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Harmonic Analysis and Evaluation on Nigeria 330kv Lines Network For Effective Energy Planning and Delivery

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ABSTRACT

The study of the harmonic orders inherently present in electric power network is required for perfect analysis and evaluation. Studying the harmonic orders on 330 kV line network in Nigeria is done in this paper using ETAP 16.0 as a tool for analysis. ETAP 16.0 software package was used to perform simulations and the input parameters were the resultant relative amplitudes and phase angles for both the current and voltage source models. The current source model spectrum of the under study revealed that the 22th and 27th harmonic orders have the highest percentage of amplitude relative to the fundamental compared to the other harmonics on different buses on the network.The voltage source model spectrum showed that the 24th, 25th, 26th, 27th, 33rd, and 34th harmonic orders have higher percentage of relative amplitude. However, only the 13th and 15th harmonic orders were seen to cause intense harmonic distortion of voltage and current after harmonic simulation. From the report (alert) reveals that the harmonics at any branch or bus exceeding its limit, thus appropriate correction equipment should be introduced in the system. It can be seen that the harmonics are maximum at harmonics of order, combination of filters which consist of 21th and 23th order. Planning of energy expansion, technical losses and overloading can be minimize, by taking actions on how to reduce the harmonic on the network

KEY WORDS: Harmonic order, Transmission Line, non-linear load, power electronics devices, instability

I. INTRODUCTION

The recent removal or reduction of government regulation in power sector results to an additional concern on the quality of the system on the sector. The degree to which the voltage, frequency and waveform has been seriously affected by the harmonics distortion of currents and voltages with its numerous dangerous consequence [1, 2]. The increase uses of power electronics devices and equipment which connected to the transmission basic system and services that are needed in order to support an economic development of the sector, such as saturated transformer, non-linear load, cyclo-converters causes harmonics on the system [3, 5]. According to [6] there are high harmonics distortion both in currents and voltages, thus results to forced outages, grid collapse, poor frequency profile and high transmission lines losses. Due to poor or low level of renewable energy to the network, damage of capacitor banks and losses of power transformer are the effects of harmonics on transmission network thus results to a serious energy challenge [7]. According to [8, 9] a quality parameter calculations and harmonics analysis shows the basic ways of finding the effects of harmonics on the network. According to [9, 10], due to the effect of harmonics, some manufacturer design were change to accommodate it by using some devices and equipment to reduced its on transmission network.

II. MODEL FORMULATION

F(t) = periodic function of Fourier Series f (t) =

$$C_o + \sum_{h=1}^{\infty} C_h \cos\left(h\omega t + \theta_h\right) \quad (1)$$

$$C_o = \frac{1}{T}\int_o^T f(t)dt, \quad C_h = \sqrt{A_h^2 + B_h^2} \tag{2}$$

$$A_h = \frac{2}{T}\int_o^T f(t)\cos(h\omega t)dt \tag{3}$$

$$B_h = \frac{2}{T}\int_o^T f(t)\sin(h\omega t)dt \tag{4}$$

h = harmonic order

$$THD_\upsilon\% = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \times 100 \tag{5}$$

$$THD_i\% = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \times 100 \tag{6}$$

$V_h = hth$ Harmonic component of the voltage, $I_h = hth$ Harmonic component of the current

$\tilde{V}_H = \sqrt{\sum_{h=2} \tilde{V}_h^2}$ RMS value of the voltage distortion

$$\tilde{I}_H = \sqrt{\sum_{h=2} \tilde{I}_h^2} \tag{7}$$

$$\tilde{I} = \sqrt{\sum_{h=1}^{\infty} \tilde{I}_h^2} \tag{8}$$

$$\tilde{V} = \sqrt{\sum_{h=1}^{\infty} \tilde{V}_h^2} \tag{9}$$

$$THD_\upsilon\% = \mathrm{HF} \times \frac{\text{Drive kVA}}{SC\ \text{kVA}} \times 100 \tag{10}$$

