-fault Results

The transmission line is first simulated for pre-fault condition, and the following waveforms of figure 14 and 15 show that, the magnitude of pre-fault voltage is greater than that of the current. This means that, there were no fault on the line.

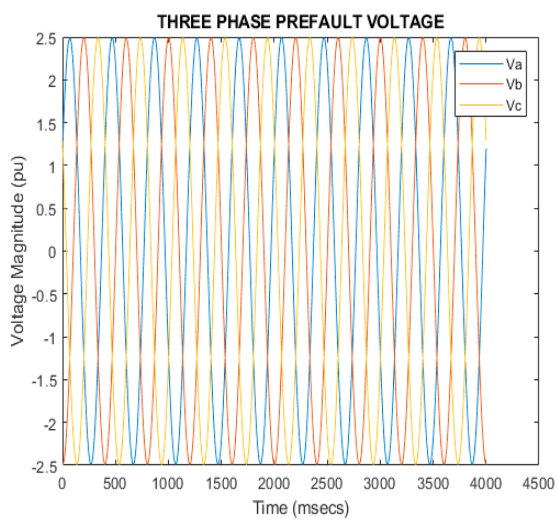

Figure 14: Pre-fault Voltage Waveform

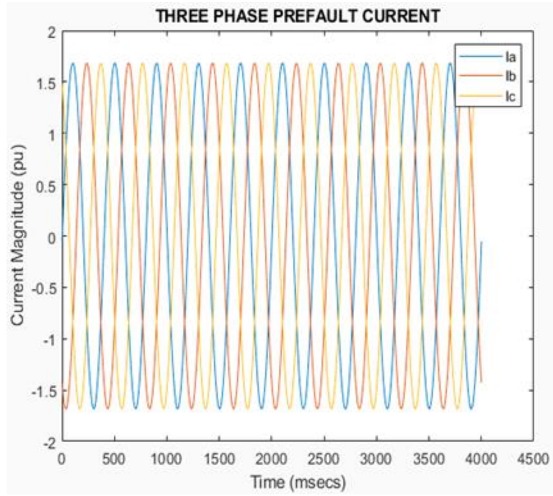

Figure 15: Pre-fault Voltage Waveform

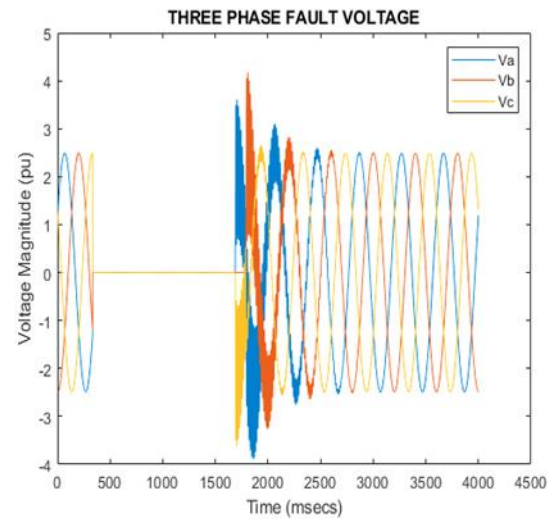

Figure 16: Three Phase fault Voltage Waveform

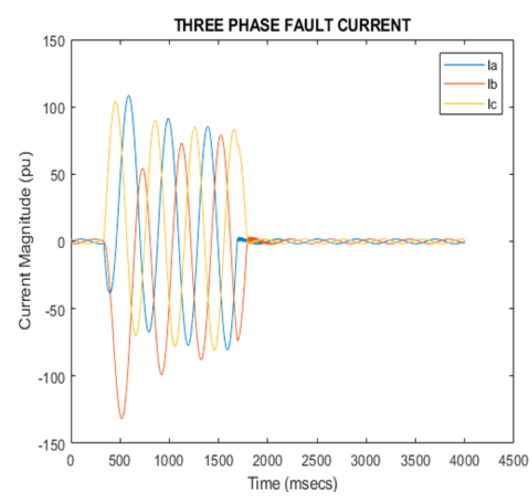

Figure 17: Three Phase fault Current Waveform

