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A New Fast Fourier Transform Algorithm for Fault Detection on the Power System Transmission Line

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***Abstract-* Fourier Transform is one of the mathematical technique use in power system fault analysis. It is employed in this work as a fundamental mathematical derivation to obtain its discrete and fast equivalent algorithm that are used in this research. A flowchart diagram is developed which shows the developmental stages of the algorithms. The DFT and FFT detection algorithms are developed based on their individual applications of Fourier Transform (FT) discretization of phase values of voltage and current to obtain the discrete versions (V_P and I_P) as the required data for the research. The discretization is followed by DFT and FFT applications to the output result (V_P and I_P) of the discretization to obtain the time – domain and frequency – domain components. Computer approach shows that DFT algorithm gave a higher voltage magnitude of 4.2pu and lowers three phase fault voltage magnitude of 2.8pu. It also gave an equal current and impedance magnitudes for pre-fault and three phase fault conditions. However, when FFT algorithm is applied, it gave equal magnitudes of voltages, currents and impedance for pre-fault and three phase fault conditions.**

***Indexed Terms-* DFT, FFT, Algorithm, Voltage, Current, Impedance, Transmission Line, Faults, Frequency, Matlab, Simulink**

I. INTRODUCTION

Owing to rapid growth in the world's population and the need for countries to grow and advance in technology and economy, the demand for electrical energy had geometrically progressed. This demand had resulted to dramatic expansion in the existing electrical infrastructures, such as power transmission grids, generation and distribution networks so as to accommodate the growing load demand and ensure fairly constant power supply to the end users. This complex system does not exist without turbulence such as symmetrical and unsymmetrical faults. The effect of these cannot be underestimated as this situation negatively affects the country's economic activity and that of the world at large.

In order to summout this adverse effect, the fault developed on the power system transmission line must be cleared as fast as possible to enable the isolated part of the transmission line due to fault, receive power supply and to prevent further damage of the power system equipment or total black – out in the country.

Various methods have been employed for detecting, classifying, locating and analyzing these faults. They include; Impedance measurement based method Travelling wave based method Signal processing based method (Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), Wavelet (WT) and S-Transform (ST) Artificial Intelligent system (AI) based method etc.

II. METHODOLOGY

Methodological procedure followed in this research is shown on figure 1. The Modeling of the power system transmission line shown in figure 2 is done using Matlab/Simulink. The modeled transmission line is shown on figure 4.

$$v_p(n) = \frac{2}{3}[\, v_a + v_b(n)e^{\frac{j2\pi}{3}} + v_c(n)e^{\frac{-j2\pi}{3}}\,] \qquad 2.1$$

$$i_p(n) = \frac{2}{3}[\, i_a + i_b(n)e^{\frac{j2\pi}{3}} + i(n)e^{\frac{-j2\pi}{3}}\,] \qquad 2.2$$

$$v(t) = V_p \sin(\theta + \emptyset) \qquad 2.3$$

$$i(t) = I_p \sin(\theta + \varphi) \qquad 2.4$$

$$V_x(n) = \sum_{n=0}^{N-1} v(t)e^{\frac{-j2\pi n}{N}} \qquad 2.5$$

$$I_x(n) = \sum_{n=0}^{N-1} i(t)e^{\frac{-j2\pi n}{N}} \qquad 2.6$$

$$V(k) = \sum_{0}^{3} v(n) e^{\frac{-j\pi nk}{2}} = \sum_{0}^{3} v(n)(-j)^{nk} \qquad 2.7$$

$$I(k) = \sum_{0}^{3} i(n) e^{\frac{-j\pi nk}{2}} = \sum_{0}^{3} i(n)(-j)^{nk} \qquad 2.8$$

Per unit three phase values of the transmission line were generated from the modeled line using an existing Benin to Onitsha 330/132kV transmission line parameters. The three phase values at no fault condition and that under three phase fault were used as input values of the discrete equation 2.1 and 2.2.

The output discrete values V_P and I_P were used as input values for the determination of complex or normal voltage or current values shown in equation 2.3 and 2.4. Then, output results of equations 2.5 and 2.6.

However, equations 2.5 and 2.6 are used to compute the DFT voltage and current values. While equations 2.7 and 2.8 were used to compute the FFT voltage and current values.

The DFT and FFT output values were used to plot the time dependent graph (time – Domain) and spectrum graph (frequency – domain) shown on figures 3.1 to 3.28 which shows the magnitude or amplitude of the signal relationship with frequency (Nimrod Peleg, 2002).

The Vx(n) or Ix(n) is the DFT of the sequence v(n), or I(n) and using v(n) and I(n) equal to;
$V(n) = [v(0), v(1), v(2), v(3)]^T$ and $I(n) = [I(0), I(1), I(2), I(3)]^T$ respectively for 4 – point DFT application having
N = 4 (number of DFT samples).

Computer **(**Simulation**)** Approach**:** Here the mathematical equations that constitutes the algorithm forcomputing DFT and FFT applications for fault detection is modeled using Matlab – Simulink 2016a. The modeled algorithm diagrams for DFT and FFT voltage and current normal and fault conditions is shown on Figure 4 and 5 respectively.

