Nigerian Journal of Technology (NIJOTECH)
Vol. 34 No. 4, October 2015, pp. **773 – 780**

ISSN: 0331-8443
www.nijotech.com
http://dx.doi.org/10.4314/njt.v34i4.15

DETERMINATION OF TOTAL HARMONIC DISTORTION (THD) ON A 33KV DISTRIBUTION NETWORK: A CASE STUDY OF ISLAND BUSINESS DISTRICT

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ABSTRACT
Modern day AC power systems are proliferated by the introduction of several kinds of nonlinear loads which generate harmonics in a power system and this has a cumulative negative effect on power quality. Examples of nonlinear loads are power electronic devices, which cause distortion of voltage and current waveforms and consequently create a number of harmonics within the power system. This paper presents the estimation of Total Harmonic Distortion (THD) of the Distribution lines in the 33kV distribution network of Island Business District, Eko Electricity Distribution Plc, taken as a case study using a set of busbar voltage results, obtained from previous studies on power flow and harmonic analyses of each time of the 33kV feeder restoration. The harmonics and their impedances on each line at the scenario time of the 33kV feeders restored are presented. The estimated THD of each line and overall network average THD are also presented.

Keywords: *Power quality, Harmonics, Total Harmonic Distortion, Feeder restoration*

1. INTRODUCTION
Power system harmonics is not a new phenomenon. In fact, a text published by Steinmetz in 1916, devoted considerable attention to the study of harmonics in 3-phase power systems. In Steinmetz's days, the main concern was third harmonic currents, caused by saturated iron in transformers and machines. He was the first to propose Delta connections for blocking third harmonic currents. Steinmetz's contribution and an overall history of harmonics have been published by Owen, E.L [1]. The emergence of power electronic loads in a power system began during the late 80's and early 90's. They offer the advantages of efficiency and controllability. However, a downside to this is that they also draw non-sinusoidal currents from AC power systems, and these currents interact negatively with the power system impedances to create voltage harmonics and in some cases, resonance. Studies have shown that harmonic distortion levels in distribution systems are on the rise as power electronic devices continue to proliferate [2]. The main effects of harmonics in power systems are heating, overloading and ageing of equipment, and increased losses. Besides the increase in the number of harmonic sources, the number of devices sensitive to the harmonic distortion has also increased [3]. Harmonics may lead to malfunctioning of power system components and electronic devices.

The harmonic distortion is one of the indices of power quality of a power system [4]. This is because of large nonlinear loads that have been used. The IEEE Standard 519-1992 provides a solution for the limitation and mitigation of harmonics [4]. The Total Harmonic Distortion (THD) is the common measurement index of harmonic distortion [5, 6]. THD is applied to both current and voltage and is defined as the root mean square (rms) value of the h^{th} harmonic voltage, divided by the rms value of the fundamental harmonic voltage, and then multiplied by 100% as shown in subsequent discussions. THD of current varies from few percent to more than 100%.THDs of voltage are usually less than 5% and widely considered to be acceptable, while values above 10% are definitely unacceptable and will cause problems for sensitive equipment and loads [5].

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2. IEEE HARMONIC STANDARDS AND TOTAL HARMONIC DISTORTION

As far as the impact of harmonics on power system equipment is concerned, it can be generally stated that harmonics cause equipment to be subjected to voltages and currents at frequencies for which it was not designed. The effects of such exposure are usually not instantly visible, but can have serious medium and long term consequences. Some of the practical harmonic related problems encountered by utilities include voltage distortion in distribution feeders, increased RMS currents, which causes overheating and line losses, malfunctioning of solid-state fuses, breakers and relays, tripping of harmonic voltage-sensitive equipment [7], interaction of harmonic currents with the capacitances of power factor correction capacitors (generally installed in industrial plants, commercial buildings and fluorescent lightings to improve individual light fittings), which can cause overheating, disrupt, and/or damage plant and equipment [8], etc.

