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Total Harmonic Distortion in a Short Distribution Line of Varying Busbar Loads

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Abstract

In Electric Power Systems, attention is being focused on poor power quality issues which, in most cases, is caused by non-linear loads connected to the network. This often leads to waveform distortion. Consequently, harmonics at various electrical equipment that are connected to the power system are created. At this condition, the current or voltage Total Harmonic Distortion (THD) values violates the limits specified by IEEE 519-1992. This paper presents an investigation into the Total Harmonic Distortion of a short Distribution line (DL) with varied restoration energy in Megawatts. The distribution line of case study (Alagbon - Alagbon local) is between Alagbon 2 X 60 MVA, 132/33kV Transmission station and Alagbon local 2 X 15 MVA, 33/11kV Injection station, both within the same perimeter fence and located in Lagos, Nigeria. An algorithm as well as a Model circuit were developed and presented. This algorithm was applied to the developed Model circuit for Harmonic simulation using the MATLAB/Simulink platform. The resulting harmonic (second harmonic) at varying Busbar loads remained the same as shown in the results presented. Necessary discussions were made with conclusions drawn accordingly.

Keywords: Harmonics, Distribution Line, Non-Linear loads, Power Quality, Total Harmonic Distortion, Harmonic Simulation, Power Systems

Introduction:

Harmonics are created by non-linear devices connected to the power system. Power system harmonics are multiples of the fundamental power system frequency and these harmonic frequencies can create distorted voltages and current. Distortion of voltages and currents can affect power system adversely causing power quality problems (Akagi, 1996). Non-linear devices such as power electronic converters can inject harmonics alternating current (AC) in the electrical power system.

However, this Power Quality Problem is due to power equipment which include adjustable-speed motor drives (ASDs), electronics power supplies, direct current (DC) motor drives, battery chargers, electronic ballast etc. The distortion in the current is due to non-linearity of the resistor. These non-linear loads are

those in which their current is not proportional to the applied voltage. A simple circuit as shown in figure 1 illustrates the concept of current distortion. In this case, a sinusoidal voltage is applied to a simple non-linear resistor in which the voltage and current varies in line with the curve shown in figure 2. While the voltage is perfectly sinusoidal, the resulting current is distorted (Buso, et al. 1998; Adesina & Fakolujo, 2015).