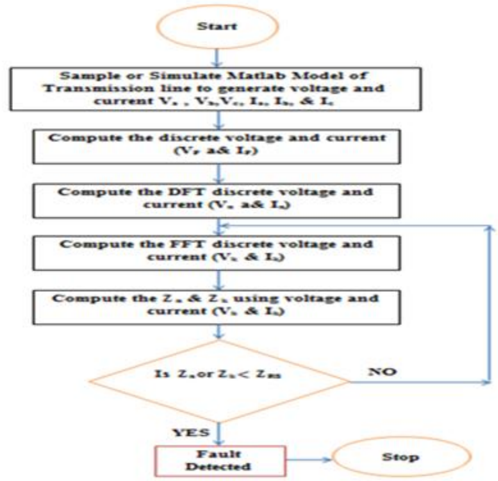

Figure 1: Flowchart diagram forthe detection algorithm

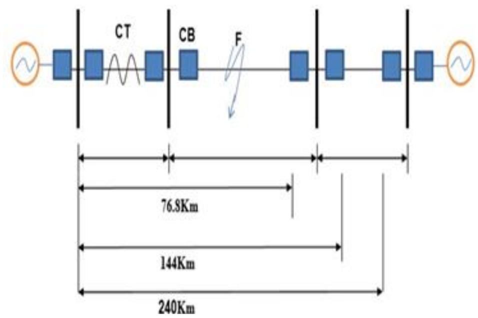

Figure 2: 330/132KV transmission linerepresenting Onitsha – Enugu

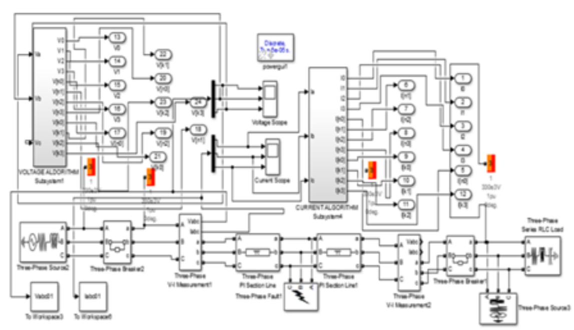

Figure 3: DFT & FFT Fault DetectionMatlab/Simulink Algorithm connected tothe 330/132KV Onitsha Power System Transmission Line

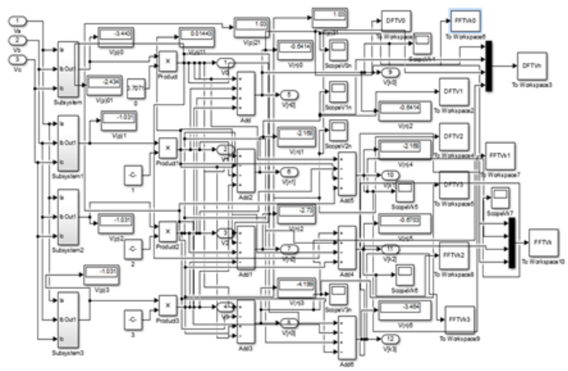

Figure 4: DFT & FFT Fault DetectionMatlab/Simulink Voltage Algorithm

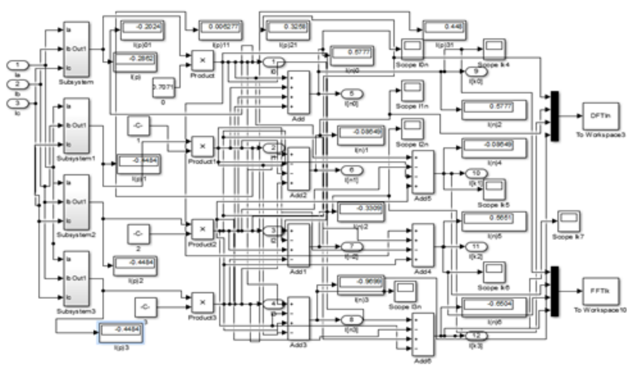

Figure 5: DFT & FFT Fault DetectionMatlab/Simulink Current Algorithm

Figure 3 represent the modeled transmission line containing the diagnostic algorithm subsystems for fault detection and classification. A flowchart of figure 1 illustrates the algorithmic process for diagnosis of fault on the transmission line.

The algorithm for fault detection for both DFT and FFT application is developed using equations 2.1 to 2.8. The equations are modelled using Matlab/Simulink 2016a as the developed algorithms. The internal structure of the modelled equations for the implementation of the proposed algorithm is shown on Figures 4 and 5

III. SIMULATION AND RESULT ANALYSIS

Table 1: Computer Approach Pre-fault discrete voltage, current and impedance values

S/N	$v_p(n)$	$i_p(n)$	$z_p(n)$	FAULTS
1	-3.4440	-0.2854	12.0673	L – G
2	-1.0310	-0.4488	2.2972	LL – G
3	-1.0310	-0.4488	2.2972	L – L
4	-1.0310	-0.4488	2.2972	LLL

Table 2: Computer Approach Three phase fault discrete voltage, current and impedance values

S/N	$v_p(n)$	$i_p(n)$	$z_p(n)$	FAULTS
1	-3.4430	-0.2862	12.0300	L – G
2	-1.0310	-0.4488	2.2972	LL – G
3	-1.0310	-0.4488	2.2972	L – L
4	-1.0310	-0.4488	2.2972	LLL

Table 1and 2 illustrate the discrete values (V_p and I_p) obtained for pre-fault and fault conditions under four categories of fault. One symmetrical and three unsymmetrical faults.

The DFT is applied to the discrete values following the methodological procedure stated in section 2 to determine the time – domain and frequency – domain components which contain the information such as fault information about the transmission line.

Table 3: Computer Approach DFT Application for Pre-fault Condition at N – POINTS (k = 0… N – 1)

S/N	N - POINTS	$V_{0,1,2,3}$ for N = 4	$I_{0,1,2,3}$ for N = 4	V(n)	I(n)	Z(n)	FAULTS
1	0	-2.4360	-0.2018	-0.6422	0.5790	-1.1092	LLL
2	1	0.0144	0.0063	-2.1690	-0.0858	25.2797	LLL
3	2	1.0300	0.3261	-2.7310	-0.3304	8.2657	LLL
4	3	1.0300	0.4484	-4.2000	-0.9701	4.3295	LLL

Table 4: Computer Approach DFT Application for Three Phase Fault Condition at N – POINTS (k = 0… N – 1)

S/N	N - POINTS	$V_{0,1,2,3}$ for N = 4	$I_{0,1,2,3}$ for N = 4	V(n)	I(n)	Z(n)	FAULTS
1	0	-2.4340	-0.2024	-0.6412	0.5777	-1.1099	LLL
2	1	0.0144	0.0063	-2.1680	-0.0865	25.0636	LLL
3	2	1.0300	0.3258	-2.7300	-0.3309	8.2502	LLL
4	3	1.0300	0.4480	-4.1990	-0.9699	4.3293	LLL

Table 5: Computer Approach FFT Application for Pre-fault Condition at N – POINTS (k = 0,…, N – 1)