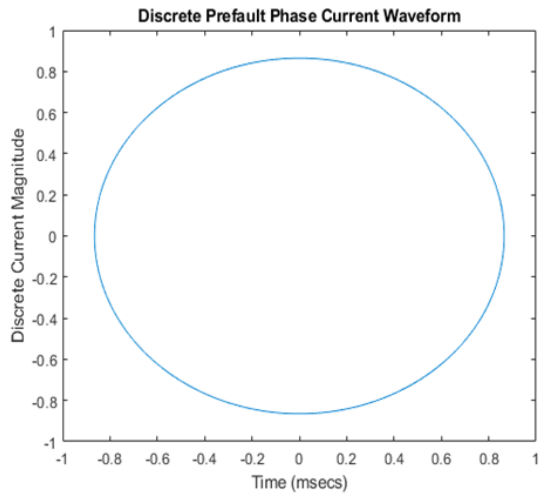

Figure 18: S-Transform Discrete Pre-fault Current Waveform

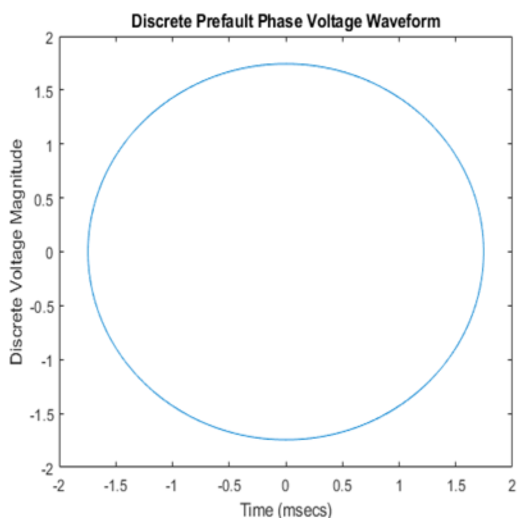

Figure 19: S-Transform Discrete Pre-fault Voltage Waveform

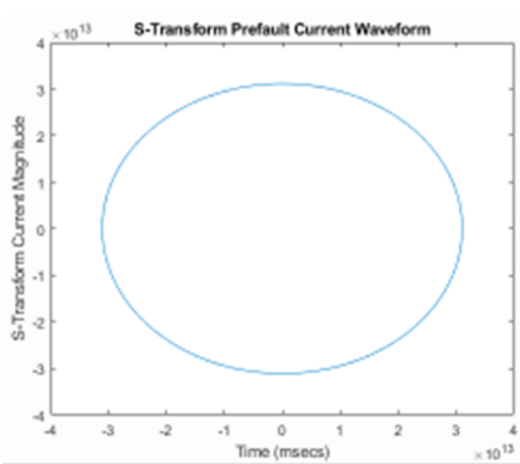

Figure 20: S-Transform Pre-fault Current Waveform

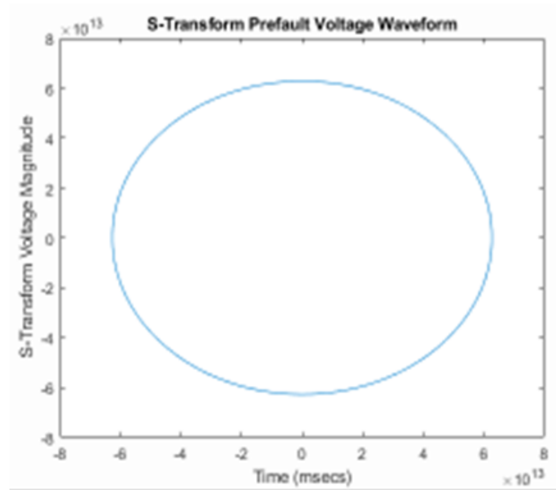

Figure 21: S-Transform Pre-fault Voltage Waveform

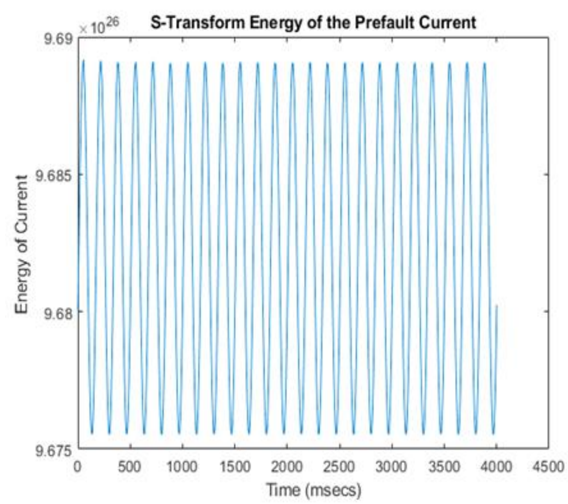

Figure 22: S-Transform Energy of Pre-fault Current Waveform

Figure 18 to 23 show the pre-fault S-Transform waveforms when the power line is in normal condition.

