Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.11 n.52, p. 156-164. March./April., 2025.
DOI: https://doi.org/10.5935/jetia. v11i52.1565

RESEARCH ARTICLE OPEN ACCESS

ASSESSMENT OF THE EFFECT OF SERIES PASSIVE FILTER ON HARMONIC DISTORTION-POWER LOSSES RELATIONSHIP IN AN ELECTRICITY DISTRIBUTION NETWORK

Okuo Michael Ozaveshe[1], Adebisi Oluseun Ibrahim[2], Akinola Olubunmi Adewale[3]

[1,2,3] Department of Electrical engineering, Federal university of agriculture, Abeokuta, Nigeria

[1]http://orcid.org/0009-0001-3373-0494, [2]http://orcid.org/0000-0001-8958-4951, [3]http://orcid.org/0000-0001-6532-1698

Email: okuomichael5@gmail.com, adebisioluwaseun@funaab.edu.ng, akinolaoa@funaab.edu.ng

ARTICLE INFO

Article History
Received: January 16, 2025
Revised: February 20, 2025
Accepted: March 15, 2025
Published: April 30, 2025

Keywords:
Non-linear load,
Power loss,
Power Quality,
Series passive filter,
Total Harmonic Distortion.

ABSTRACT

Technological innovations in recent times have led to widespread use of non-linear loads in power networks. These loads generate harmonics which result in the distortion of the system's voltage and current signals and consequently, leads to power loss. This research assessed the total harmonic distortion (THD) mitigation capability of series passive filters (SePF) in an electricity distribution network (EDN) with a high penetration level of non-linear loads and the resulting effect on power loss (PL). The EDN for 250-seater computer laboratory facility in Federal University of Agriculture, Abeokuta (FUNAAB), Nigeria was considered as a case study. The network modelled and simulated without and with SePF in MATLAB/Simulink environment (R2023a version). The system's voltage-current THD (THDV-I) and PL were evaluated to determine the relationship between the two parameters. The obtained results showed that when no filter was applied, the THDV-I and PL were 37.38% and 9,703 W, respectively. However, when SePF was used on the network, the THDV-I reduced to 4.90% and the PL minimised to 146 W. These results indicated that PL reduces with decrease in THDV-I. The series passive filter application on the considered facility in this research appropriately mitigated the observed THD and the associated PL.

I. INTRODUCTION

Power quality problems, especially harmonic distortion and power losses, have grown to be major issues in the current electrical distribution network because non-linear loads are used so frequently. These non-linear loads, which include things like computers, variable speed drives, and fluorescent lights, absorb current in a way that isn't sinusoidal, which adds harmonic currents to the power system. [1-3]. The presence of these harmonic currents distorts the ideal sinusoidal waveform of the voltage and current, leading to various adverse effects, including increased power losses, malfunctioning of sensitive equipment, and overheating of transformers and cables [1], [4-6]. Harmonic distortion in electricity distribution systems, if left unmitigated, can lead to severe reliability and efficiency issues, thereby affecting the overall performance of the system [7-10].

The relationship between power losses and harmonic distortion is essential to comprehending the overall effectiveness of the electrical distribution network. Due to the components with higher frequency in the current waveform of the system, electrical systems' losses which are mostly caused by resistive losses in conductors and transformers increase when harmonic currents are present. Additional losses are caused by the conductors' increased eddy current losses, core losses, and skin effects as a result of these higher-frequency currents. Also, harmonic distortion can increase system losses by causing voltage instability and interfering with protective device functionality. [1], [8], [11], [12]. Therefore, an effective harmonic mitigation strategy must not only reduce distortion but also minimize the resultant power losses.

Different solutions techniques have been proposed to mitigate harmonic distortion in power networks. To begin with, authors [6], [13-16] explored how to lower harmonic emission from non-linear loads by modifying power network topologies, isolating, and using harmonic reduction transformers. More so, authors [6], [17],[18] discussed the use of power filters as mitigating techniques for harmonic reduction in power networks, encompassing both passive and active filters as well as their hybrids. Installing passive power filters is one of the commonest ways to reduce harmonic distortion. By creating low-impedance pathways for certain harmonic frequencies to avoid the load, passive filters that consist of resistors, inductors, and capacitors which are intended to lessen particular harmonic frequencies from the electrical network [13], [17-19]. Since each strategy has its advantages and disadvantages, it is impossible to definitively identify which is optimal. To choose the optimal solution and avoid wasting financial resources on inappropriate ones, a preliminary analysis of the problem must be carried out. [9], [13], [20]. On the overall, it has been shown that when these mitigation measures are applied, harmonic distortion reduces drastically, thereby reducing power losses in the system [19], [21], [22].

In this context, the assessment of the effect of series passive filters on the harmonic distortion-power loss relationship is essential for improving the efficiency and reliability of electricity distribution networks [20], [23]. The main goal of such assessments is to determine how the installation of these filters influences both the level of harmonic distortion and the associated power losses in the system.

It must define the problem and importance of the research carried out, it presents a (not very extensive) review of the literature on the subject of the article, including the authors' contributions to the state of the art. If you use abbreviations or acronyms, first write the words that identify them and then, in parentheses, the acronym. This set also establishes the research question, the objectives of the work and hypothesis, if necessary, the importance and limitations of the study. Establishes the method used at work. It is written in the present tense.

II. THEORETICAL REFERENCE

A number of investigations have been conducted on mitigating harmonic distortion and establishing its relationship with power loss without and with filter application.

An assessment of how harmonics affect the distribution of power in the system. Author [4] conducted research on the influence of harmonic effects on energy distribution in a medium voltage network (20kV). The study suggested formulas for calculating energy loss assessments resulting from THDI and power factor noncompliance within the limits imposed by standards. Comparative analysis of ShPF and SAF (shunt active filter) for electrical distribution network harmonic mitigation was presented by author [18]. The study considered a typical bottling company in Nigeria as a test network. Evidence from the results showed that ShPF and SAF minimised the network's THDV and THDI with an indication that ShPF demonstrated better performance than SAF, making it more suitable for mitigating harmonics on the bottling company. Author [19] investigated the effectiveness of harmonic filters in improving power quality under industrial load. Shunt passive filters and hybrid combinations of series active filter and shunt passive filter and shunt active filter and shunt passive filter were shown to be effective harmonic distortion reduction techniques for the test network taken into consideration in this work.