S/N	N - POINTS	$DFTV_{0,1,2,3}$ for N = 4	$DFTI_{0,1,2,3}$ for N = 4	FFT V(k)	FFT I(k)	FFT Z(k)	FAULTS
1	0	-2.4360	-0.2018	-0.6422	0.5790	-0.3718	LLL
2	1	0.0144	0.0063	-2.1690	-0.8581	2.5277	LLL
3	2	1.0300	0.3261	-0.6711	0.5664	-1.1849	LLL
4	3	1.0300	0.4484	-3.4650	-0.6503	5.3283	LLL

Table 6: Computer Approach FFT Application for Three Phase Fault Condition at N – POINTS (k = 0,…, N – 1)

S/N	N - POINTS	$DFTV_{0,1,2,3}$ for N = 4	$DFTI_{0,1,2,3}$ for N = 4	FFT V(k)	FFT I(k)	FFT Z(k)	FAULTS
1	0	-2.4340	-0.2024	-0.6414	0.5777	-1.1103	LLL
2	1	0.0144	0.0063	-2.1680	-0.0865	25.0636	LLL
3	2	1.0300	0.3258	-0.6703	0.5651	-1.1862	LLL
4	3	1.0300	0.4480	-3.4640	-0.6504	5.3260	LLL

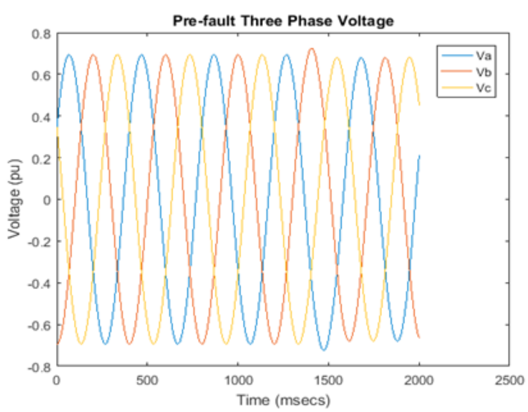

Figure 3.1: Computer Approach Pre-fault Three Phase Voltage Waveform

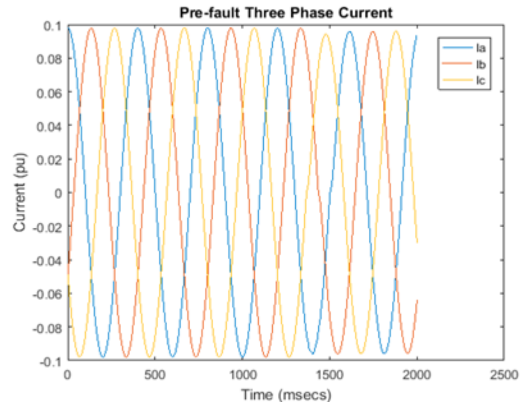

Figure 3.2: Computer Approach Pre-fault Three Phase Current Waveform

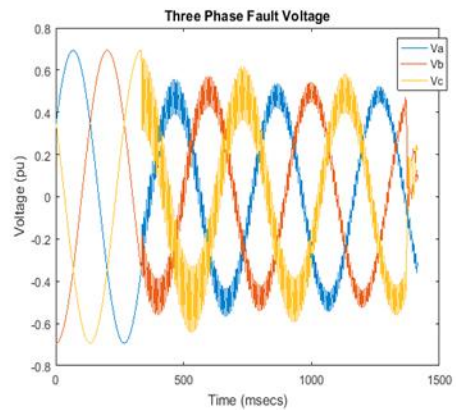

Figure 3.3: Computer Approach Three Phase Fault Voltage Waveform

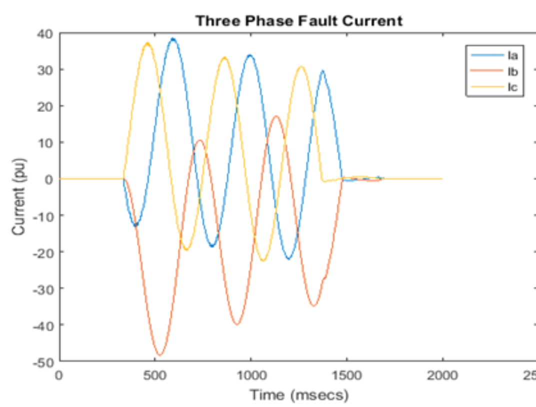

Figure 3.4: Computer Approach Three Phase Fault Current Waveform

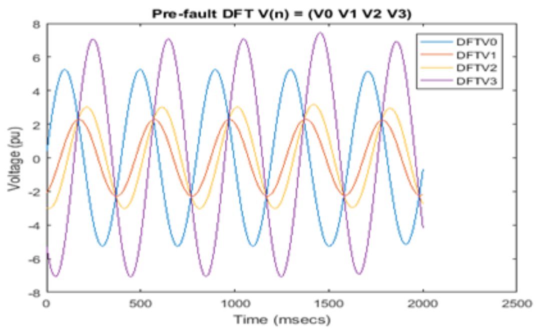

Figure 3.5: Computer Approach Three Phase Pre-fault DFT Voltage Waveform

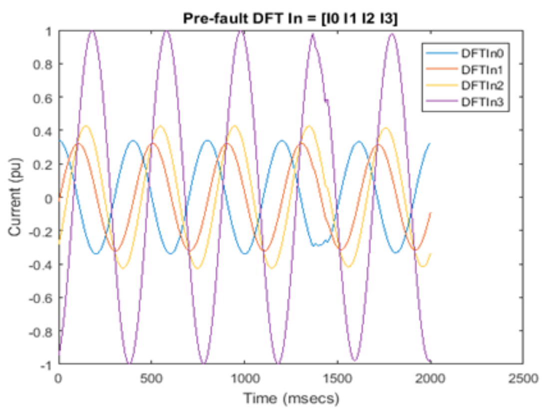