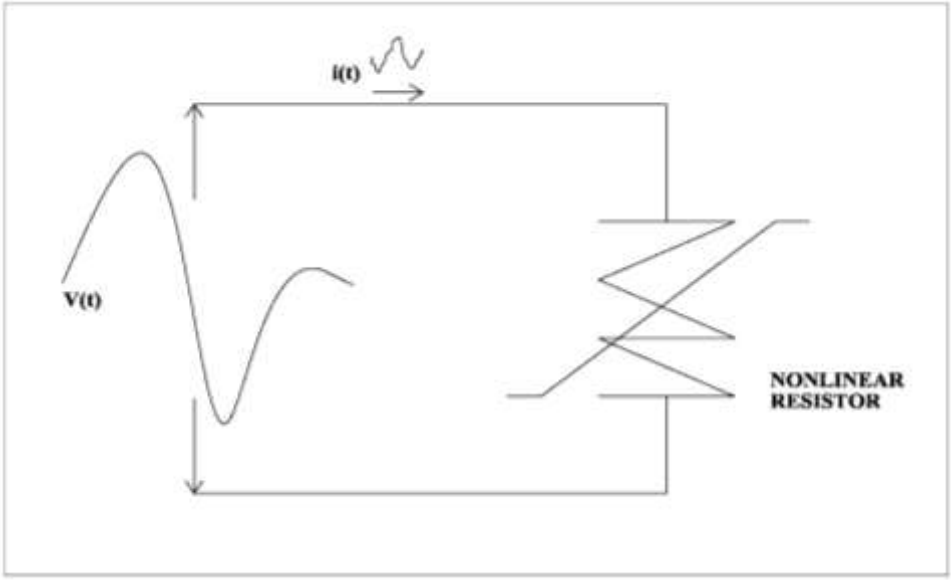


Figure 1: Current distortion caused by non-linear resistance

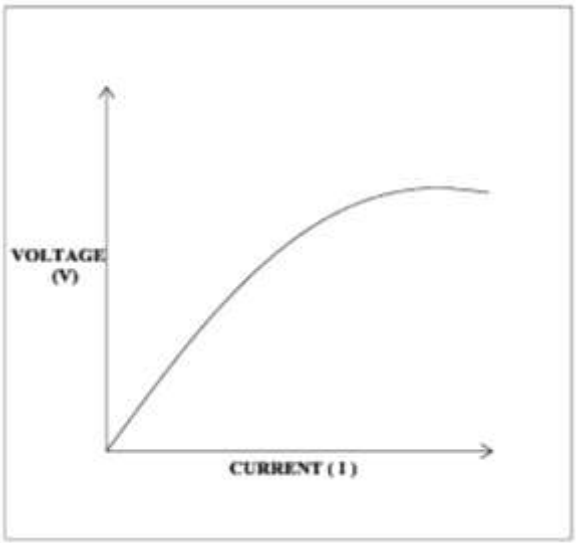


Figure 2: Voltage and Current relation not straight due to non-linear resistance

Non-linear loads seem to be the main source of harmonic distortion in a power distribution system. Non-linear loads produce the harmonic currents which are injected back to the power distribution network by the point of common coupling (CCP). These harmonic currents can interact negatively with a broad range of power systems equipment, especially capacity transformers and motors, and produce more losses, overheating, and overloading (Czarnecki, 2002; Adesina & Abdulkareem, 2016). Also, the number of sensitive loads that require ideal sinusoidal supply voltage for their proper operation has been increasing. Harmonics also increases the overall reactive power demanded by equivalent load.

The impact of harmonics on a power system equipment is of greater concern. It can be generally stated that harmonics are causing equipment to be subjected to voltages and currents at frequencies for which they were not designed (Adesina & Fakolujo, 2015; Tan et al., 2005). The effects of such exposure are usually not instantly visible, but can have serious consequences in the medium and long term. Summarily, harmonics have effects on Transformers, Induction Motors, Cables, Breakers, Fuses, Lightning Systems etc. (Mazumdar, 2006; Adesina & Fakolujo, 2015).

IEEE Standard 519 - 1992 attempts to establish reasonable harmonic goals for electrical systems that contain non-linear loads. The objective is to propose steady state harmonic limits that are considered reasonable by both electrical utilities and their customers. For voltage and current harmonics, the obtained information (Magnitude and Phase) are usually compared with standards like IEEE 519 to evaluate their net influence in the power system. IEEE 519 is applied to all voltage levels, including 220V Single-phase residential services. All the standards make use of the Total Harmonic Distortion (THD) Voltage or Current defined as (Adesina & Fakolujo, 2015):

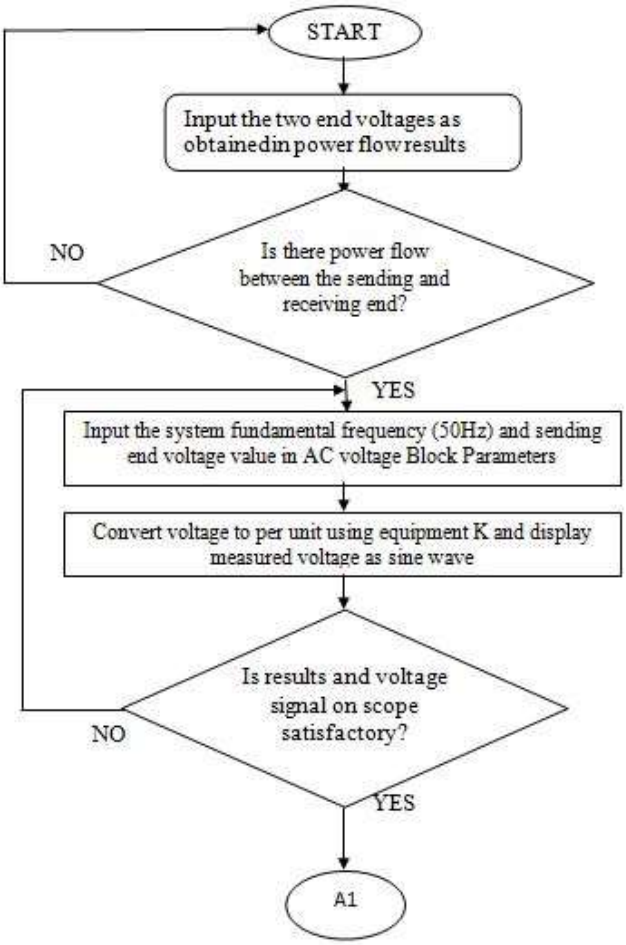
$$THD = 100\left(\sum_{h=2}^{n} U_h^2\right)/U_1 \quad (1)$$

Where,

U_1 is the fundamental Component

U_2 and Un are the harmonic components respectively

Development of Algorithm for Harmonic generation between two Buses:


START
Input the two end voltages as obtained in power flow results
NO
Is there power flow between the sending and receiving end?
YES
Input the system fundamental frequency (50Hz) and sending end voltage value in AC voltage Block Parameters
Convert voltage to per unit using equipment K and display measured voltage as sine wave
Is results and voltage signal on scope satisfactory?
NO
YES
A1

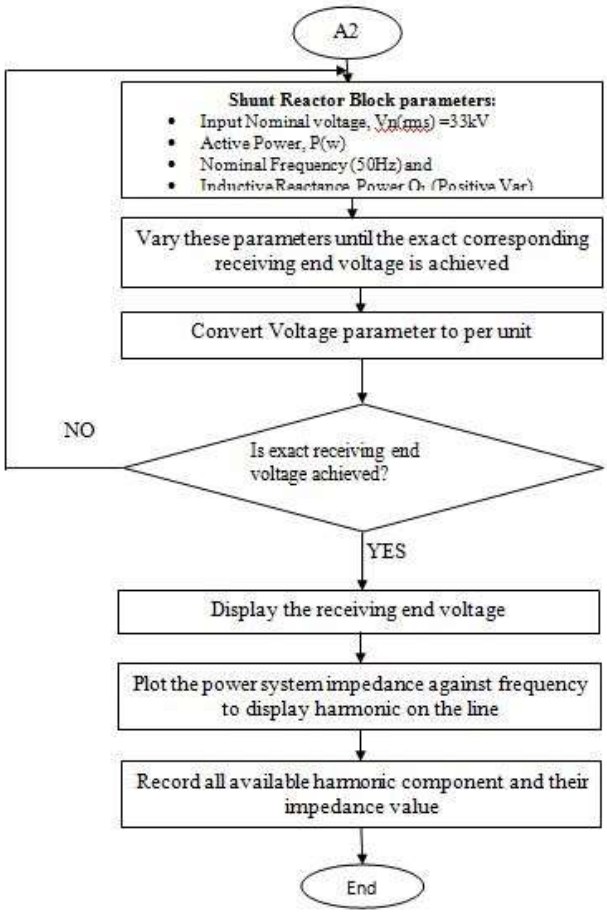


Figure 3: Development of Flow chart for harmonic evaluation on model TT Distribution line between two buses

Description of Case study:

Figure 2 is an extract from a complex utility power system 33kV schematic in Eko Electricity Distribution PLC, Lagos, Nigeria. It comprises of a transmission yard having a 2 x 60MVA 132/33kV Power Transformer which supplies the Distribution yard having 2 x 15MVA 33/11kV Power Transformer. The two power yards are enclosed by the same perimeter fence. The distance between Busbar 1 and 2 shown in figure 4 is approximately 150m.