Furthermore, Harmonic currents are injected from harmonic producing loads into the utility network in radial distribution feeders. These harmonic currents affect the operation of other electrical and electronic equipment connected on the same distribution feeder, including the harmonic producing loads. Deeper into the utility distribution and transmission system, it becomes difficult to discern the direction of harmonic power flow, partly due to the highly interconnected and meshed nature of such systems, and partly due to the impact on voltage support capacitors used by the utility and its customers. As utilities and customers change their connected loads, system impedance also changes, resulting into resonances and harmonic problems which were initially none existent [9]. Such problems are not easily identified without a detailed system analysis [10, 11]. An important aspect of power quality monitoring is the collection of information regarding the performance of the system in terms of voltage and current harmonics. For voltage and current harmonics, the obtained information (magnitude and phase) are usually compared with standards like IEEE 519 harmonic standards to evaluate the influence of these events.

2.1 IEEE 519-1992 Harmonic Standard

IEEE 519 was initially introduced in 1981 as an "IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters". It originally established levels of voltage distortion acceptable to the distribution system for individual non-linear loads. With the rising increase usage of industrial non-linear loads, such as variable frequency drives, it became necessary to revise the standard.

In USA, IEEE applies whereas in Europe, a different standard (IEC) applies. Measured harmonics significantly higher than the recommended levels are considered unacceptable. All of the standards make use of the total harmonic distortion (THD) voltage or current, defined as [12]:

$$THD = \frac{100\sqrt{\sum_{h=2}^{k} U_{hrms}^2}}{U_{1rms}} \qquad (1)$$

Where U_{1rms} and U_{hrms} are the fundamental and h^{th} (higher order) harmonic voltage components respectively.

The main standards are the followings (9):

IEEE 519: this standard sets limits for percentage "individual harmonic component distortion" and "THD". It limits both utility voltage and end user current distortion at the point of common coupling.

a) IEC 1000-2-4 (1994): it prescribes the compatibility levels for industrial and non-public networks. It applies to low and medium voltage supplies.
b) IEC 1000-1-1 (1992): Definitions used in IEC 1000
c) IEC 1000-2-2 (1990): It defines the compatibility levels for individual harmonic voltages in public low voltage systems.

The IEEE 519-1992 standard established recommended guidelines for harmonic voltages on the utility distribution system as well as harmonic currents within the industrial distribution system [8]. According to the standard, the industrial system is responsible for controlling the harmonic currents created in the industrial workplace. Since harmonic currents reflected through distribution system impedances generate harmonic voltages on the utility distribution systems, the standard proposes guidelines based on industrial distribution system design. IEEE 519-1992 defines levels of harmonic currents and voltages that an industrial user can inject onto the utility distribution system [13-16].

2.2 Total Harmonic Distortion (THD)

Although the harmonic content of a power system may be quite small relative to the fundamental in most circumstances, for exactness the rms value of a current or voltage waveform requires the harmonic content to be considered such that:

$$U_{rms} = \sqrt{\sum_{h=1}^{\infty}\left(\frac{1}{\sqrt{2}}U_h\right)^2} \quad (2)$$

Where U_{rms} and U_h are the rms value and peak h^{th} harmonic component of voltage or current.

The rms voltage or current can also be used to quantify the level of distortion of the waveform. The total harmonic distortion of voltage or current waveform (THD_U) is calculated using equation (3):

$$THD_U = \sqrt{\sum_{h=2}^{\infty}(U_h)^2} = \sqrt{\left(\frac{U_{rms}}{U_{1rms}}\right)^2 - 1} \quad (3)$$

Where THD_U represents voltage or current total harmonic distortion (alternatively represented as THD_V and THD_Irespectively) and $U_{1rms}$is the rms fundamental voltage or current. Alternatively rms voltage or current can be represented in terms of total harmonic distortion:

$$U_{rms} = \sqrt{\sum_{h=1}^{\infty}{U_{hrms}}^2} = U_{1rms}\sqrt{1 + THD_U^2} \quad (4)$$