$HF = \sqrt{\sum_{h=5}^{\infty} h^2 I_h^2} \,/\, I_1$, Harmonic Factor (11)

$$P = \tilde{V}\,\tilde{\mathrm{I}}_{i,1}\cos\phi_1 \tag{12}$$

$$Q = \tilde{V}\,\tilde{\mathrm{I}}_{i,1}\sin\phi_1\,, \quad \mathrm{S} = \tilde{\mathrm{V}}\,\tilde{\mathrm{I}} \tag{13}$$

$$D = \text{Distortion} \quad \text{VA} = \sqrt{\mathrm{S}^2 - P^2 - Q^2} \tag{14}$$

$$D^2 = S^2 - \left(\tilde{V}^2 \tilde{I}_{i,1}^2\right) = \tilde{V}^2 \sum_{h=2}^{\infty} \tilde{I}_{i,h}^2 \tag{15}$$

$$\lambda = \text{True Power Factor} = \frac{\mathrm{P}}{\mathrm{S}} = \left(\frac{I_{i,1}}{I}\right)\cos\phi_1 = \text{Distortion Factor} \times \text{Displacement Factor} \tag{16}$$

NONSINE WAVEVOLTAGEANDCURRENT

$$P = \sum_{h=1}^{\infty} \tilde{V}_h \tilde{I}_h \cos\phi_h\,, \quad Q = \sum_{h=1}^{\infty} \tilde{V}_h \tilde{I}_h \sin\phi_h \tag{17}$$

$$D = \text{Distortion Power} = \sum_{\substack{n\ m\\ n\neq m}}^{\infty} S_{nm} S_{nm}^{*} - \sum_{\substack{n\ m\\ n\neq m}}^{\infty} S_n S_m^{*} \tag{18}$$

$$S^2 = P^2 + Q^2 + D^2 \tag{19}$$

$$S = \sqrt{\sum_{h=1}^{\infty} \tilde{V}_h^2 \tilde{I}_h^2} = \left(\tilde{V}_1 \tilde{I}_1\right)^2 + \left(\tilde{V}_1 \tilde{I}_H\right)^2 + \left(\tilde{V}_H \tilde{I}_1\right)^2 + \left(\tilde{V}_H \tilde{I}_H\right)^2 = S_1^2 + S_N^2 \tag{20}$$

$$S_1 = \text{Fundamental Apparent Power} = \tilde{V}_1 \tilde{I}_1 \tag{21}$$

$$S_N = \text{Non fundamental Apparent Power}$$

$$S_N^2 = \left(\tilde{V}_1 \tilde{I}_H\right)^2 + \left(\tilde{V}_H \tilde{I}_1\right)^2 + \left(\tilde{V}_H \tilde{I}_H\right)^2 \tag{22}$$

$$\tilde{V}_1 \tilde{I}_H = \text{Current Distortion Power}, \tilde{V}_H \tilde{I}_1 = \text{Voltage Distortion Power}$$

$$\tilde{V}_H \tilde{I}_H = \text{Harmonic Apparent Power}$$

$$S_H^2 = P_H^2 + N_H^2 = \text{Total Harmonic Active Power} + \text{Total Harmonic Non Active Power} \tag{23}$$

$$X_C = \text{Reactance of the capacitor} = \left(V_{L\text{-}L}\right)^2 / VAR_{3-phase} \tag{24}$$

METHODOLOGY FOR COMPUTING DISTORTION

I_b= Base current in Amps $= \dfrac{MVA_b \times 10^3}{\sqrt{3} kV_b}$ Amps, Z_s **= System impedance** $\dfrac{MVA_b}{MVA_{sc}}$ p.u., **V_H (Percent individual harmonic voltage distortion)** $= \dfrac{I_h}{I_b}(h)(Z_s) \times 100$ Volts

$$THD_v\% = \frac{\left[\sum_{h=2}^{\infty} V_h^2\right]^{1/2}}{V_1} \times 100, \quad THD_i\% = \frac{\left[\sum_{h=2}^{\infty} I_h^2\right]^2}{I_1} \times 100$$