Figure 3.6: Computer Approach Three Phase Pre-fault DFT Current Waveform

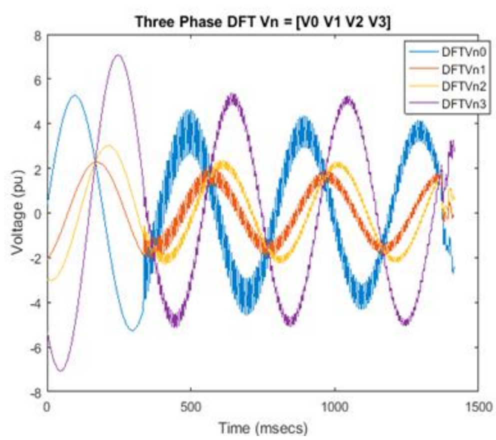

Figure 3.7: Computer Approach Three Phase Fault DFT Voltage Waveform

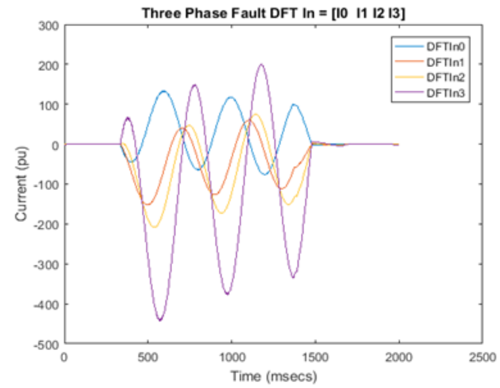

Figure 3.8: Computer Approach Three Phase Fault DFT Current Waveform

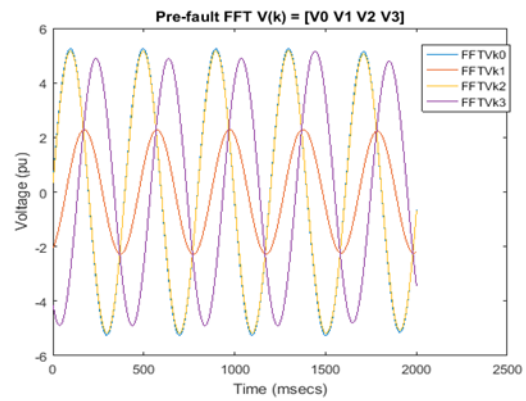

Figure 3.9: Computer Approach Three Phase Pre-fault FFT Voltage Waveform

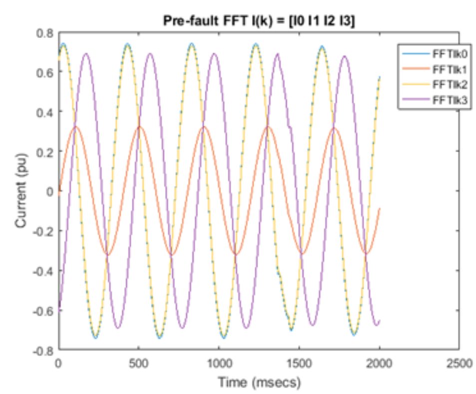

Figure 3.10: Computer Approach Three Phase Pre-fault FFT Current Waveform

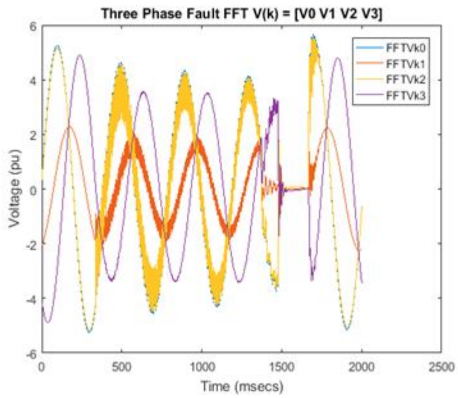

Figure 3.11: Computer Approach Three Phase Fault FFT Voltage Waveform

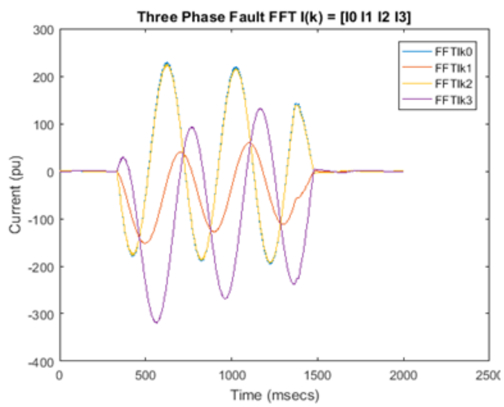

Figure 3.12: Computer Approach Three Phase Fault FFT Current Waveform

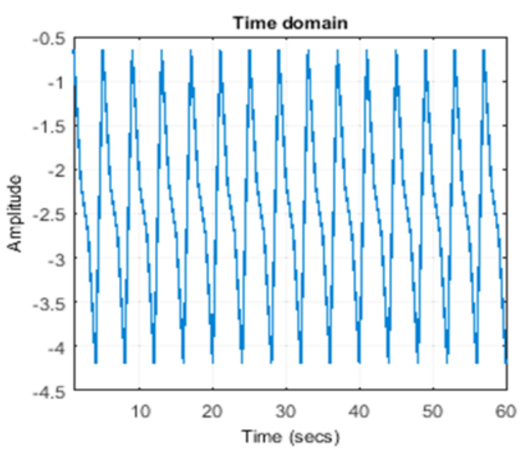

Figure 3.13: Computer Approach Pre-Fault DFT Voltage (Vn) Signal Waveform

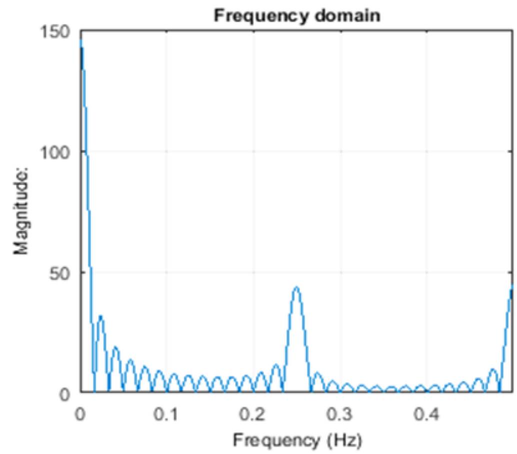

Figure 3.14: Computer Approach Pre-Fault DFT Voltage (Vn) Signal Waveform

Figure 3.14 is the time and frequency – domain pre-fault DFT voltage signal waveform obtained by plotting the V_n against time t and frequency respectively. The waveform is not sinusoidal even at No fault condition. It also shows that the maximum amplitude of V_n is -0.6pu maximum and -4.2 minimum at time of 2secs and largest magnitude of 48pu at 0.25Hz.