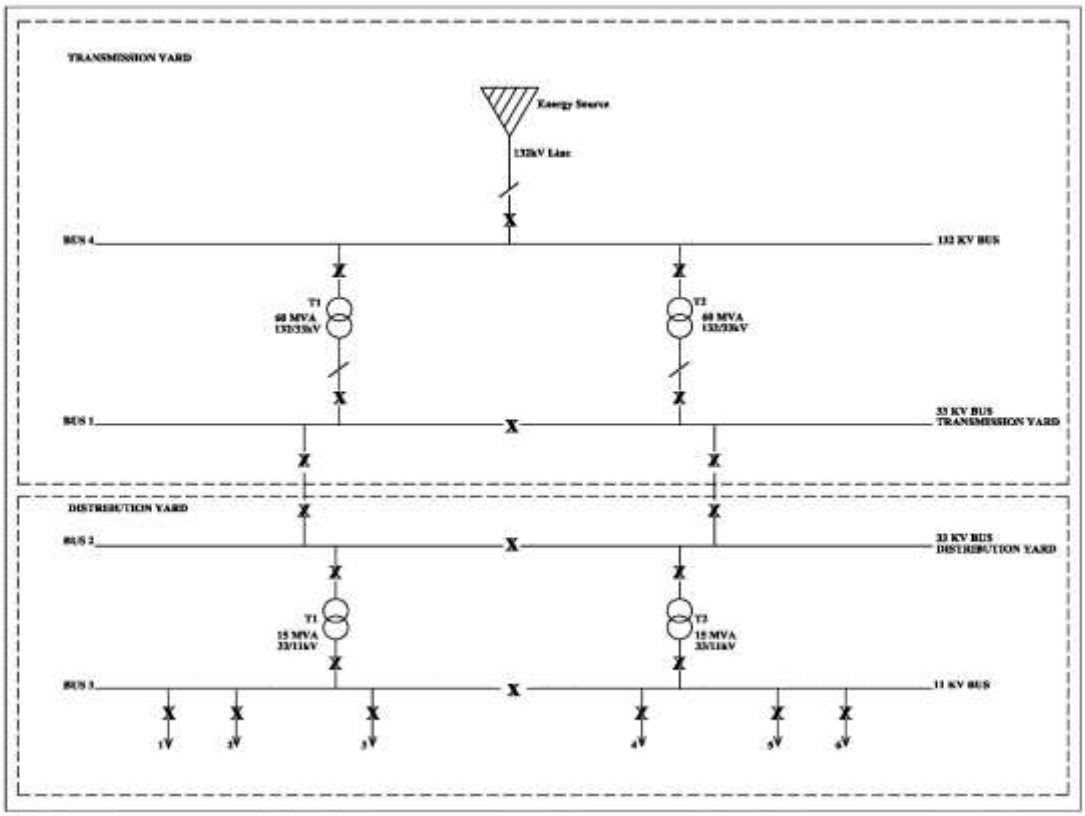


Figure 4: Typical 2 X 60 MVA 132/33kV Transmission yard at close proximity to 2 X 15 MVA 33/11kV Distribution Yard

Harmonic Simulation:

The algorithm described in the flow chat shown in figure 3 was implemented for harmonic generation using the MATLAB/Simulink platform. The processes include Power flow analysis of the entire network at different times of the feeder restoration within a 48-hour period. Thereafter, harmonic analysis was also carried out for the distribution lines of the network using the voltage results obtained from the earlier power flow analysis.

This research focuses on the harmonics between busbar 1 (Alagbon) and 2 (Alagbon Local) i.e. between the Transmission yard 33kV busbar and the Distribution yard 33kV busbar. Figure 5 and 6 presents the circuit and block diagram of the model arrangement used for harmonic generation by MATLAB Simulink application respectively.

The observed harmonic in all cases considered was only second harmonic component (which is the first even harmonic) for different values of power restored to the same Busbars at various time of the day and within the 48-hour period consideration. Table 2.1 shows the Busbar loads and voltages at different time of power supply availability within the period considered.

Table 2.1: Busbar Data.

S/N	BUS LOAD (MV)	BUS VOLTAGE (KV)	TIME OF THE DAY	DAY
1	4.5	32.997	2:00 Hrs	1
2	3.6	32.997	9:00 Hrs	1
3	6.5	32.995	2:00 Hrs	2
4	10.5	32.997	6:00 Hrs	2
5	10.2	32.996	9:00 Hrs	2
6	11.2	32.960	21:00 Hrs	2

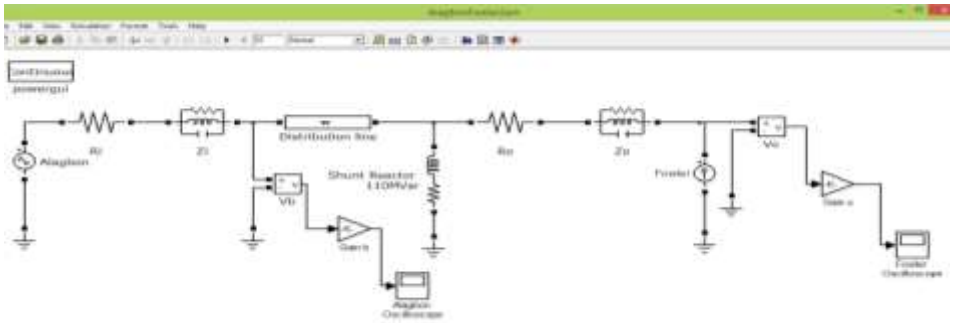


Figure 5: Developed Model Circuit of Alagbon – Alagon Local Distribution Line for Harmonic Generation using MATLAB/Simulink simulation

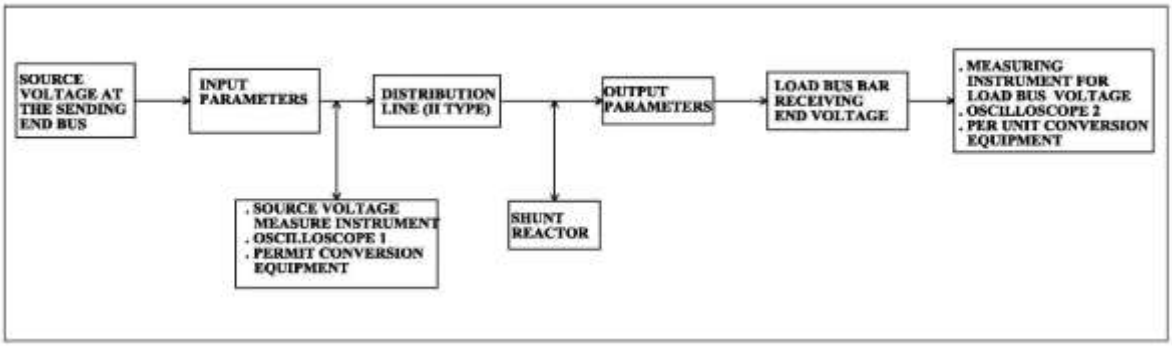


Figure 6: Block diagram representation of the Developed Model Circuit of figure 5