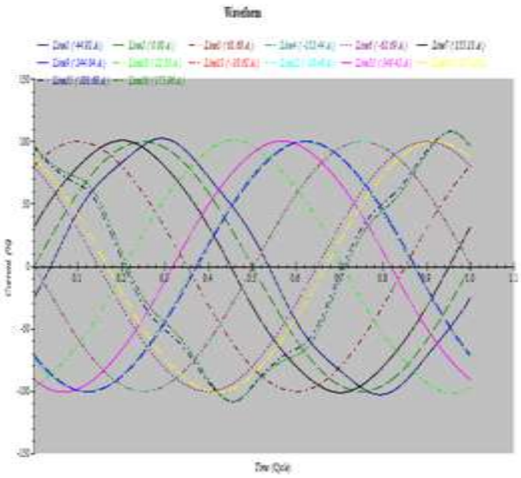
h = harmonic order, **I_H** = (Percent individual harmonic distortion) $\dfrac{I_h}{I_L} \times 100$

I_{sc} = Short Circuit current at the point under consideration, I_L = Estimated maximum demand load current S.C. Ratio = Short circuit Ratio $= \dfrac{I_{sc}}{I_L} = \dfrac{MVA_{sc}}{MVA_D}$

K Factor $= \sum_{h=1}^{\infty} (h)^2 \times \left(\dfrac{I_h}{I_L}\right)^2$

III. RESULT PRESENTATION.

The results are presented below, is in two sections, firstly the current wave form in percent against time in cycle and the current spectrum against the harmonics order.



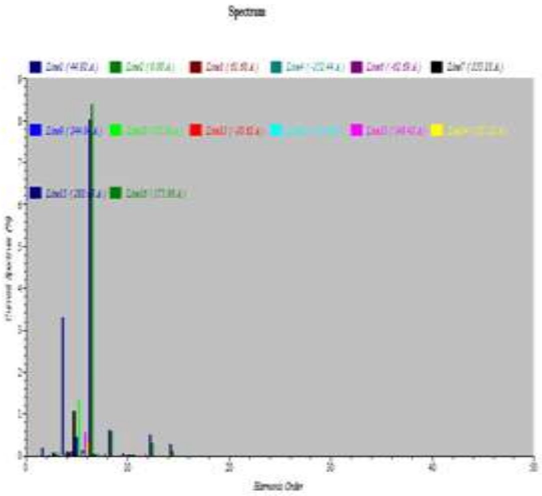
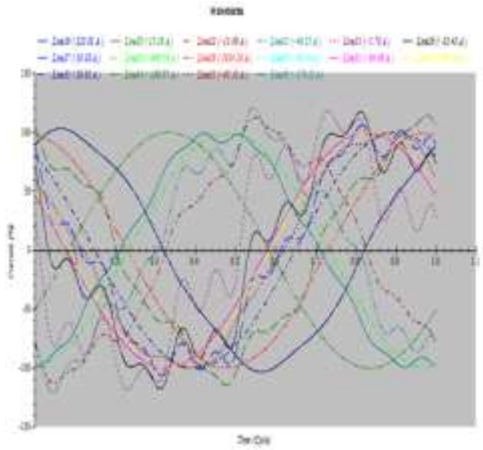


Fig. 1a: Graph of Current (%) against Time(cycle) Fig.1b: Graph of current spectrum against harmonics order