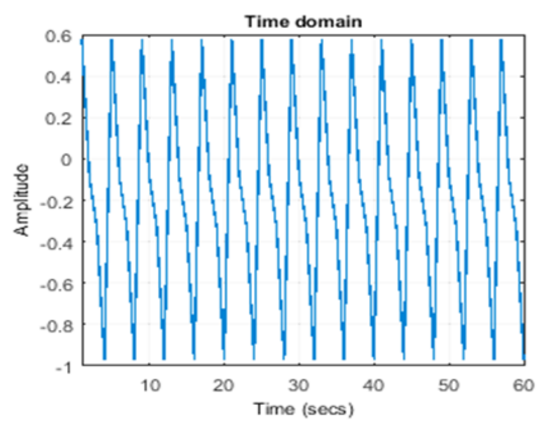

Figure 3.15: Computer Approach Pre-Fault DFT Current (In) Signal Waveform

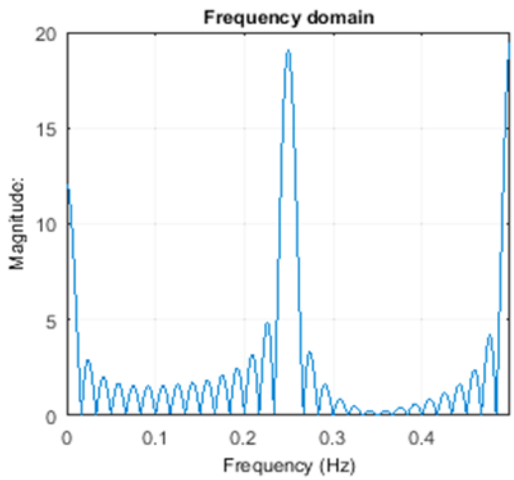

Figure 3.16: Computer Approach Pre-Fault DFT Current (In) Signal Waveform

Figure 3.16 is the time and frequency – domain pre-fault DFT current signal waveform obtained by plotting the I_n against time t and frequency respectively. It also shows that the maximum amplitude of I_n is 0.6pu maximum and -0.9 minimum at time of 2secs and largest magnitude of 18pu at 0.25Hz.

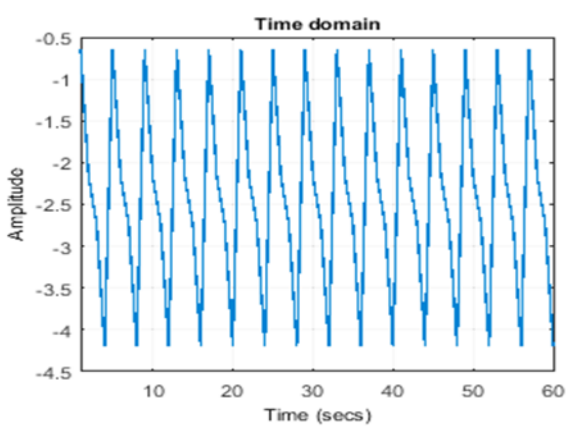

Figure 3.17: Computer Approach Three Phase Fault DFT Voltage (Vn) Signal Spectrum Waveform

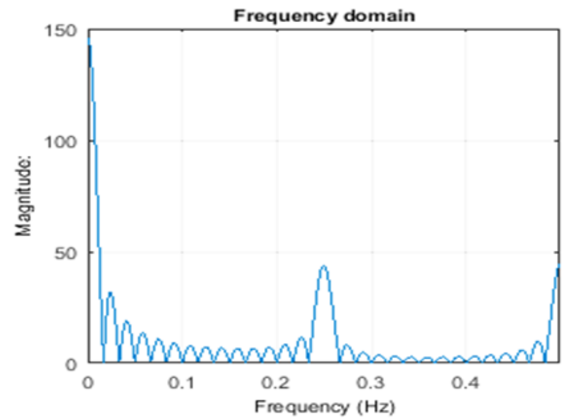

Figure 3.18: Computer Approach Three Phase Fault DFT Voltage (Vn) Signal Spectrum Waveform

Figure 3.18 is the time and frequency – domain three phase fault DFT voltage signal waveform obtained by plotting the V_n against time t and frequency respectively. It also shows that the maximum amplitude of V_n is -1.4pu at time of 2secs and largest magnitude of 48pu at 0.25Hz.

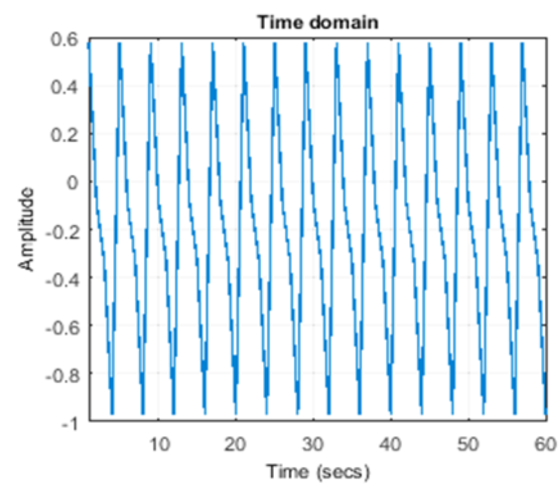

Figure 3.19: Computer Approach Three Phase Fault DFT Current I(n) Signal Spectrum Waveform

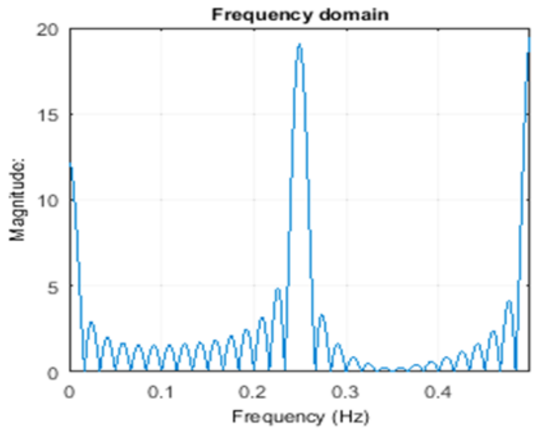

Figure 3.20: Computer Approach Three Phase Fault DFT Current I(n) Signal Spectrum Waveform

Figure 3.20 is the time and frequency – domain three phase fault DFT current signal waveform obtained by plotting the I_n against time t and frequency respectively. It also shows that the maximum amplitude of I_n is 0.6pu at time of 2secs and largest magnitude of 18pu at 0.25Hz.