The results of harmonic generation on the line due to the above simulation at a frequency range of 50 Hz to 1500Hz are shown in figure 7 to figure 12

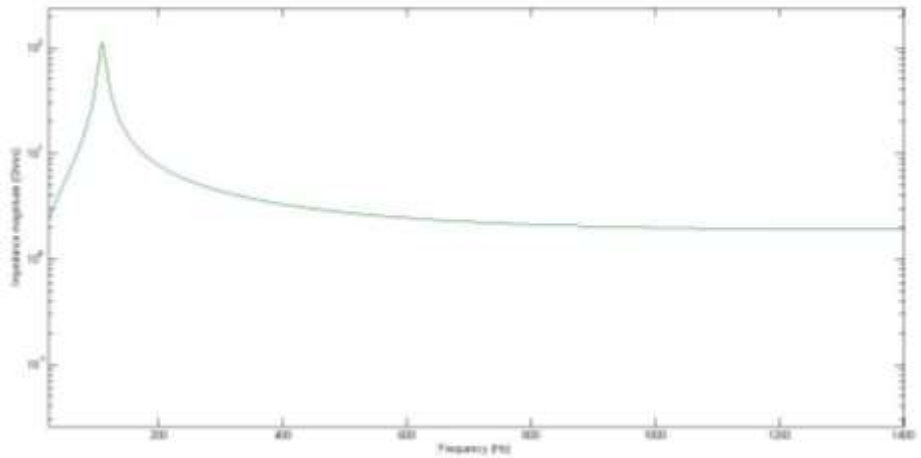


Figure 7: Harmonic on Alagbon – Alagbon Local Distribution Line at 02:00Hrs.

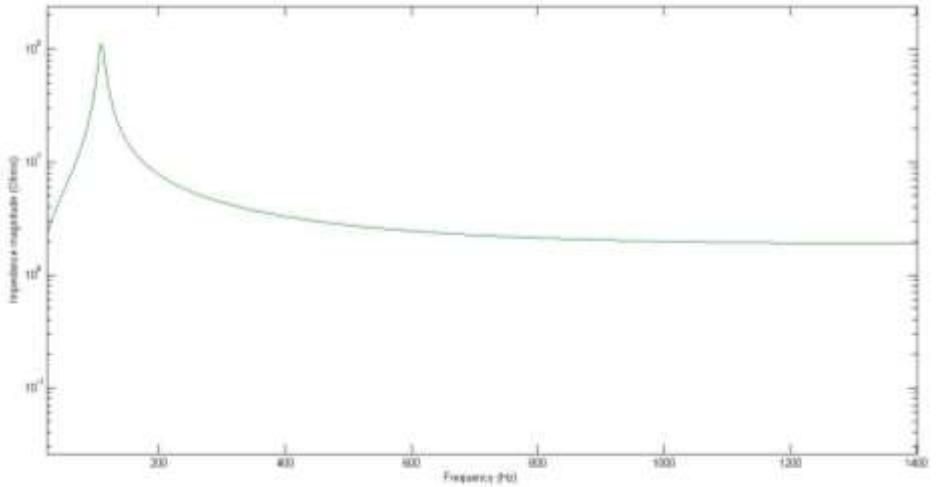


Figure 8: Harmonic on Alagbon – Alagbon Local Distribution Line at 09:00Hrs.