As distribution system fundamental voltage and current rarely remain static in magnitude at different times throughout the day, the definition for total harmonic distortion may at times provide a misleading value for the harmonic distortion level. This is especially true for distribution system fundamental currents that fall close to zero at certain periods of the day, resulting in large values of THD_I. For this reason a modified index for harmonic distortion may be used with the harmonic content of the waveform expressed as a percentage of a fixed nominal value rather than the fundamental value, giving total demand distortion (TDD_U) [12]:

$$TDD_u = \frac{1}{U_{nom}}\sqrt{\sum_{h=2}^{\infty}\left(\frac{1}{\sqrt{2}}U_h\right)^2} \quad (5)$$

The fixed value U_{nom} is required to be specified and may be a maximum rms value, maximum demand, average or selected nominal system value.

Generally, one of the most important tools for understanding and analysing of harmonics as well as for the standardization work is harmonic measurements. The estimation of harmonics is of high importance for efficiency of the power system network [17]. Harmonic measurements are also important for grid companies and end users to characterize the performance of their networks and develop solutions to harmonic problems.

3. 33KV NETWORK OF ISLAND BUSINESS DISTRICT OF EKO ELECTRICITY DISTRIBUTION PLC (EKEDP): CASE STUDY

The success of a power system harmonic study depends critically on the data used to model power system components. Consequently, this paper makes use of the Busbar voltage solutions obtained from a power flow study and harmonic analysis results of scenario hours of feeder restoration per day, on 33kV network of Island Business District (IBD) of EKEDP shown in Figure 1. The results obtained from the research work were used as the source data for the analysis of network THD, presented in this paper. Figure 2, however, shows the line model of the distribution network used earlier on in obtaining the harmonics on various lines of the network.