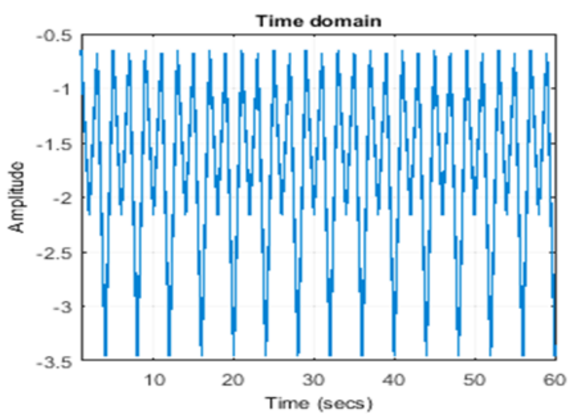

Figure 3.21: Computer Approach Pre-Fault FFT Voltage V(k) Signal Spectrum Waveform

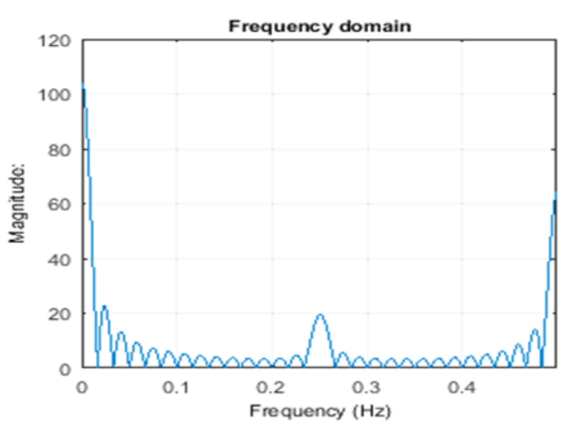

Figure 3.22: Computer Approach Pre-Fault FFT Voltage V(k) Signal Spectrum Waveform

Figure 3.22 is the time and frequency – domain pre-fault FFT voltage signal waveform obtained by plotting the V_k against time t and frequency respectively. It also shows that the maximum amplitude of V_k is -0.6pu at time of 2secs and largest magnitude of 20pu at 0.25Hz.

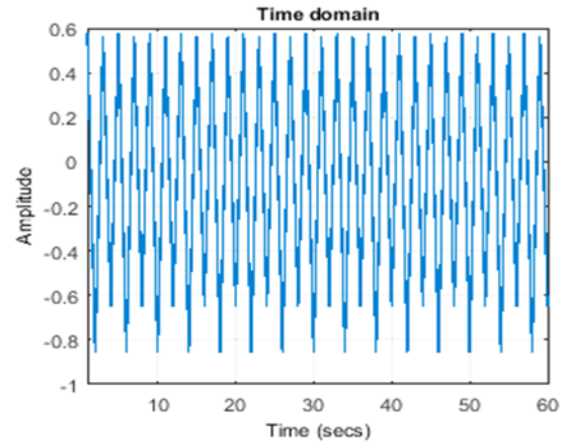

Figure 3.23: Computer Approach Pre-Fault FFT Current I(k) Signal Spectrum Waveform

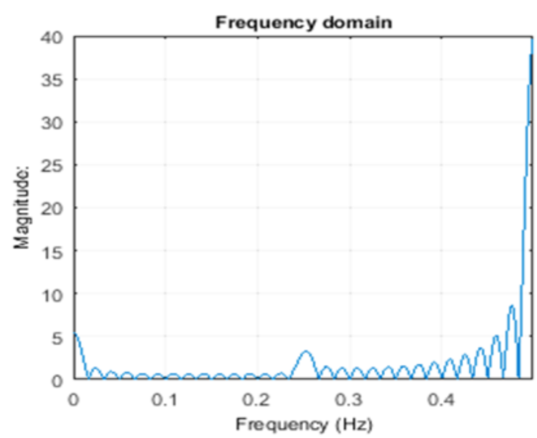

Figure 3.24: Computer Approach Pre-Fault FFT Current I(k) Signal Spectrum Waveform

Figure 3.24 is the time and frequency – domain pre-fault FFT current signal waveform obtained by plotting the I_k against time t and frequency respectively. It also shows that the maximum amplitude of I_k is 0.6pu at time of 2secs and largest magnitude of 3.6pu at 0.25Hz.

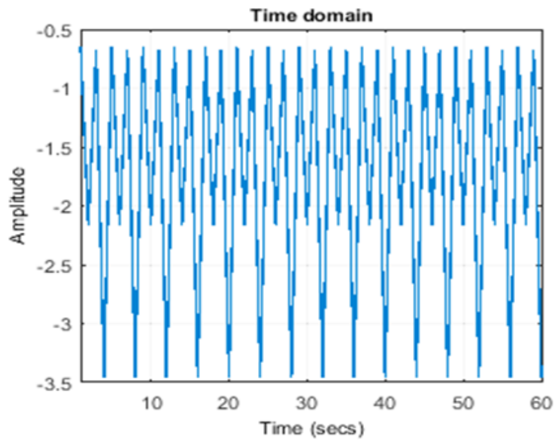

Figure 3.25: Computer Approach Three Phase Fault FFT Voltage V(k) Signal Spectrum Waveform