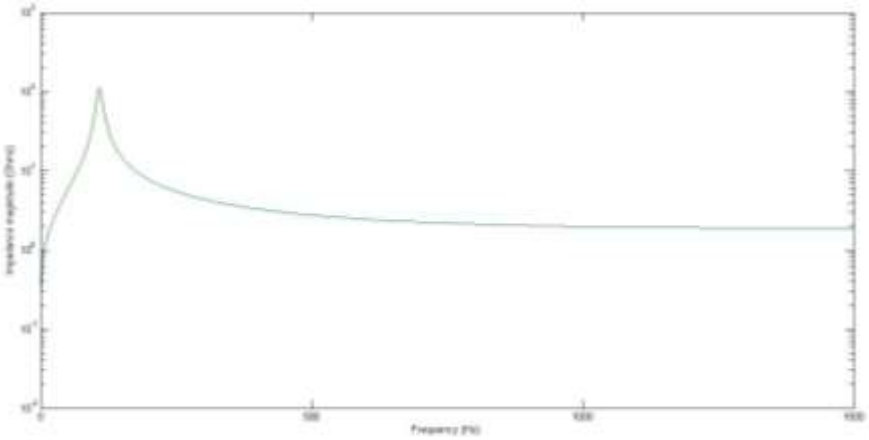


Figure 9: Harmonic on Alagbon – Alagbon Local Distribution Line at 02:00Hrs

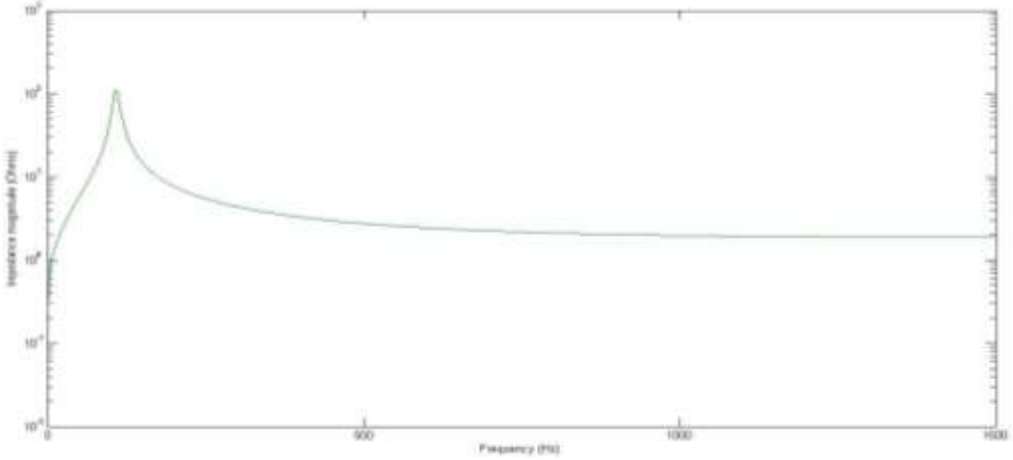
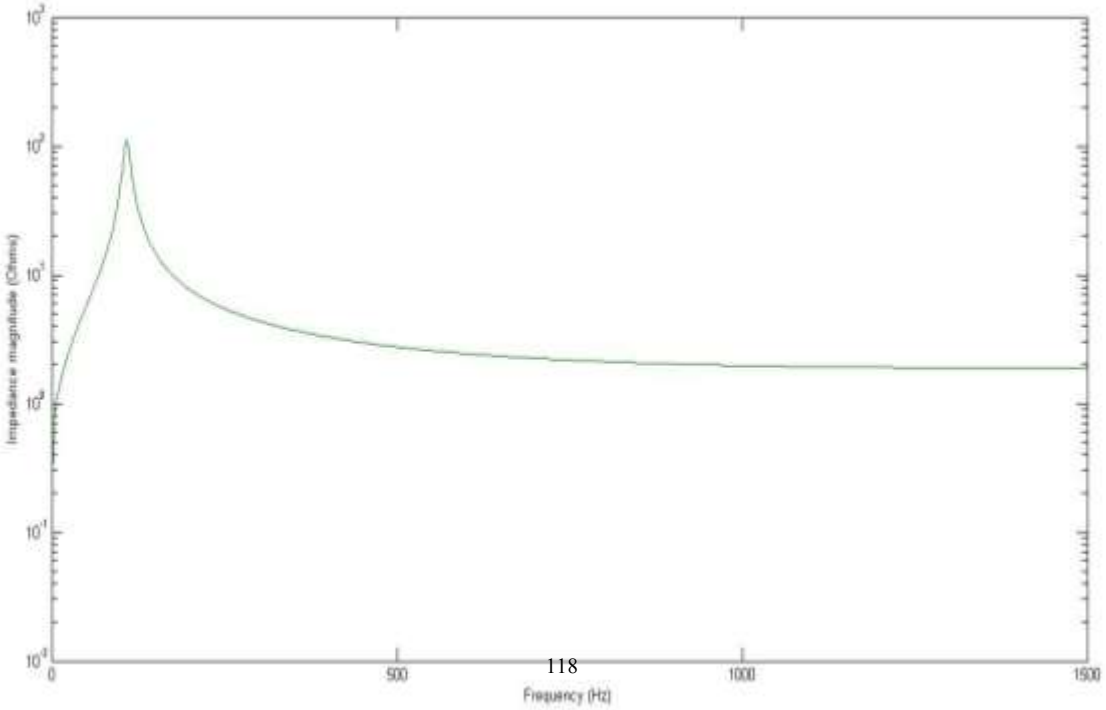