By simultaneously determining the maximum voltage and current harmonic contribution in interconnected networks, Author [22] created a novel technique for reducing harmonic magnitude. According to simulation results, the suggested approach yields more concrete outcomes for accurately identifying the harmonic source that produces the most reduction in harmonic voltage or current in the designated network bus or line. Author [24] presented harmonic analysis in power distribution networks. The research focused on the improvement of the accuracy and reliability of harmonic analysis in the power distribution network. Author [25] looked at how harmonics affected a distribution transformer's temperature rise and power loss. This study examined the elevated losses and temperature rise under well-defined harmonics in a 25kVA oil-filled distribution transformer. The theoretical and practical data were directly correlated, demonstrating the detrimental harmonics' impact on power losses and the accompanying increase in distribution transformer's temperature.

Previous studies reviewed have shown that passive filters are capable of significantly reducing harmonic distortion, but their impact on power losses has been varied depending on the system configuration, filter design, and the level of harmonics present. The objective of this research is to fill this gap by providing a detailed analysis of how series passive filters influence both harmonic distortion levels and power losses in an electricity distribution network.

III. MATERIALS AND METHODS

II.1. HARMONIC INDICES

Harmonic indices are key parameters used to quantify the level of harmonic distortion in power systems, enabling the evaluation of power quality and the identification of potential issues caused by harmonic currents. These indices help in assessing the impact of harmonics on system performance and guide in the design of mitigation strategies like passive filters [11].

II.2. TOTAL HARMONIC DISTORTION (THD)

One of the most widely used indexes for figuring out a waveform's harmonic content is total harmonic distortion (THD). It can be used to measure the total distortion level of both voltage and current, making it an indicator of a waveform's effective value [14],[26]. Put another way, it is the harmonics' potential heating value in relation to the fundamental. It is possible to compute this index for voltage or current using equation (1)[18],[24]:

$$THD=\frac{\sqrt{\sum_{h>1}^{h_{max}} M_h^{\,2}}}{M_1} \tag{1}$$

where M_h is the M quantity of the RMS value of harmonic component h.

The square root of the sum of the squares is the distorted waveform's RMS value. The THD and the waveform's RMS value are connected by equation (2):

$$RMS=\sqrt{\sum_{h>1}^{h_{max}} M_h^{\,2}}=M_1\sqrt{1+THD^2} \tag{2}$$

When a distorted voltage is placed across a resistive load, the THD can give a fairly accurate estimate of the additional heat generated, but for many applications, one must be mindful of its limitations[14], [26]. The most common usage of the Voltage harmonic distortion is characterized by the THD index. The waveform's fundamental value at the time of the sample is nearly always used as a reference for harmonic voltages. THD_V is virtually always a substantial figure as the underlying voltage only changes by a few percent. Relating to this work we first have to determine the total harmonic distortion for both current and voltage. A harmonic affected waveform's current and voltage THD can be written respectively as equations (3) and (4) as:

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \quad (3)$$

$$THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \quad (4)$$

Equations (5) and (6) are alternate form of equations (3) and (4) respectively while equation (7) gives the combined expression relating both current and voltage.

$$I^2 = I_1^2(1+THD_I^2) \quad (5)$$

$$V^2 = V_1^2(1+THD_V^2) \quad (6)$$

$$THD_{V-I} = \sqrt{THD_V^2 + THD_I^2} \quad (7)$$

Where the fundamental current and voltage values are I_1 and V_1, and the RMS current and voltage values are I and V.

The equation (7) is primarily used in power systems research to assess the cumulative effect of voltage and current harmonics on system performance. This combination provides a holistic measure of distortion in systems with complex harmonic interactions, especially when studying the impacts of harmonic pollution on power quality and reliability [27], [28].

II.3. HARMONIC DISTORTION-POWER LOSS RELATIONSHIP IN DISTRIBUTION NETWORK

Harmonic active power, a product of the same order of harmonic voltage and current, is injected into the distribution system by non-linear loads. Even though It is substantially lesser than the underlying active power, the power due to harmonic distortion will raise the utility supply system's losses.. Power loss and harmonic distortion are related via equations (8) to (21) [29],[30]:

$$\text{Power loss due to harmonics (PL)} = RI^2 \quad (8)$$

where R is the resistance of the system and I is the RMS current values and I_h is harmonic current at individual harmonic h

From equation (3) above we have:

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \quad (9)$$

Equation (14) can be modified into equations (10) and (11)

$$THD_I . I_1 = \sqrt{\sum_{h=2}^{\infty} I_h^2} \quad (10)$$

$$THD_I^2 . I_1^2 = \sum_{h=2}^{\infty} I_h^2 \quad (11)$$

where RMS current is

$$I^2 = \sum_{h=2}^{\infty} I_h^2 + I_1^2 \quad (12)$$

Making $\sum_{h=2}^{\infty} I_h^2$ the subject, equation (13) is obtained.

$$\sum_{h=2}^{\infty} I_h^2 = I^2 - I_1^2 \quad (13)$$

Putting equation (13) in equation (11), equations (14) to (16) are obtained.

$$I^2 - I_1^2 = (I_1^2 . THD_I^2) \quad (14)$$

$$I^2 = I_1^2 + (I_1^2 . THD_I^2) \quad (15)$$

$$I^2 = I_1^2(1+THD_I^2) \quad (16)$$

Putting Equation (16) into equation (8), equation (17) was obtained

$$P_L = RI_1^2(1+THD^2_I) \quad (17)$$

Putting equation (12) in equation (8), equation (18) was obtained

$$P_L = R(I^2 + \sum_{h=2}^{\infty} I^2_h) \quad (18)$$

where R is resistance of the conductor, n is the harmonic order, I_n is the current in harmonic order n.