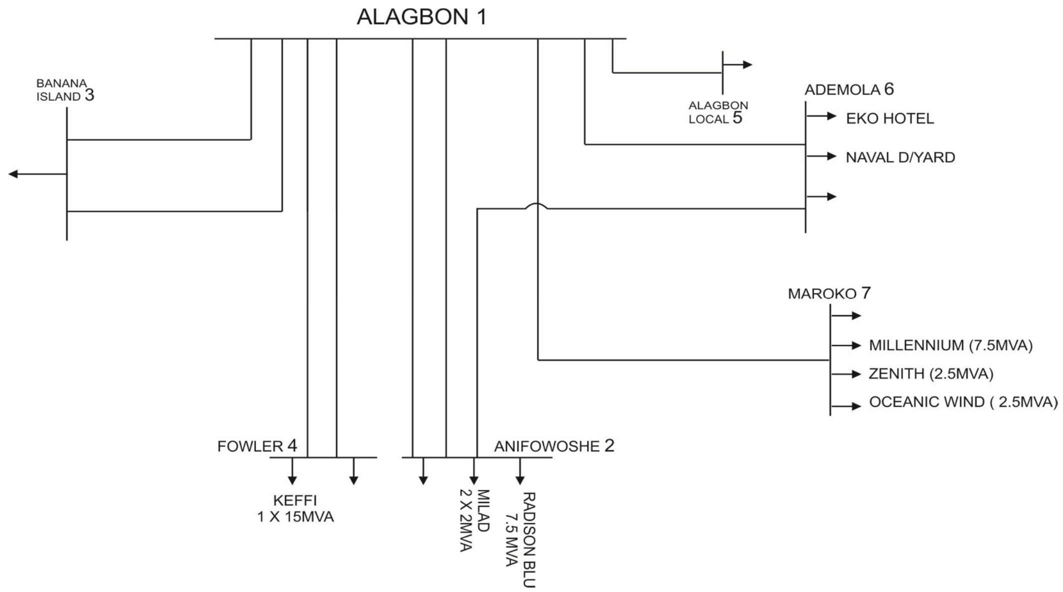

Figure 1: 33kV Network of Islands Business Unit, EKEDP

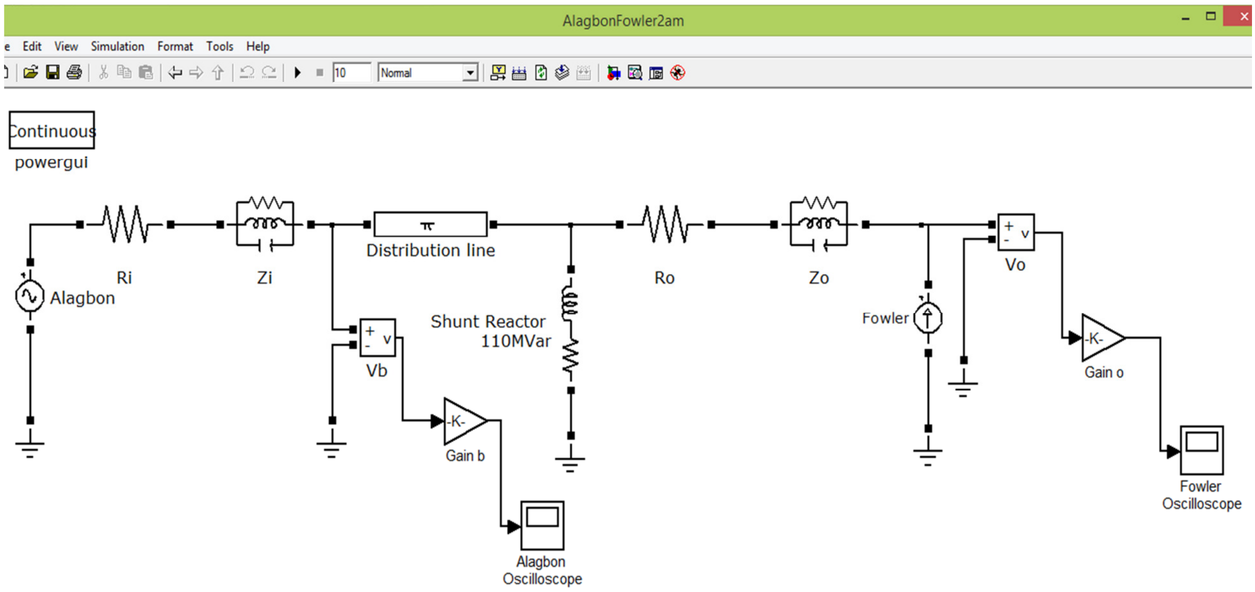

Figure 2: Formulated Model of Distribution Line Alagbon – Fowler Busbars as example

The source data were obtained from the real life simulations using the MATLAB/Simulink platform and the summaries of the findings/observations from the simulations are given in Tables 1 to 4, which show the distribution line harmonics and their Impedances at a frequency range of 1500Hz, for all the cases of scenario hours of the 33kV feeder's restoration in the network of case study. However, the seven distribution lines, within the 33kV distribution network of IBD considered during simulation are as follows:

1. Alagbon (ALG) – Ademola (ADM)
2. Alagbon (ALG) – Alagbon Local (ALG/L)
3. Alagbon (ALG) – Anifowoshe (ANI)
4. Alagbon (ALG) – Fowler (FOW)
5. Ademola (ADM) – Maroko (MAR)
6. Ademola (ADM) – Anifowoshe (ANI)
7. Alagbon (Alagbon) - Banana Island (BAN/I)

During simulation, 10 cascaded π-networks were used in order to observe all harmonics present on each of the lines. The reason for selecting the π-network topology for the simulation was because the longest of the Distribution lines within the 33kV network is 6.84km. The harmonic impedance values given in tables 1 to 4 are extracted from the harmonic Impedance / Frequency plots results of the harmonic analysis of the same network as shown in [18].