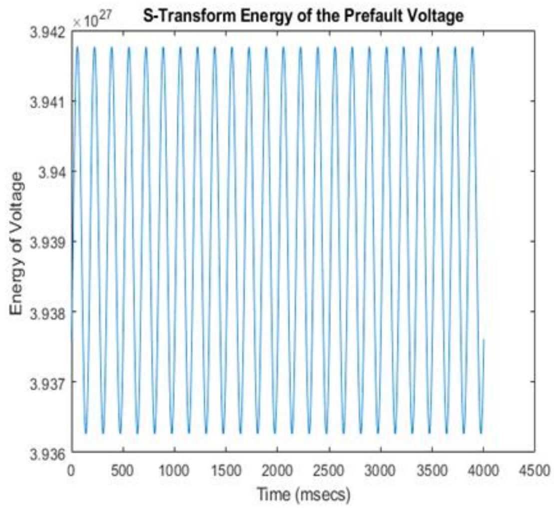

Figure 23: S-Transform Energy of Pre-fault Voltage Waveform

(ii) Three Phase Fault Result

However, when the transmission line is simulated for Three-Phase fault, the magnitude of the fault voltage signal decreased drastically while the current magnitude signal is increased. This is seen in figure 24 to 29 show the S-Transform three phase fault waveforms.