For a three-phase three-wire utility, the total losses are expressed in equations (19) and (21)

$$\text{loss due to harmonics} = 3R_P I_P^2 + R_N I_N^2 \quad (19)$$

$$\text{where } I_N^2 = \sum_{h=1}^{\infty} I_{Nh}^2$$

RMS phase current is expressed in equation (20)

$$I_p^2 = \sum_{h=1}^{\infty}(I_{ah}^2 + I_{bh}^2 + I_{ch}^2) \quad (20)$$

$$\text{loss due to harmonics} = 3R_p \sum_{h=1}^{\infty}(I_{ah}^2 + I_{bh}^2 + I_{ch}^2) + R_N \sum_{h=1}^{\infty} I_{Nh}^2 \quad (21)$$

where the neutral line current is I_N, while the balanced network's phase current is I_p. The hth harmonic of the neutral current is I_{Nh}, the phase and neutral resistances are R_p and R_n, and the harmonic h currents in phases A, B, and C are I_{ah}, I_{bh}, and I_{ch} respectively [29],[30] . Currents that are zero-sequence and unbalanced can cause overloading due to the neutral wire's significant loss.

II.4. DESIGN OF SERIES PASSIVE FILTER

A filter connected in series with a system is called a series passive filter. Harmonics are blocked before they may enter the system using high impedance passive filters in series. Passive filters are typically connected in series with main switchboards, motor control systems, switch gears, busbars, etc. [3], [13], [17], [31]. Designs of single or double-tuned passive filters are very good options for applications that need the suppression of particular harmonics. For this research, SePF with special attention on single tuned filter. The basic configuration of a tuned filter is represented in Figure 1 while the schematic diagrams of SePF is shown in Figure 2.

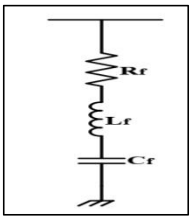


Figure 1: Schematic diagram of a single tuned passive filter.
Source: Authors, (2025).

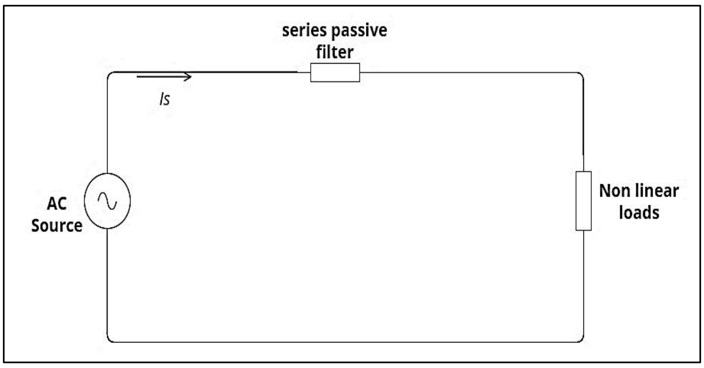


Figure 2: Schematic diagram of SePF.
Source: Authors, (2025).

From a power factor standpoint, selecting the appropriate capacitor size is crucial when designing tuned passive filters. According to author [32] The filter capacitor C_f is usually sized for a known reactive power compensation Q_C in order to boost power factor. Consequently, C_f and Q_C are related by equation (22):

$$C_f = \frac{Q_c}{2\pi f V^2}\left(1 - \frac{1}{n^2}\right) \quad (22)$$

where n is the harmonic order and f is the fundamental frequency, and V is the supply voltage.

Equation (28) governs the series resonance provided by the filter reactor Lf at the harmonic frequency fn = nf.:

$$X_L = X_c \quad (23)$$

where the capacitive reactance is denoted by X_C and the inductive reactance by X_L.

The values for X_L and X_C are provided by equations (24) and (25) as:

$$X_L = 2\pi f_n L_f \quad (24)$$

$$X_c = \frac{1}{2\pi f_n C_f} \quad (25)$$

In equations (29) and (30) make L_f and C_f the subjects, respectively. equations (26) and (27) are obtained as:

$$L_f = \frac{X_L}{2\pi f_n} \quad (26)$$

$$C_f = \frac{1}{2\pi f_n X_c} \quad (27)$$

The use of equations (24) and (25) in equation (23) yields equation (28) providing the filter's inductive value..

$$L_f = \frac{1}{4\pi^2 f_n^2 C_f} \quad (28)$$

The filter's quality factor Q, which determines how sharp the tuning is, determines the resistance R_f of a tuned filter [32],[33]. Equation (34), from which R_f is mathematically derived, is further adjusted in equations (30) and (31) using equation (28) in (29).

$$R_f = \frac{2\pi f_n L_f}{Q} \quad (29)$$

$$R_f = \frac{\sqrt{\frac{L_f}{C_f}}}{Q} \quad (30)$$

$$R_f = \sqrt{\frac{L_f}{Q^2 C_f}} \quad (31)$$

The value of Q ranges from 20 to 100; a higher value of Q results in better harmonic distortion mitigation. [32],[33]

II.5. CASE NETWORK

250 seater's computer laboratory electrical network is going to be used as the test system in this study. 250 seater's computer laboratory is a facility in Federal university of Agriculture Abeokuta (FUNAAB) in Ogun state, Nigeria. The facility was fed from a dedicated 33 kV feeder which was stepped down to 11/0.415 kV through a 33 MVA rating power transformer. The facility has a back-up consisting of a generator of 300 kVA rating. The layout of the facility's electrical distribution network is shown in Figure 3, Tables 3 and 4 displays the power requirements of the primary loads.

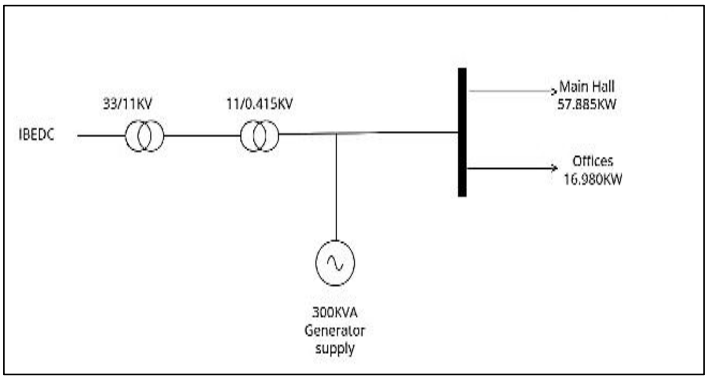


Figure 3: The power network layout of the 250 seater's computer lab.
Source: Authors, (2025).