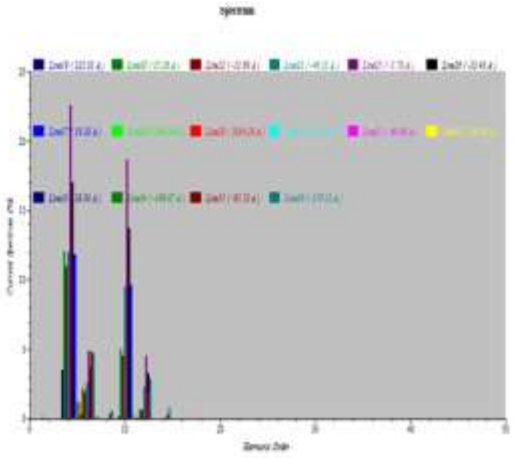
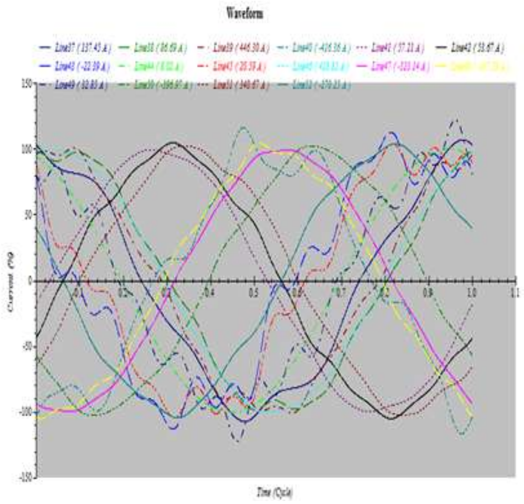


Fig.2a: Graph of Current (%)against Time(cycle) Fig.2b:Graph of current spectrum against harmonics order



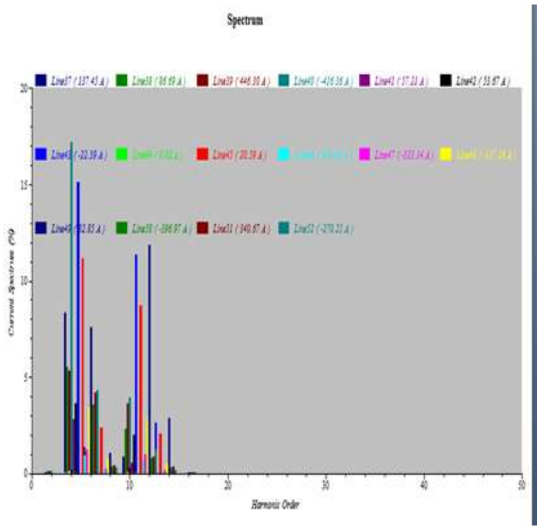
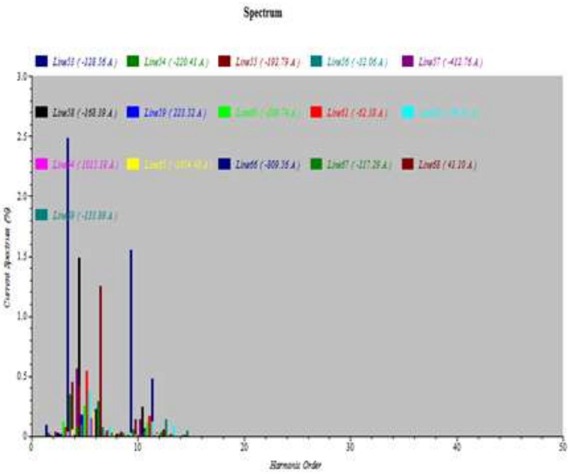


Fig. 3a: Graph of Current (%)against Time(cycle) Fig.3b: Graph of current spectrum against harmonics order



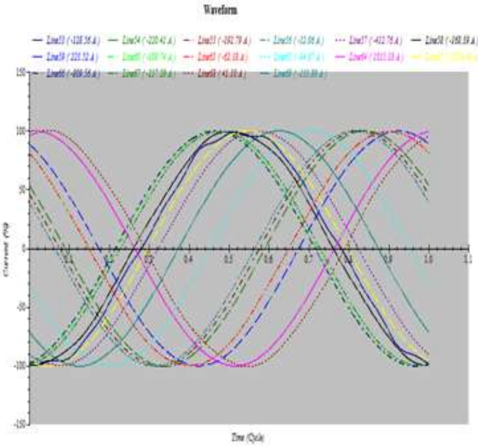
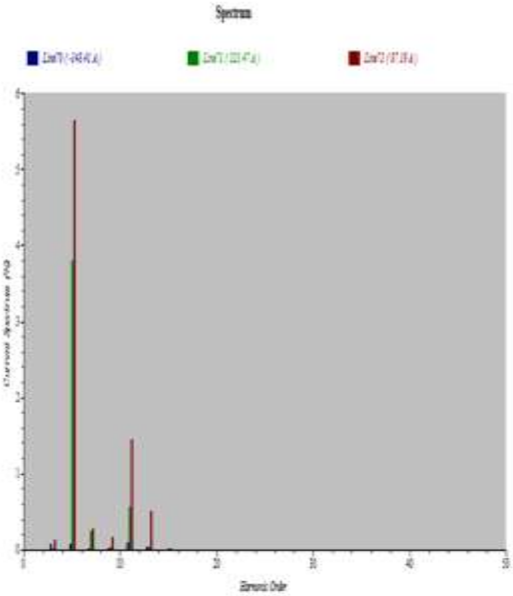