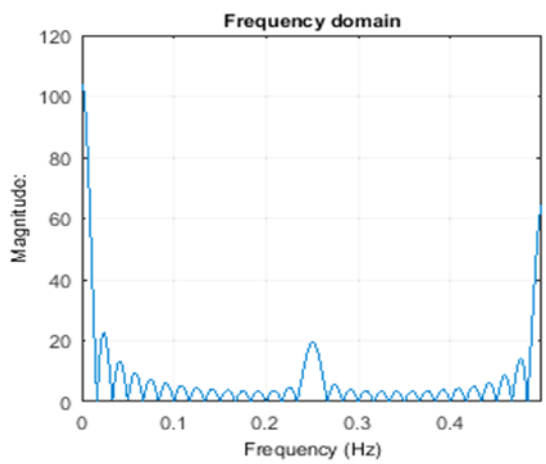

Figure 3.26: Computer Approach Three Phase Fault FFT Voltage V(k) Signal Spectrum Waveform

Figure 3.26 is the time and frequency – domain three phase fault FFT voltage signal waveform obtained by plotting the V_k against time t and frequency respectively. It also shows that the maximum amplitude of V_k is -0.6pu at time of 2secs and largest magnitude of 20pu at 0.25Hz.

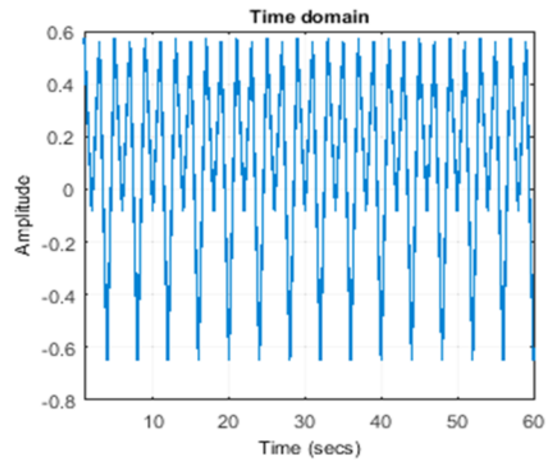

Figure 3.27: Computer Approach Three Phase Fault FFT Current I(k) Signal Spectrum Waveform

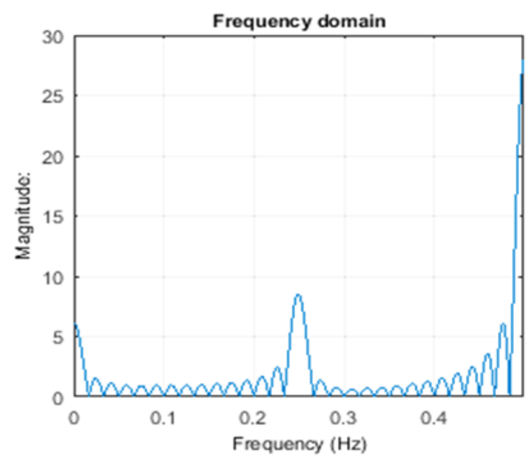

Figure 3.28: Computer Approach Three Phase Fault FFT Current I(k) Signal Spectrum Waveform

Figure 3.28 is the time and frequency – domain three phase fault FFT current signal waveform obtained by plotting the I_k against time t and frequency respectively. It also shows that the maximum amplitude of I_k is 0.6pu at time of 2secs and largest magnitude of 8pu at 0.25Hz.

Notice that the frequency of occurrence of the three phase fault using both approaches is constant at 0.25Hz. This is to show that the results obtained are correct.

According to Robi P. (2013) and Capolino et al (2003) in chapter two of this research, the frequency spectrum of any signal is basically the frequency components of that signal. It shows that the frequencies that exist in that signal tell more about the condition of the signal (healthy or faulty conditions). He continued that, whenever a waveform or its magnitude or frequency components changes from its original form of normal healthy condition, it then means that the signal whose frequency components changes is not healthy and has been affected by unwanted disturbance which is referred to as fault in power system.

However, we conclude that such signals such as voltage and current fault signals of a transmission line obtained when the DFT or FFT algorithm is applied using mathematical or computer (simulation) approach contains fault information that describes the faulty condition of the transmission line. Thus, the mathematical and computer algorithm has been used to detect three phase fault occurred on the transmission line.

Comparing the pre-fault and three phase fault signal DFT and FFT waveforms with respect to their tables, one can easily observe an increase in the amplitude or magnitude of the three phase fault current signals as against the amplitude or magnitude of the three phase fault voltage signal. This is opposite of what we have in the amplitude or magnitude of the pre-fault voltage and current signals.

For instance, using mathematical approach, DFT pre-fault voltage gives 14pu while its current gives 0.6pu. But DFT three phase fault voltage gives 2.0pu while that of current gives 2.8pu. The FFT pre-fault voltage gives 1.6pu while its current is 1.25pu. But FFT three phase fault voltage gives 1.6pu while its current is 2.4pu.

This is in conformity with the characteristics of fault on the power system, were the increase in DFT and FFT fault current magnitude and decrease in the voltage magnitude is because of the presence of fault on the line which caused increase in current, thus over-current fault (three phase fault).

While using computer (simulation) approach, DFT pre-fault voltage gives -0.60pu maximum and -4.2pu minimum while its current gives 0.6pu maximum and -0.9pu minimum. But DFT three phase fault (three phase fault) voltage gives -0.57pu maximum and -4.15pu minimum.

The same is observed in DFT discretized voltage and current magnitudes. Where $Vn = [V0\ V1\ V2\ V3]^T$ gives varied values and have V_3= 7.0pu which is the largest magnitude among other N – point values with I_3 = 1.0pu. But when DFT is applied for three phase fault simulation, it gave a fault current magnitude of I_3 = -400pu which is very large current magnitude.

However, FFT applied for pre-fault condition gave V2 = 5pu as the largest magnitude and current I_2 = 0.75pu. While when simulated with three phase fault gives V(k) = [V0 V1 V2 V3] = 0, I_3 = -320pu and I_2 = 220pu.