Table 3: Power requirements of the main hall loads in 250 seater's computer laboratory.

Loads	Type	Unit	S(VA)	P(W)	Q(Var)
Computers	N	291	23643.75	18915	14186.23
fans	N	30	1312.5	1050	787.2
Compact fluorescent	N	116	4350	3480	2610
Split Air conditioner	N	6	42750	34200	25650
CCTV cameras	N	16	300	240	180
Total			**72356.3**	**57885**	**43413.6**

Source: Authors, (2025).

Table 4: Power requirements of the office loads in 250 seater's computer laboratory.

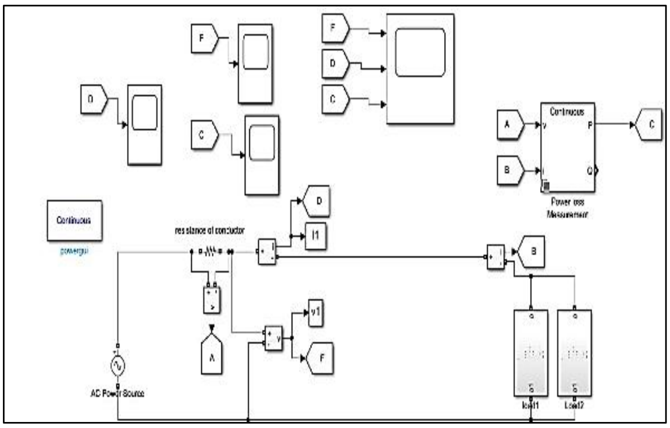
Loads	Type	Unit	S(VA)	P(W)	Q(Var)
Computers	N	12	975	780	585
fans	N	12	525	420	315
Compact fluorescent	N	12	450	360	270
Air conditioner	N	12	18750	15000	11250
printer	N	12	525	420	315
Total			**21225**	**16980**	**12735**

Source: Authors, (2025).

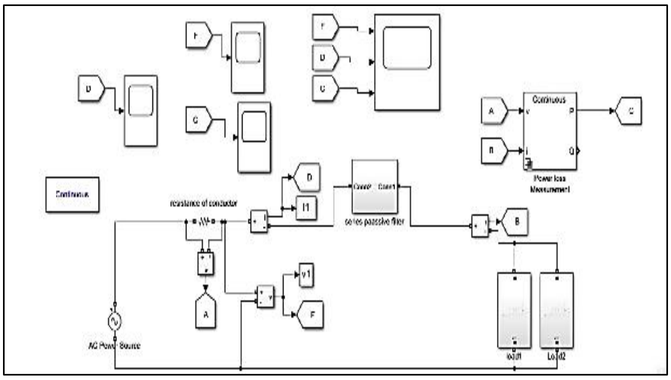
Where N is nonlinear load.

II.6. CHOICE OF SIMULATION SOFTWARE

In order to be able to investigate properly the harmonic distortion's effects on power losses, a virtual environment of the distribution network will simulated using Matlab/Simulink software. Simulink is a graphical programming environment for modelling and analysing dynamical systems. It is interactive and provides an enabling environment to explore design concept to model non-linear system at any level of complexity. The Simulink model of the considered 250 seater's computer laboratory distribution network. Apart from being interactive, Simulink allows the systematic construction of the distribution network and harmonic mitigation device using basic function blocks [34] . Among its other benefits are the provision of solvers, customized libraries and graphical editors for non-linear systems design and analysis. Hence, the choice of MATLAB/Simulink software for this study. The fast Fourier transform application will be used in deriving the THD of the system as it is very useful in transforming time series signal to frequency axis signal. The Simulink model for the different configuration of filters is depicted in Figure 4.



(a)



(b)

Figure 4: Simulink model (a) without filter (b) SePF for 250 seater computer laboratory power distribution network.

Source: Authors, (2025).

IV. RESULTS AND DISCUSSION

III.1. SIMULATION RESULTS OF TEST NETWORK WITH NO FILTER

The obtained results from simulating the Simulink model of 250 Seater's Computer Laboratory facility network layout without any use of filter are displayed in Figures 5 to 8. Figure 5 and 6 are the three phase waveforms of the network's voltage and current respectively. Figure 7 is the power loss three phase wave form and Figures 8a and 8b is the spectrum for both voltage and current

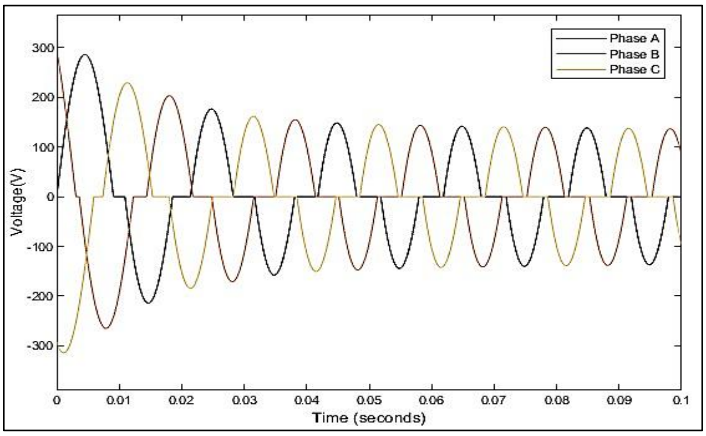


Figure 5: Three phase voltage waveform of the case network without filter.

Source: Authors, (2025).