At 02:00Hrs

Case 1: ALG – ALG/L

Case 2: ALG – FOW Distribution Line

Table 1: Distribution Line Harmonics and their Impedance for cases of 02:00Hrs

Distribution Line	Length(km)	Sending Bus Voltage (kV)	Receiving Bus Voltage (kV)	Harmonics	Harmonic Impedance (Ω)
ALG-ADM	6.13	33	0	-	-
ALG-ALG/L	0.15	33	32.997	2nd	$10^{1.881}$
ALG-ANI	6.84	33	0	-	-
ALG-FOW	3.00	33	32.881	2nd, 6th, 15th, 24th	$10^{2.0}$, $10^{2.51}$, $10^{2.27}$, $10^{2.2}$
ADM-MAR	1.80	0	0	-	-
ADM-ANI	2.40	0	0	-	-
ALG-BAN/I	5.00	33	0	-	-

At 09:00Hrs

Case 1: ALG – ADM Distribution Line

Case 2: ALG –ALG/L Distribution Line

Case 3: ALG – ANI Distribution Line

Case 4: ALG – FOW Distribution Line

Case 5: ADM – ANI Distribution Line
Case 6: ALG –BAN/I Distribution Line

Table 2: Distribution Line Harmonics and their Impedance for cases of 09:00Hrs

Distribution Line	Length (km)	Sending Bus Voltage (kV)	Receiving Bus Voltage (kV)	Harmonics	Harmonic Impedance (Ω)
ALG-ADM	6.13	33	32.711	2nd, 3rd, 8th, 12th, 16th, 20th, 23rd, 26th, 28th, 29th	$10^{2.01}$, $10^{2.65}$, $10^{2.28}$, $10^{2.15}$, $10^{2.05}$, $10^{2.01}$, $10^{1.56}$, $10^{1.95}$, $10^{1.86}$, $10^{1.74}$
ALG-ALG/L	0.15	33	32.997	2nd	$10^{2.05}$
ALG-ANI	6.84	33	32.645	2nd, 3rd, 7th, 11th, 14th, 18th, 21st,23rd, 25th, 26th, 27th	$10^{2.12}$, $10^{2.65}$, $10^{2.30}$, $10^{2.14}$, $10^{2.06}$, $10^{1.97}$, $10^{1.91,}$ $10^{1.84}$, $10^{1.69}$, $10^{1.49}$, $10^{0.99}$
ALG-FOW	3.00	33	32.860	2nd, 6th, 15th, 24th	$10^{1.99}$, $10^{2.51}$, $10^{2.27}$,$10^{2.20}$
ADM-MAR	1.80	32.711	0	-	-
ADM-ANI	2.40	32.711	32.645	2nd, 8th, 19th	$10^{1.98}$, $10^{2.47}$, $10^{2.28}$
ALG-BAN/I	5.00	33	32.942	2nd, 3rd, 9th, 15th, 20th, 24th, 29th	$10^{1.96}$, $10^{2.61}$, $10^{2.28}$, $10^{2.15}$, $10^{2.08}$, $10^{2.05}$, $10^{2.01}$

At 21:00Hrs
Case 1: ALG – ADM Distribution Line
Case 2: ALG – ANI Distribution Line
Case 3: ALG – FOW Distribution Line
Case 4: ADM – ANI Distribution Line