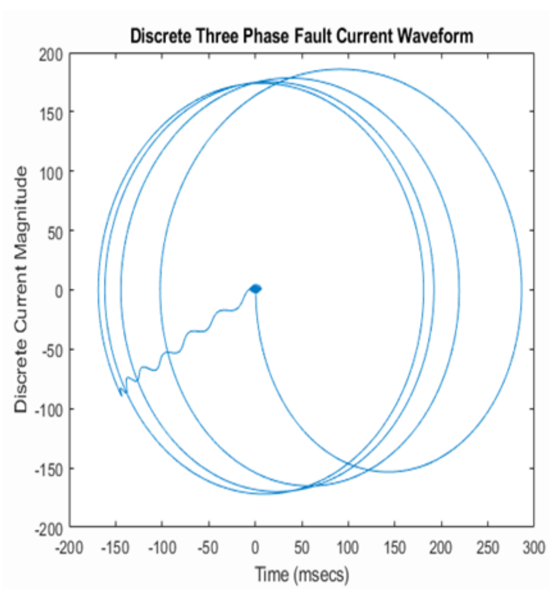

Figure 24: S-Transform Discrete Pre-fault Current Waveform

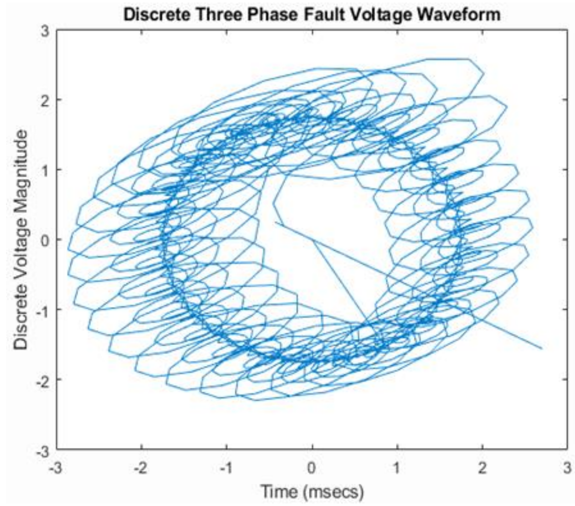

Figure 25: S-Transform Discrete Pre-fault Voltage Waveform

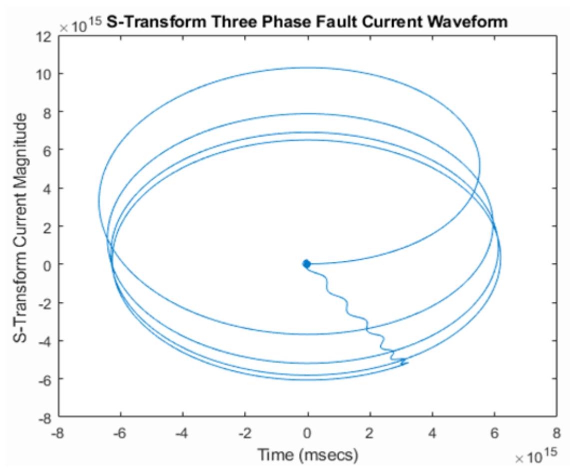

Figure 26: S-Transform Three Phase fault Current Waveform

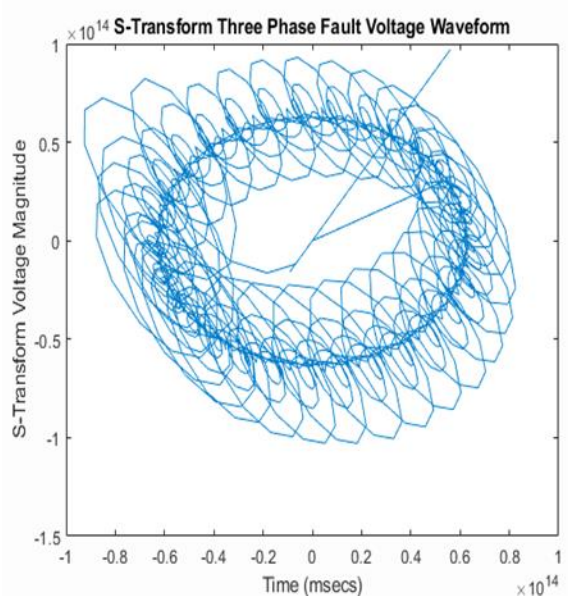

Figure 27: S-Transform Three Phase fault Voltage Waveform

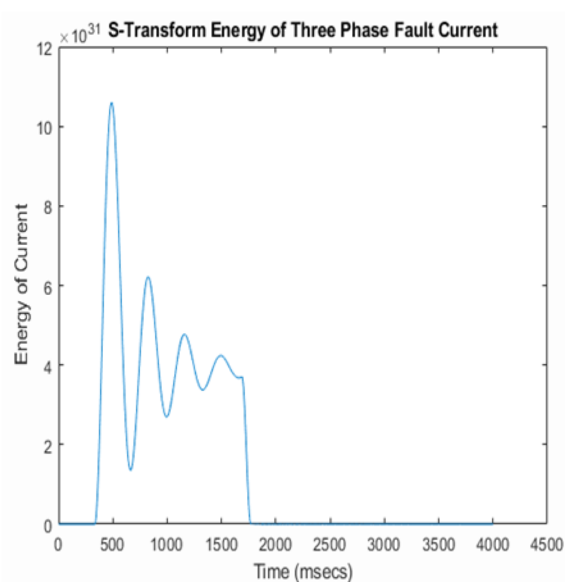

Figure 28: S-Transform Energy of Three Phase fault Current Waveform

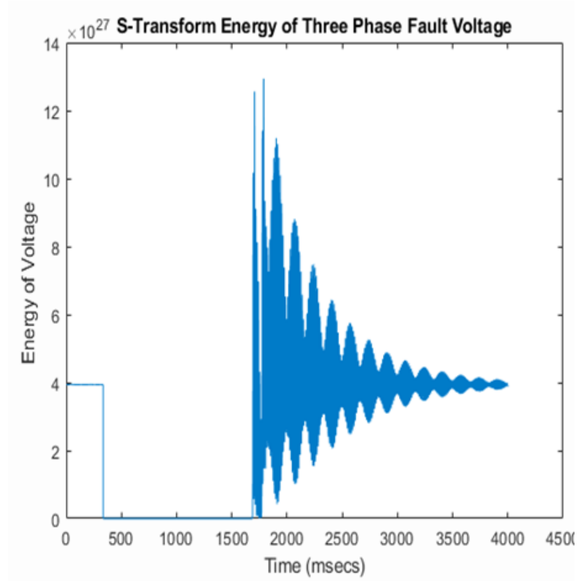

Figure 29: S-Transform Energy of Three-Phase fault Voltage Waveform

Table 1: Pre-fault & Three Phase Voltage and Current of the Line

S/N	Va	Vb	Vc	Ia	Ib	Ic	Fault Condition
1	2.5	2.5	2.5	1.6	1.6	1.6	Pre-fault
2	0.0	0.0	0.0	110	-140	100	A-B-C