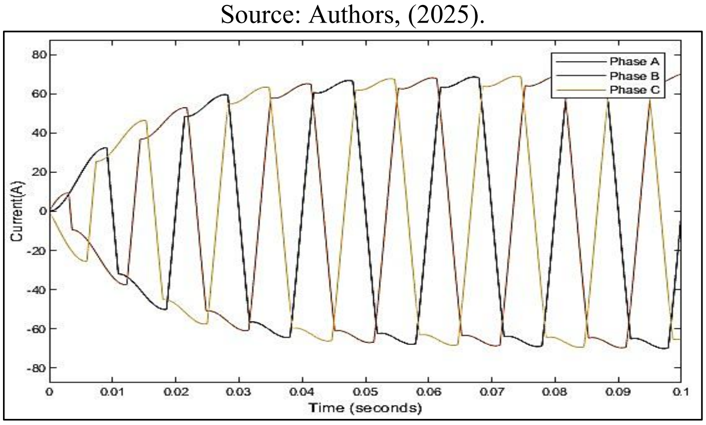


Figure 6: Three phase Current waveform the case network without filter.

Source: Authors, (2025).

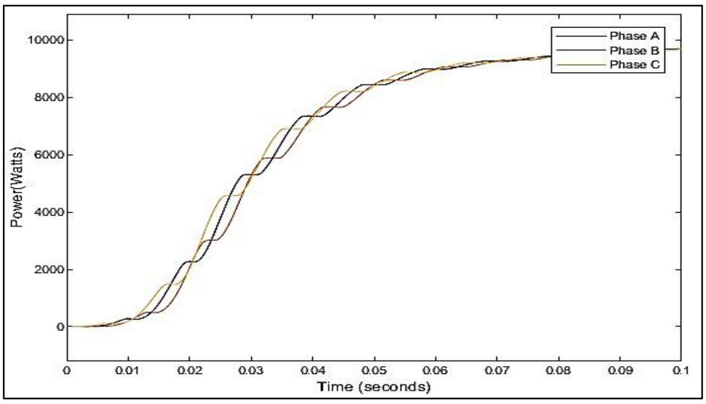
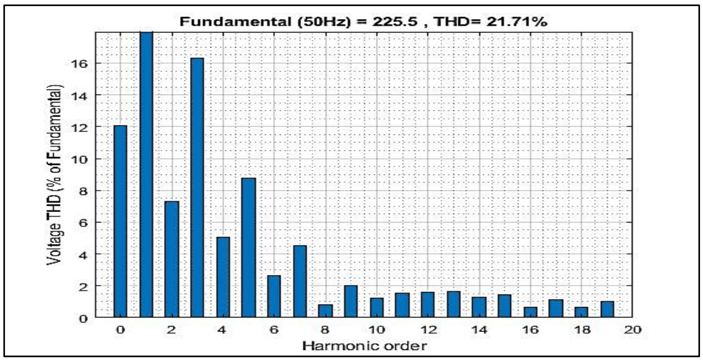
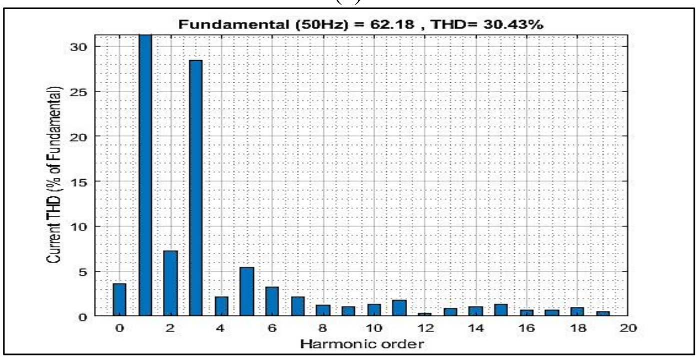


Figure 7: Three phase Power loss waveform the case network without filter.
Source: Authors, (2025).



(a)



(b)

Figure 8: The spectrums of case network without filter (a) voltage (b) Current.
Source: Authors, (2025).

The THD_V and THD_I in Figure 8a was evaluated as 21.71% and 30.43% respectively. From figure 6 and 7 we can see the distortions in the system's voltage and current signal in their spectrums respectively without filter. According to Figure 7 the maximum power loss in the system was measured as 9703 W. The THD_{V-I} is calculated using Equation (7) and the value was 37.38% which is very high without filter applied.

III.2. SIMULATION RESULT OF TEST NETWORK WITH SePF

The results obtained from the simulation of the Simulink model of 250 Seater's Computer Laboratory facility network layout with Series passive filter applied are presented in Figure 9 to 12. Figures 9 and 10 shows the three phase wave form for the system's voltage and current respectively. Figure 11 shows the power loss three phase wave form of the case network and Figures 12a and 12b shows the spectrum for voltage and current respectively.

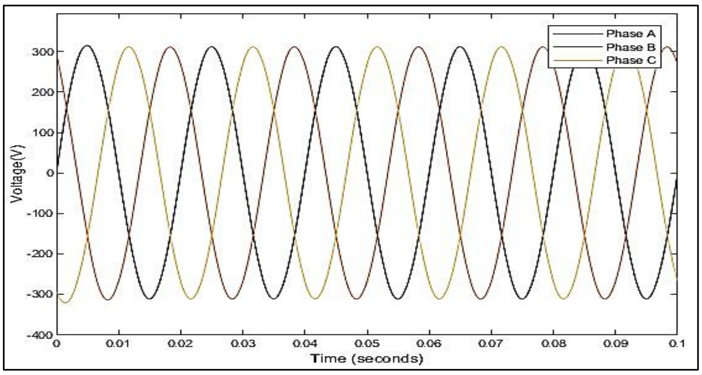


Figure 9: Three phase voltage waveform of the case network with the use of SePF.
Source: Authors, (2025).

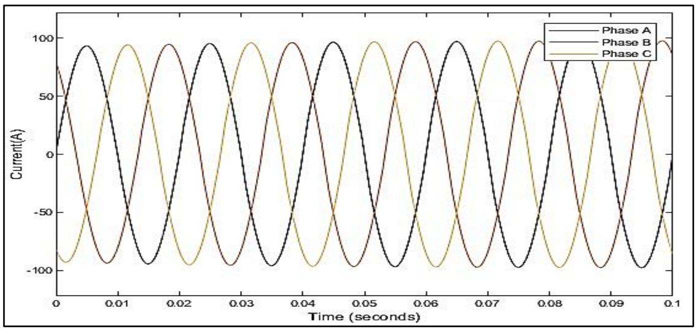


Figure 10: Three phase current waveform of the case network with the use of SePF.
Source: Authors, (2025).