Table 3: Distribution Line Harmonics and their Impedance for Cases of 21:00Hrs

Distribution Line	Length (km)	Sending Bus Voltage (kV)	Receiving Bus Voltage (kV)	Harmonics	Harmonic Impedance (Ω)
ALG-ADM	6.13	33	32.83	2nd, 3rd, 8th, 12th, 16th, 20th, 23rd, 26th, 28th, 29th	$10^{2.01}$,$10^{2.64}$, $10^{2.27}$, $10^{2.15}$, $10^{2.05}$, $10^{2.01}$, $10^{1.93}$, $10^{1.86}$, $10^{1.74}$, $10^{1.56}$
ALG-ALG/L	0.15	33	0	-	-
ALG-ANI	6.84	33	32.73	2nd, 3rd, 7th, 11th, 14th, 18th, 21st, 23rd, 25th, 26th, 27th	$10^{2.12}$, $10^{2.66}$, $10^{2.37}$, $10^{2.14}$, $10^{2.06}$, $10^{1.97}$, $10^{1.91}$, $10^{1.84}$, $10^{1.69}$, $10^{1.49}$, $10^{0.99}$
ALG-FOW	3.00	33	32.87	2nd, 6th, 15th, 24th	$10^{1.99}$, $10^{2.51}$, $10^{2.27}$, $10^{2.20}$
ADM-MAR	1.80	32.83	0	-	-
ADM-ANI	2.40	32.83	32.73	2nd, 8th, 19th	$10^{1.98}$, $10^{2.47}$, $10^{2.28}$
ALG-BAN/I	5.00	33	0	-	-

At 23:00Hrs
Case 1: ALG – ANI Distribution Line

Table 4: Distribution Line Harmonics and their Impedance for Cases of 23:00Hrs

Distribution Line	Length (km)	Sending Bus Voltage (kV)	Receiving Bus Voltage (kV)	Harmonics	Harmonic Impedance (Ω)
ALG-ADM	6.13	33	0	-	-
ALG-ALG/L	0.15	33	0	-	-
ALG-ANI	6.84	33	32.695	2nd, 3rd, 7th, 11th, 14th, 18th, 21st, 23rd, 25th, 26th, 27th	$10^{2.12}$, $10^{2.65}$, $10^{2.30}$, $10^{2.14}$, $10^{2.06}$, $10^{1.97}$, $10^{1.91}$, $10^{1.84}$, $10^{1.69}$, $10^{1.49}$, $10^{0.99}$
ALG-FOW	3.00	33	0	-	-
ADM-MAR	1.80	32.83	0	-	-
ADM-ANI	2.40	32.83	0	-	-
ALG-BAN/I	5.00	33	0	-	-

4. ESTIMATION OF THD VOLTAGE AND CASCADED HARMONIC VOLTAGE (U_H) ON THE DISTRIBUTION LINES

Total Harmonic Distortion Voltage (THD_U) of each Distribution line, where the 33kV feeder is restored, is estimated using the following parameters:

1. The harmonic impedances of the existing harmonics.
2. The exact value of the receiving end voltage of the Distribution line.
3. Active power in MW at the receiving end Busbar.
4. Number of cascaded Distribution lines used during MATLAB/Simulink simulation. In this case, 10 no. were used.
5. Power factor of 0.85

Based on these parameters, Cascaded Harmonic Voltages, U_h were obtained for each harmonic generated or involved using equation (6), while THD_u is then estimated using equation (7).

$$U_h = \sqrt{\frac{Power(p) \times Harmonic\ Impedance(Z)}{\sqrt{3}Cos\emptyset}} \quad (6)$$

$$THD_u = \frac{1}{N_c U_1}\sqrt{\sum_{h=2}^{n} U_h^2} \quad (7)$$

This THD_u estimation is repeated for all cases under a particular Distribution line. Table 5 shows harmonic frequencies, Cascaded Harmonic Voltage, U_h, as well as estimated THD voltage, (THD_u) presented under hours of feeder restoration.