Figure 10: Harmonic on Alagbon – Alagbon Local Distribution Line at 06:00Hrs



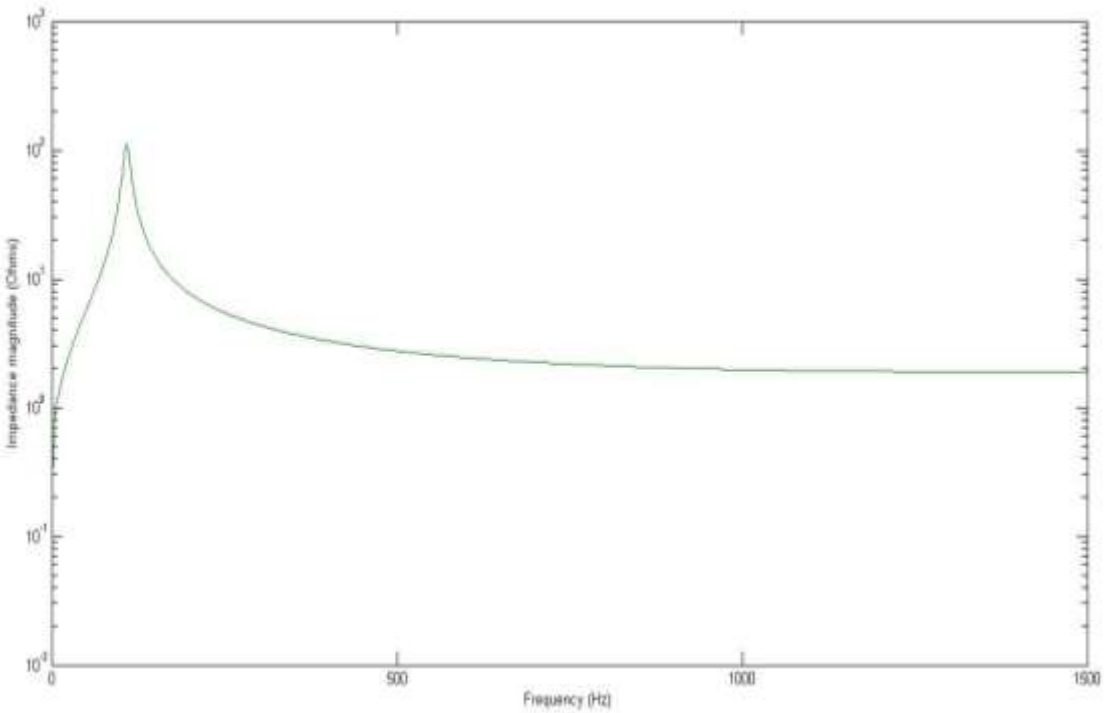


Figure 11: Harmonics on Alagbon – Alagbon Local Distribution Line at 09:00Hrs

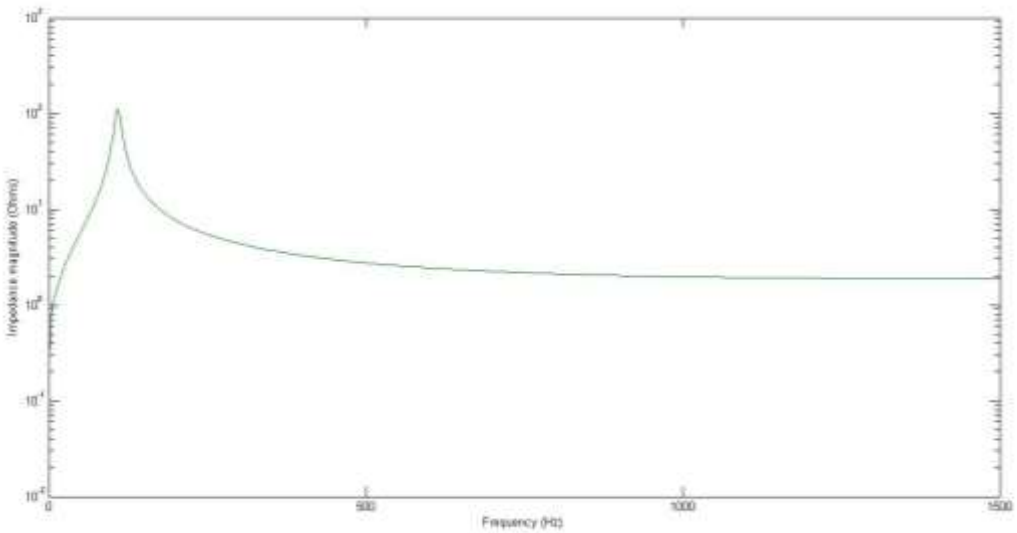


Figure 12: Harmonics on Alagbon – Alagbon Local Distribution Line at 21:00Hrs

Determination of Total Harmonic Distortion:

From the harmonic results above the THD of the line at various time of restoration of the 33kV feeder can be obtained using equations (2) and (3); while equation (3) was a modification of equation (1) to suite the parameters used in MATLAB Simulation.

$$CHV = \sqrt{\frac{P * Zh}{\sqrt{3}\ cos\theta}} \quad (2)$$

Where

P = Load on the Busbar in MW

Z_h = Harmonic Impedance in ohms obtainable from harmonic plots above

Cos θ = Power System networks power factor

And

$$THD\frac{100}{NcU1}\sqrt{\sum_{h=2}^{n} U_h^2} \quad (3)$$

Where,

N_c = Number of Cascaded Distribution Line during Simulation. In this research, N_c = 10

U_1 = Fundamental Power System Voltage

H = Harmonic

U_n = Harmonic voltage

Using equations (2) and (3) as well as Table 2.1, the percentage THD of the Distribution line at each of the 33kV feeder restoration time were evaluated as shown in Table 2.2. Also, from Table 2.2, a graphical relation between Busbar Loads and percentage THD was plotted as shown in figure 13.

Table 2.2: Calculate % THD

S/N	BUSBAR LOAD (MW)	% THD
1	4.5	5.26
2	3.6	5.03
3	6.5	6.76
4	10.5	10.87
5	10.2	8.47
6	11.2	29.29

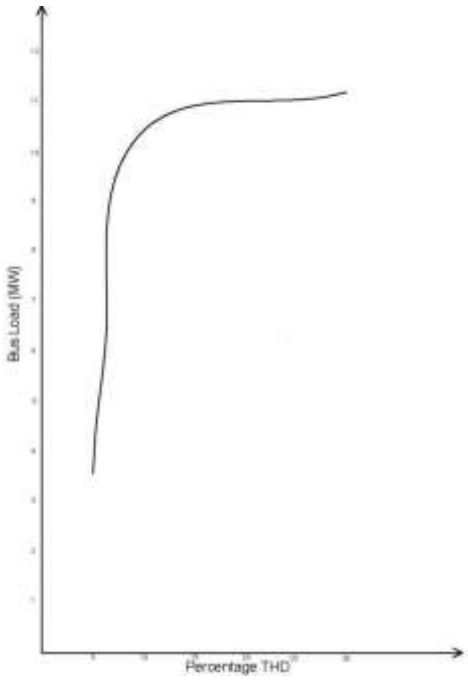


Figure 13: Busbar Load Versus %THD of the Line with the Specified Period of 33kV Feeder Restoration

Discussion of Results:

The results of the harmonic simulation are presented in figures 7-12. It is obvious that the plotted graphs showing the relationship between harmonic impedance and harmonic frequencies are similar in shape. Also, the frequency at peaks of these plots depict the existing harmonics on the distribution line. Hence, the peak of all the plots occur at an approximate frequency of 100 Hz, often referred to as second harmonic with respect to 50Hz frequency of power supply used in Nigeria. This implies that for all the varied load restoration by Transmission Operators on Distribution Busbar at different time of the period in consideration, the only harmonic on the line is the second harmonic. Similarly, an average peak harmonic impedance of $10^{2.052}\Omega$ was recorded for all the harmonic simulation plots irrespective of the loads on the Busbar.

Furthermore, Table 2.2 shows that Total Harmonic Distortion of the line at any time increases with Load increase to an extent, provided the distance between the two buses remain the same. Thus, the relationship between Busbar loads and the THDs of the line is non-linear.

7.0 Conclusion

Some basic information about power system harmonics have been highlighted, which includes the meaning, causes of harmonic and the effects in power system operation. An Algorithm was developed to generate harmonics on the Distribution Line. This Algorithm was implemented using the developed Model circuit for the case study network based on the available data. The results of these harmonic simulation are presented and discussed extensively. For all the loads on busbar considered at different times, the similarity of simulation plots and same peak values of harmonic impedance implies that electricity supply feeder should be radiated at a short distance as much as possible. Apart from higher harmonics that would be avoided, reasonable supply voltage gets to the customers and technical losses would also be minimized. The restored power to the receiving busbar varies non-linearly with its Total

Harmonic Distortion (THD). This implies that loads on 33kV feeder (i.e. on Busbar 2) should be maintained as low as possible.

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