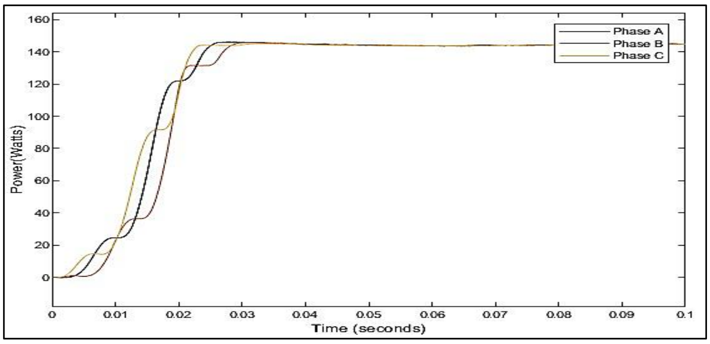
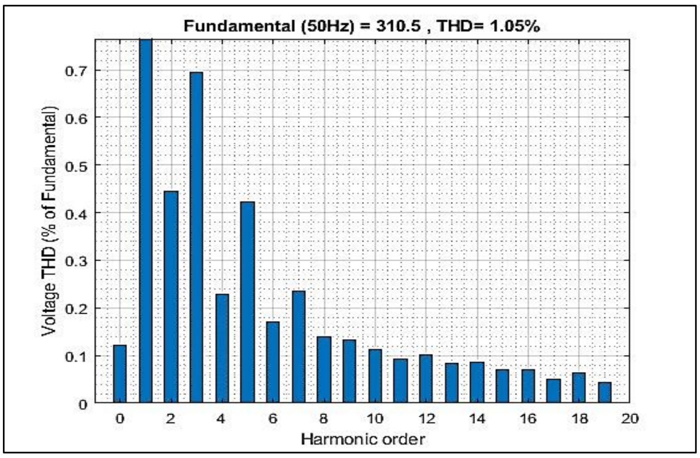
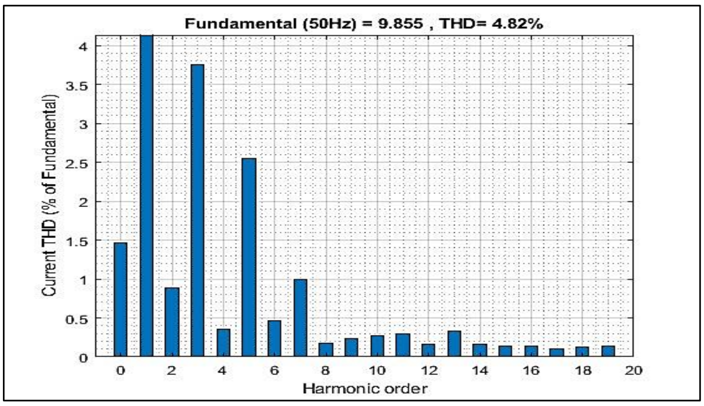


Figure 11: Three phase power loss waveform of the case network with the use of series passive filter.
Source: Authors, (2025).

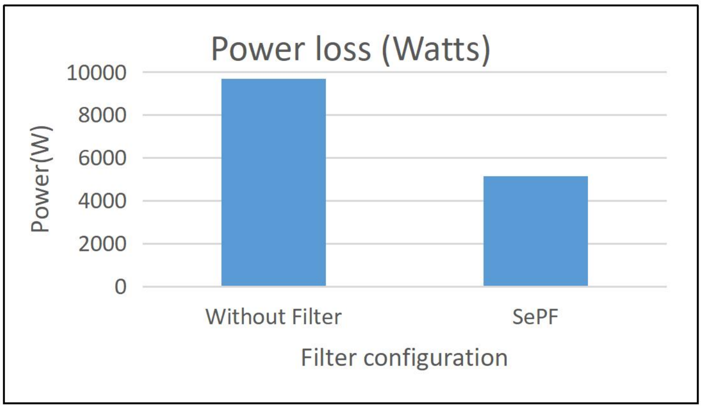


(a)



(b)

Figure 12: The spectrums of the case network with the use of SePF (a) voltage (b) Current.
Source: Authors, (2025).



(b)

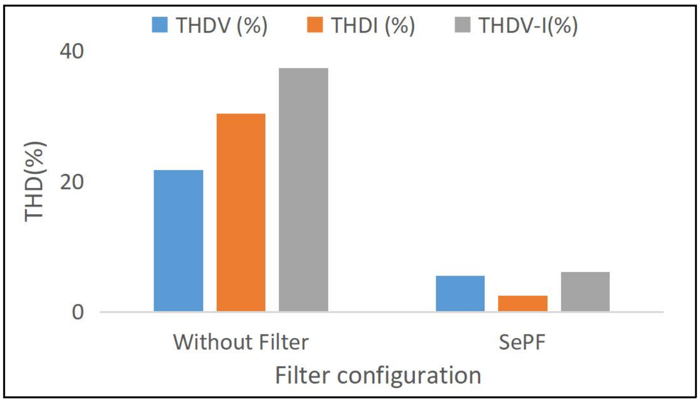
Figure 13: (a) Bar chart of THD_V THD_I and THD_{V-I} (b) Bar chart of Power loss of the simulated results of the 250 Seater's Computer Laboratory facility distribution network without and with application of SePF.
Source: Authors, (2025).

Figure 13 and 14 shows the minimized distortion in the voltage and current signals respectively when SePF was applied to the network. THD_V in Figure 16(a) was evaluated as 0.90% given a reduction of 20.81% when compared with Figure 8(a), while THD_I in Figure 16(b) was evaluated as 4.82% given a reduction of 25.61% when compared with Figure 8(b). According to Figure 15 the maximum power loss in the system was measured as 146 W given a reduction of 9557 W as when compared with Figure 7. The THD_{V-I} is calculated using Equation (7) and the value was 4.90% with SePF applied.