Table 5: Cascaded Harmonic Voltages for each Harmonic Generated on different distribution lines at different times.

h^{th} harmonic	*Harmonic Freq. (Hz)*	*$U_h(V)$*	*$U^2_h(V)$*
02:00 Hrs			
Case 1: ALG-ALG/L Distribution Line, $V_{Alagbon\ Local}$ = 32.999kV, Number of Cascaded Lines, N_C = 10, $P_{Alagbon\ Local}$ = 4.5MW, Power Factor = 0.85, THD_u = 5.26%, U_h=18.56			
Case 2: ALG – FOW Distribution Line V_{Fowler} = 32.881kV, P_{Fowler}= 8.7MW, THD_u = 20.4%			
2^{nd}	100	23.89	570.73
6^{th}	300	43.63	1903.58
15^{th}	750	33.10	1,095.61
24^{th}	1200	30.54	932.42
			4502.34
09:00 Hrs			
Case 1: ALG - ADM Distribution Line, $V_{Ademola}$ is 32.711kV, $P_{Ademola}$ is 10.6MW, THD_u = 30%			
2^{nd}	100	27.05	731.70
3^{rd}	150	56.58	3201.30
8^{th}	400	37.00	1369.00
12^{th}	600	31.82	1012.51
16^{th}	800	28.46	809.97
20^{th}	1000	27.27	743.70
23^{rd}	1150	25.19	634.45
26^{th}	1300	22.81	520.47
28^{th}	1400	19.92	396.64
29^{th}	1450	16.09	259.06
			9678.80
Case 2: ALG – ALG/L Distribution Line, 2^{nd} Harmonic is 100Hz, $V_{Alagbon\ Local}$ is 32.997kV and $P_{AlagbonLocal}$ is 3.6MW, U_h = 16.60kV and THD_u =5.03%			
Case 3: ALG - ANI Distribution Line $V_{Anifowoshe}$ is 32.645kV, $P_{Anifowoshe}$ is 11.7MW, THD_u = 31.9%			
2^{nd}	100	32.22	1038.19
3^{rd}	150	59.59	3550.41
7^{th}	350	39.73	1578.62
11^{th}	550	33.24	1104.79
14^{th}	700	30.11	906.31
18^{th}	900	27.33	746.92
21^{st}	1050	25.54	652.05
23^{rd}	1150	23.48	551.16
25^{th}	1250	19.73	389.29
26^{th}	1300	15.67	245.63
27^{th}	1350	8.85	78.39
			10841.76
Case 4: ALG - FOW Distribution Line, V_{Fowler} is 32.868kV, P_{Fowler} is 9.6MW, THD_u = 21.4%			
2^{nd}	100	25.10	630.03
6^{th}	300	45.83	2100.70
15^{th}	750	34.77	1208.82
24^{th}	1200	32.08	1028.88
			4968.43
Case 5: ADM - ANI Distribution Line, $V_{Anifowoshe}$ is 32.645kV, $P_{Anifowoshe}$ is 11.7MW, THD_u = 20.7%			
2^{nd}	100	27.65	764.32
8^{th}	400	48.32	2335.00
19^{th}	950	38.69	1497.19
			4596.51
Case 6: ALG – BAN/I Distribution LineV$_{Banana\ Island}$ is 32.942kV, $P_{Banana\ Island}$ is 3.0MW, THD_u = 14.8%			
2^{nd}	100	13.66	186.73
4^{th}	200	28.81	830.26
9^{th}	450	19.62	384.78
15^{th}	750	17.00	289.21
20^{th}	1000	15.71	246.73
24^{th}	1200	15.09	227.62
29^{th}	1450	14.39	207.12
			2372.45
21:00 Hrs			
Case 1: ALG – ADM Distribution Line, $V_{Ademola}$ is 32.825kV, $P_{Ademola}$ is 6.7MW, THD_u = 23.77%			
2^{nd}	100	21.53	463.63
3^{rd}	150	44.78	2005.24
8^{th}	400	29.25	855.40