This sharp increase is an evidence of fault. Thus, due to the presence of fault on the transmission line, the transmission line under fault condition is characterized by the increase in current magnitude greater than the voltage magnitude making the impedance smaller than the relay preset value. On this condition, the relay will send a tripping signal to the circuit breaker to isolate the faulty section of the line.

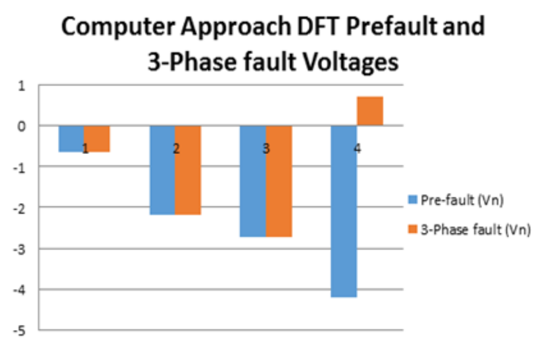

Figure 3.29: Computer Approach DFTPre-fault and Three Phase fault Voltage

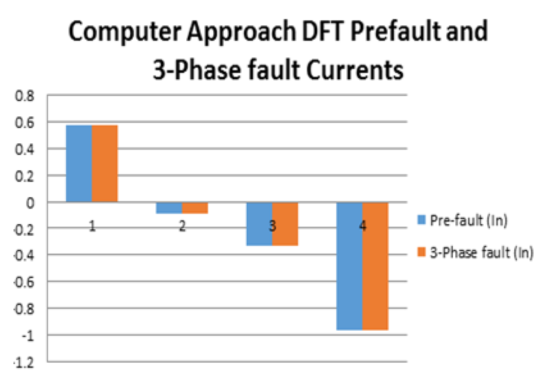

Figure 3.30: Computer Approach DFTPre-fault and Three Phase fault Currents

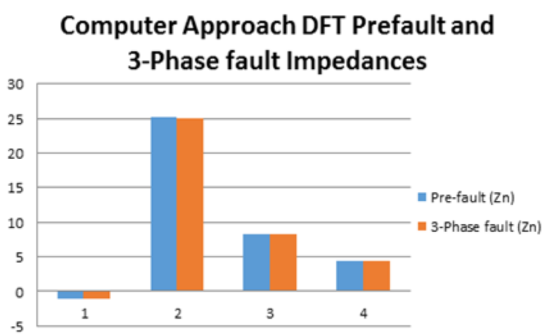

Figure 3.31: Computer Approach DFTPre-fault and Three Phase fault Impedances

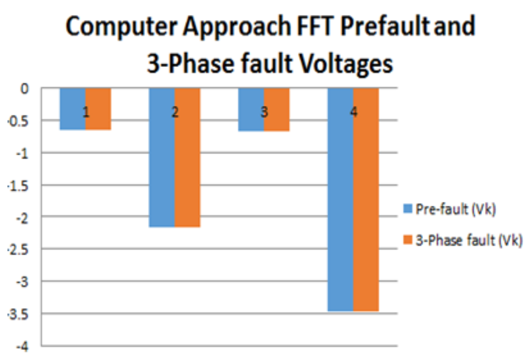

Figure 3.32: Computer Approach DFTPre-fault and Three Phase fault Voltages

Here, the magnitude of voltage for both pre-fault and three phase fault is equal.

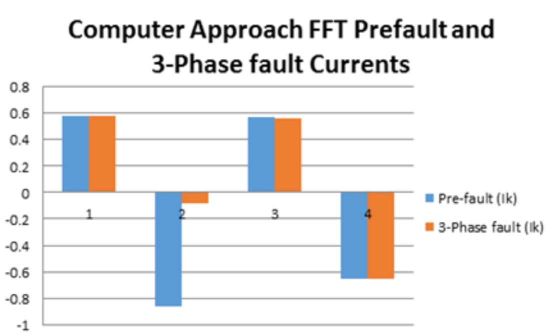

Figure 3.33: Computer Approach DFTPre-fault and Three Phase fault Currents

The pre-fault and three phase current is almost equal except on N = 1, where the pre-fault current higher than that of three phase fault by 0.6pu.

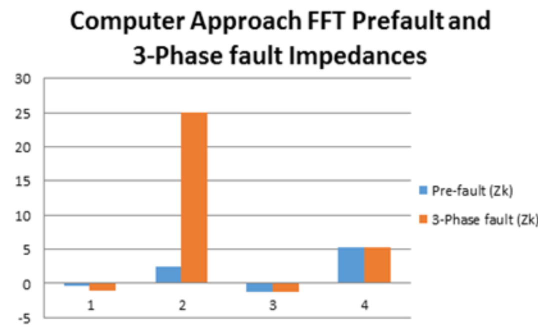

Figure 3.34: Computer Approach DFTPre-fault and Three Phase fault Impedances

The three phase fault is supposed to be lesser than that of pre-fault value but here it is far higher than that of pre-fault.

REFERENCES

[1] Müslüm A. 2010. 'FFT Based Fault Location Algorithm for Transmission Lines'Inonu University, Engineering Faculty, Electrical & Electronics Eng. Dept., Malatya, Turkey, 1mehmet.mamis@inonu.edu.tr, 2muslum.arkan@inonu.edu.tr

[2] Chengzong P., Mladenk, Zhang N., 2010. 'Wavelet Based Method for Transmission Line Fault Detection and Classification During Power Swing', Texas A & M University College Station, TX77843, USA, WERC 323, MS 3128

[3] Reddy B. R., 2009, 'Detection and Location of Faults on Transmission Line Using Coiflet Mother Wavelet Transform', Journal of Theoretical and Applied Information Technology. 2005 – 2009. www.jatit.orgWikipedia, 2017

[4] Turan G.' Modern Power System Analysis'.John Wiley and Sons Inc. publishing. TK 1001. G66. 1987. ISBN 0 - 471 – 85903 – 6.

[5] Nimrod P., 2002, 'Fast Fourier Transform Document'.

[6] Capolino G. A., Henao H. Assaf T. 'Discrete Fourier Transform for Computation of Symmetrical Components Harmonics'. 2003 IEEE Bologna, Italy.