The values of THD_V and THD_I gotten from the results of the simulation where inputted in equation (7) to calculate the THD_{V-I} which is the combination of both THD_V and THD_I. Figure 13a shows the comparison of THD_V, THD_I, and THD_{V-I} and Figure 13b shows the power loss comparison without filter and with SePF applied in the 250 Seater's Computer Laboratory facility distribution network.

II.3. COMPARISON OF THD ON PL WITHOUT AND WITH THE APPLICATION OF FILTER TO 250 SEATER'S COMPUTER LABORATORY FACILITY DISTRIBUTION NETWORK

The values THD_V and THD_I gotten from the results of the simulation where inputted in equation (12) to calculate the THD_{V-I} which is the combination of both THD_V and THD_I. Figure 13 shows the comparison between HD and PL in the 250 Seater's Computer Laboratory facility distribution network. from Figure 21 it can be established that total harmonic distortion is directly proportional to power loss.



(a)

III.4. DISCUSSION OF THE FINDINGS

The harmonics present causes the basic system parameters such as voltage and current to deviate from the statutory or tolerance limit, leading to poor operation of the distribution system and consequently, causing power quality problems and high system losses. From the results obtained, it was observed that the THD_V and THD_I of the system when no filter was applied were above the recommended harmonic distortion limits of 5 and 16% respectively [2],[35],[36] . However, when SePF were applied respectively, the THD_V and THD_I obtained in each filter state reduced drastically to values within the recommended harmonic distortion limit [2],[35],[36]. Assessing from Figure 13, it was found out that power loss increases with increase in THD which indicated that there was a positive correlation between THD and power loss.

The results of the harmonic distortion in the test network in this study aligned with the findings of authors [18], [21]. [13], 19] that the application of passive filters has the capabilities of reducing harmonic distortion level within a power network. Authors [25],[37],[38] also asserted that harmonic distortion effects power quality negatively with resulting increase in power loss. This assertion was in tandem with the findings of this research. Hence, this study established that power quality improvement could be achieved with the application of the passive filters to reduce the harmonic distortion levels and by extension reducing power loss within power distribution network.

Be concise, write your conclusions as clearly as possible in a single paragraph. It must be consistent with the objectives of the research and the scientific issues described in it.

V. CONCLUSIONS

The harmonics present in any power network can cause serious efficiency problems in such system, hence, threatens power quality. The study assessed the THD-PL relationship on a test facility electrical distribution network of 250 Seater's Computer Laboratory in FUNAAB, Nigeria and the mitigation capabilities of SePF on the system. The study noticed high penetration level of harmonics which caused high distortion level and PL in the case network without application of filters. The THD and consequently, the PL reduced appreciably with the use of SePF on the system. The study demonstrates a clear correlation between harmonic distortion and power losses in electricity distribution networks. By examining the role of series passive filters, the study confirms their effectiveness in reducing harmonic distortion, thereby minimizing associated power losses.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Okuo Michael Ozaveshe, Adebisi Oluseun Ibrahim, Akinola Olubunmi Adewale.
Methodology: Okuo Michael Ozaveshe, Adebisi Oluseun Ibrahim, Akinola Olubunmi Adewale.
Investigation: Okuo Michael Ozaveshe, Adebisi Oluseun Ibrahim, Akinola Olubunmi Adewale.
Discussion of results: Okuo Michael Ozaveshe, Adebisi Oluseun Ibrahim, Akinola Olubunmi Adewale.
Writing – Original Draft: Okuo Michael Ozaveshe, Adebisi Oluseun Ibrahim, Akinola Olubunmi Adewale.
Writing – Review and Editing: Okuo Michael Ozaveshe, Adebisi Oluseun Ibrahim, Akinola Olubunmi Adewale.
Resources: Okuo Michael Ozaveshe, Adebisi Oluseun Ibrahim, Akinola Olubunmi Adewale.
Supervision: Okuo Michael Ozaveshe, Adebisi Oluseun Ibrahim, Akinola Olubunmi Adewale.
Approval of the final text: Okuo Michael Ozaveshe, Adebisi Oluseun Ibrahim, Akinola Olubunmi Adewale.

VIII. REFERENCES

[1] U. Agus and M. S. Eka, "The influence of harmonic distortion on losses and efficiency of threephase distribution transformer," Journal of Physics: Conference Series 1858 012084, pp. 1-10, 2021.

[2] R. M. Mohd, M. Azizan and B. Ismail, "Observatory case study on total harmonic distortion in current at laboratory and office building," Journal of Physics: Conference series, vol. 1432, no. 1, pp. 1-9, 2020.

[3] A. A. Hussein, M. El-Metwally and F. M. Osama, "Harmonic Distortion Effects and Mitigation in Distribution Systems," Journal of American Science, vol. 6, no. 10, pp. 173-183, 2010.

[4] B. Nicolae and S. Valentin, "Evaluation of Harmonic Effects on the Power System," The Annals of "Dunarea de Jos" University of Galati Fascicle III Electrotechnics Electronics Automatic Control and Informatics, vol. 43, no. 1, pp. 10-18, 2020.

[5] P. Jong-il, L. Hangsang, Y. Minhan and P. Chang-Hyun, "A Novel Method for Assessing the Contribution of Harmonic Sources to Voltage Distortion in Power System," IEEE Access, 2017.

[6] E. K. Mehdi, "Causes, Effect and Practical Methos of Harmonic Reduction In Iranian Cement Factories with Focus on Plant Developnevt," JETIA, vol. 10, no. 50, pp. 61-75, 2024.

[7] M. Bamigbola, M. Ali and K. Awodele, "Predictive Models of Current, Voltage, and Power Losses on Electric Transmission Lines," Journal of Applied Mathematics, vol. 2014, no. 3, pp. 1-5, 2014.

[8] N. C. Bogdan, G. Gheorghe and S. Florina, "The Influence of Harmonics on Power Losses in Urban Distribution networks," International symposium on fundamentals of electrical engineering, pp. 1-4, 2016.

[9] I. A. Adejumobi, O. I. Adebisi and J. Amatu, "Harmonics mitigation on industrial loads using series and parallel resonant filters," Nigerian Journal of Technology, vol. 36, no. 2, pp. 611-620, 2017.