h^{th} harmonic	Harmonic Freq. (Hz)	$U_h(V)$	$U^2_h(V)$
12th	600	25.33	641.46
16th	800	22.55	508.35
20th	1000	21.66	468.99
23rd	1150	19.98	399.18
26th	1300	18.18	330.50
28th	1400	15.87	251.86
29th	1450	12.80	163.74
			6088.35
Case 2: ALG ANI Distribution Line, $V_{Anifowoshe}$ is 32.725kV, $P_{Anifowoshe}$ is 9.3MW, THD_u = 28.4%			
2nd	100	28.76	827.13
3rd	150	53.43	2854.79
7th	350	35.38	1251.92
11th	550	29.60	876.14
14th	700	26.84	720.40
18th	900	24.39	595.08
21st	1050	22.74	517.10
23rd	1150	20.91	437.09
25th	1250	17.63	310.87
26th	1300	13.99	195.69
27th	1350	07.87	61.88
			8648.09
Case 3: ALG - FOW Distribution Line, V_{Fowler} is 32.867kV, P_{Fowler} is 9.7MW, THD_u = 18.5%			
2nd	100	24.62	606.14
8th	400	43.18	1864.55
19th	950	34.50	1190.08
			3660.77
23:00 Hrs			
Case 1: ALG - ANI Distribution Line, $V_{Anifowoshe}$ is 32.695kV, $P_{Anifowoshe}$ is 10.20MW, THD_u = 18.5%			
2nd	100	30.22	913.25
3rd	150	55.64	3095.81
7th	350	37.18	1382.35
11th	550	30.93	956.66
14th	700	23.21	795.80
18th	900	25.42	646.18
21th	1050	23.73	563.11
23th	1150	21.89	479.17
25th	1250	18.42	339.30
26th	1300	14.63	214.04
27th	1350	08.23	67.73
			9453.41

5. NETWORK AVERAGE THD_u

For the determination of the network average THD_u, (equation 8) is used and the respective values obtained for each of the D/Ls in the network is shown in Table 6.

$$Average\ THD_u = \sum_{n=1}^{k}(THD_u)_n \qquad (8)$$

6. DISCUSSION

From the result of the analysis in the forgoing section, it can be seen that the THD_u value on ALG – ALG/L at 02:00Hrs in the first case was 5.26% at a total cascaded harmonic voltage value of 18.5kV. On ALG – FOW Distribution Line at the same time, the THD_u value was estimated to be 20.4%.

Table 6: Average Network THDu

Distribution Line	THD records (%)				Average THD_u (%)
	02:00	09:00	21:00	23:00	
ALG – ALG/L	5.26	5.03	-	-	5.145
ALG – FOW	20.40	21.40	18.50	-	20.100
ALG – ADM	-	30.00	23.77	-	26.885
ALG – ANI	-	31.90	28.40	18.50	26.266
ADM – ANI	-	20.70	-	-	20.700
ALG – BAN	-	14.80	-	-	14.800
Network average THD_u (%)					18.98%

At 09:00Hrs, the THD_u values on ALG – ADM Distribution Line, ALG – ALG/L Distribution Line, ALG – ANI Distribution Line, ALG – FOW Distribution Line, ADM – ANI Distribution Lineand ALG – BAN/IDistribution Line were calculated to be 30%, 5.03%, 31.9%, 21.4%, 20.7% and 14.8% respectively.

At 21:00Hrs, the value of THD_u for the case of ALG – ADM Distribution Linewas 23.77%; for the case of ALG – ANI Distribution Line, THD_u was estimated to be 28.4%, whereas, for the case of ALG – FOW Distribution Line, the value was calculated to be 18.5%.

Finally, at 23:00Hrs, the value of ALG – ANI Distribution Linewas also estimated to be 18.5%.

7. CONCLUSION

This paper has presented fundamentals of harmonic studies and also reviewed issues related to the concept. The results of power flow and its harmonic analysis of the Distribution Lines obtained from a research study were made use in this paper. However, parts of the result of harmonic analysis are presented as harmonics with corresponding impedances. Hence, the THD_u of the Distribution Lineswere computed using the harmonic content parameters of the waveform, i.e. harmonic voltage and impedance magnitude values. The results of these THD_u for the Distribution Lines are also presented. Network average THD_u was evaluated, while a summary discussion of these THD_u values of the lines was presented.

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