Fig. 4a: Graph of Current (%)against Time(cycle) Fig.4b: Graph of current spectrum against harmonics order



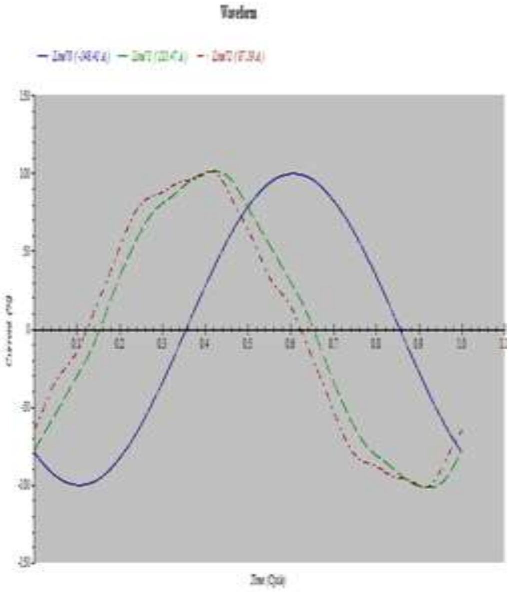


Fig. 5a: Graph of Current (%) against Time(cycle) Fig.5b: Graph of current spectrum against harmonics order

IV. DISCUSSION RESULTS

The simulation was done using Etap16.0, the network consist about 75 buses of 330KV line network. The results are presented in figures a's as graph of Current (%) against Time (cycle) for and b's as graph of current spectrum against harmonics order.Bus 55 has voltage distortion of 131.01% in RMS, 123.97% in ASUM and VTHD of 34.46%. Bus 38 has voltage distortion of 157.63% in RMS, 348.53% in ASUM and VTHD of 89.31%. For current distortion, Bus 55 has RMS amp of 349.71A, ASUM amp of 462.34 A and ITHD of 49.27%. Bus 38 has RMS amp of 254.34A, ASUM amp of 367.08 A and ITHD of 63.97%. Bus 65 has voltage distortion of 141.01% in RMS, 193.97% in ASUM and VTHD of 29.6%. Bus 28 has voltage distortion of 187.30% in RMS, 378.51% in ASUM and VTHD of 79.21%. For current distortion, Bus 65 has RMS amp of 391.22A, ASUM amp of 471.42 A and ITHD of 43.70%. Bus 28 has RMS amp of 354.42A, ASUM amp of 337.11 A and ITHD of 93.97% At bus 65, 28, 65 and bus 38, the harmonic voltage at 15th harmonics order is 29.65 %, at 19th harmonic order 45.30% and at 21th&23thharmonics order it is 12.53% of the fundamental voltage.

CONCLUSION

From the report (alert) reveals that the harmonics at any branch or bus exceeding its limit, thus appropriate correction equipment should be introduced in the system. It can be seen that the harmonics are maximum at harmonics of order, combination of filters which consist of 21th and 23th order. The system contains a high harmonics which causes some effects to the entirely network thus affect the currents wave form on the network from a pure sinusoidal to a wave form with quite different quality. Planning of energy expansion, technical losses and overloading can be minimize, by taking actions on how to reduce the harmonic on the network

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