[10] T. R. Muhammad, M. A. Muhammad and M. A. Sheikh, "Analysis and Evaluating the Effect of Harmonic Distortion Levels in Industry," in 4th International Conference on Energy Conservation and Efficiency, 2021.

[11] E. Benedict, D. Collins, D. Gotham, S. Hoffman, D. Karipides, S. Pekarek and R. Ramabhadran, "Losses In Electric Power Systems," ECE Technical Reports, 1992.

[12] Y. Gu, "Power quality in distribution networks: estimation and measurement of harmonic distortion and voltage dips," Technische Universiteit Eindhoven, geboren te Xining, 2017.

[13] Z. F. Ahmed, A.-A. H. Shady and B. E. Murat, "Power System Harmonics - Analysis, Effects and Mitigation Power System Harmonics - Analysis, Effects and Mitigation," InTech. , 2019.

[14] B. Angelo and H. Zbigniew, Voltage and Current Harmonics, Sussex: John Wiley & Sons Ltd, 2008.

[15] S. Meera and S. Deepa, "A Review of Hybrid Filter Topologies for Power Quality Compensation," Ineernational Research Journal of Engineering and technology, 2, vol. 2, no. 4, pp. 613-621, 2015.

[16] A. A. Mohamad, J. Alireza and M. R. P. Behbahani, "A new method for evaluation of harmonic distortion in reconfiguration of distribution network," Wiley, vol. 30, no. 12, pp. 2-13, 2020.

[17] C. A. Eric, "Causes, effects and mitigation of harmonics on distribution transformers," 2021.

[18] O. Ogundele, O. Adebisi, I. Adejumobi and A. Alabi, "Comparative Evaluation of Shunt Passive and Shunt Active Power Filters for Harmonic Mitigation in an Electrical Distribution Network," Nigerian Research Journal of Engineering and Environmental Sciences, vol. 8, no. 2, pp. 383-396, 2023.

[19] O. Adebisi, I. Adejumobi, R. Jokojeje and O. Adekoya, "Assessing the Performance of Harmonic Filters for Power Quality Improvement on Industrial Load: 7-Up Industry Plc Power Network as a Case Study," ABUAD Journal of Engineering Research and Development (AJERD), vol. 1, no. 1, pp. 32-48, 2017.

[20] R. Soares, M. Oliveira, M. Freitas, G. Viajante and E. Chaves, "Loss Analysis Due to Influence of Harmonics in a Distribution System," International Conference on Renewable Energies and Power Quality, vol. 19, no. 3, pp. 402-406, 2021.

[21] H. A. A. Muhamad, M. A. Muhammad, S. Zaliman and W. Y. Mohd, "A review on harmonic mitigation method for non-linear load in electrical power system," 2021.

[22] M. A. Javad, T. E. Mehdi and V. Behrooz, "A New Method to Reduce Harmonic Magnitude Based on Simultaneous Determination of Maximum Voltage and Current Harmonic Contribution in Interconnected Networks," Electric Power Components and Systems, vol. 47, no. 8, pp. 1-13, 2019.

[23] S. Rosalia, A.-A.-E. M. Khaled and K. T. Mohamed, "Efficiency in Distribution Networks with Harmonic Distortion," Cape Town, 2020.

[24] Y. Wang, "Harmonic analysis in distribution network," Manchester, 2020.

[25] T. Soumya, M. B. Nipun and H. Joachim, "Effects of harmonics on temperature rise and power loss of a distribution transformer," in CMD, 2022.

[26] S. Santoso, M. F. Mark, D. C. Roger and B. H. Wayne, Electrical Power Systems Quality, 3rd ed., McGraw-Hill, 2012.

[27] F. Alasali, N. Khaled, F. Husam, H. William, V. Arangarajan and A. Asma, "Modern Optimal Controllers for Hybrid Active Power Filter to Minimize Harmonic Distortion," MDPI Journals, vol. 11, no. 9, pp. 1-17, 2022.

[28] F. Peng, A. Hirofumi and N. Akira, "A new approach to harmonic compensation in power systems-a combined system of shunt," IEEE Transaction on Industry Applications, vol. 20, no. 6, pp. 983-990, 1990.

[29] G. M. Jawad and H. Mokhtari, "Impact of Harmonics on Power Quality and Losses in Power Distribution Systems," International Journal of Electrical and Computer Engineering, vol. 5, no. 1, pp. 166-174, 2015.

[30] L. Johan, "harmonic distortion in power system," Goteborg, 2001.

[31] Candence, 28 June 2024. [Online]. Available: https://resources.pcb.cadence.com/blog/2023-passive-electronic-components-building-blocks-of-electronic-circuits.

[32] M. Tali, A. Obbadi, A. Elfajri and Y. Errami, "Passive Filter for Harmonic Mitigation in Standalone PV System for Non Linear Load," IEEE, pp. 499-504, 2014.

[33] Z. Memon, M. Uquaili and M. Una, "Harmonics Mitigation of Industrial Power System Using Passive Filters," Mehran University Research Journal of Engineering and Technology, vol. 31, no. 2, 2016.

[34] O. Ejiofor, N. Benneth, O. Uche and C. Nnabugwu, "Dynamic modelling and simulation of an induction motor with completely reduced stator transients," Journal of Asian scientific Research,, vol. 9, no. 7, pp. 56-64, 2019.

[35] S. Daniel, N. Mathew, K. Kevin and J. Steven, "IEEE Power Quality Standards," in 20th International Conference on Harmonics & Quality of Power (ICHQP), Naples, 2022.

[36] IEEE, "IEEE Standard for Harmonic Control in Electric Power Systems," IEEE Std 519-2022 (Revision of IEEE Std 519-2014), pp. 1-31, 5 August 2022.

[37] F. A. A. Basholli, "Monitoring and assessment of the quality of electricity in a building.," Engineering Applications, vol. 2, no. 1, pp. 32-48, 2023.

[38] Y. Wenqian, Y. Xiang, X. Longwei, Z. Chao and M. Xinsheng, "Harmonic Loss Analysis of Low-Voltage Distribution Network Integrated with Distributed Photovoltaic," MDPI Sustainability, vol. 15, no. 4334, pp. 1-23, 2023.