Table 2: S-Transform & Discrete Values of Pre-fault & Three Phase Voltage and Current of the Line

S/N	Vp	Ip	S-Tv	S-Ti	Ev	Ei	Fault Condition
1	1.7	0.8	6e15	3e13	3.9e27	9.7e.24	Pre-fault
2	2.5	180	1e14	11e15	13e27	11e31	A-B-C

Where,

Va, Vb & Vc are phase voltages of the three lines. While Ia, Ib & Ic are phase currents of the three lines. Vp and Ip are Discrete voltage and current signals respectively. S-Ti and S-Tv are S-Transform current and voltage computed. However, Ev and Ei are S-Transform Energy of voltage and current computed which tells more about the abnormal or fault condition of the line.

From the above Tables 1 and 2, one can observe that, pre-fault voltage magnitude is greater than that of current. While the three-phase fault voltage magnitude is less than the current counterpart.

This is the same when S-Transformation is applied to the transmission line to determine if fault occurred on the line.

One can observe that, all the three phase S-Transform Current parameters are all greater than their voltage counterpart. This is due to the presence of fault on the line.

(d) Location of Fault Distance

The Enugu – Nsukka Power System transmission line is a 200km power line. In this section, the line is divided into total line distance from 100Km, 120Km, 140Km, 160Km, 180Km, 200Km five possible outcomes. Travelling wave technique is applied to locate three-phase (A-B-C) fault distance on each of lines. The results obtained, its analysis is shown on table 3 and discussed below.

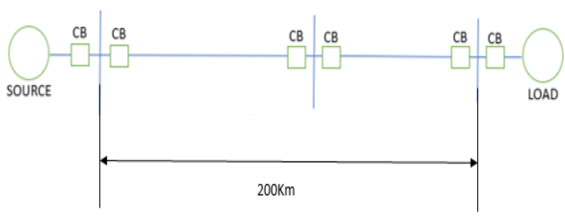

Figure 30: Single Line Diagram of Enugu – Nsukka Transmission Line

Table 3: Location of Three-Phase Fault (A-B-C) Distance using MATLAB/Simulink Traveling Wave Model

S/N	Line Length (Km)	Line Impedance Z (pu)	Located Distance (Km)	Propagation Velocity (m/s)	Wave Departure Time τ_l	Wave Arrival Time τ_r
1	100	0.68	52.0	0.95	0.48	1.80
2	120	0.60	60.3	0.92	0.48	1.80
3	140	0.56	72.2	0.85	0.48	1.80
4	160	0.52	80.2	0.83	0.48	1.80
5	180	0.48	94.1	0.80	0.48	1.80
6	200	0.43	91.5	0.75	0.48	1.80

Table 3 illustrates the results obtained when traveling wave mathematical model is employed for the location of fault distance on Enugu – Nsukka 330KV power system transmission line. Here, only three-phase fault result is shown since it will very ambiguous to show all the results obtained when the traveling wave model is employed for both symmetrical and unsymmetrical faults.

The table 3 is the simulation results obtained when the fault location MATLAB/Simulink model of figure 12 is simulated for symmetrical (three-phase fault) fault. The results show that, as the line length increases, the located fault distance increases with decrease in impedance and the propagation velocity of the wave signals. This is because of the change in topography of the line and change in incident point of fault (Anazia A.E., 2014 and Ogboh V.C., 2015).

This is in line with the standard that, the shorter the distance of the power lines, the shorter the line length, due to the closeness of the traveling waves traveling through the power lines and which does not experience much disturbance on the line, the more stable and steady the impedance of the line. But, the longer the length of the line, the lesser the impedance and the more the line is exposed to various disturbances such as line losses, symmetrical and unsymmetrical faults, effects of wind force etc. [5][1].

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