ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلــة جـــامعة بـــــابــل للعلــــــوم الهندسية
Vol. 34, No. 2. \ 2026 ISSN: 2616 - 9916

Mitigation of 3rd Harmonic in Three-Phase Four-Wire Distribution Power Systems Based on Zigzag Transformer with Passive Filter

Dhafer Mayoof Dahis

Southern Technical University, Nasiriyah Technical Institute

Email: Eng.dafer@stu.edu.iq

Received:	30/3/2026	Accepted:	6/5/2026	Published:	28/6/2026

Abstract

The broad usage of nonlinear loads in 3-phase 4-wire distribution systems defines significant 3rd-harmonic currents that accumulate in the neutral conductor and diminish quality of power. The present study examines a hybrid model of mitigation integrating Zigzag transformer connected in shunt with the load and a series passive filter installed on the utility side in the neutral conductor. The novelty of the proposed approach lies in controlling the neutral current path by shaping the frequency-dependent impedance, such that third-harmonic components are blocked from propagating toward the utility and are instead forced to circulate through the Zigzag transformer. The filter is tuned to show high impedance at the 3rd-harmonic frequency, so restricting triplen harmonic propagation to the load and directing such harmonics again via Zigzag transformer. Simulations in MATLAB/Simulink under unbalanced as well as balanced nonlinear loading validate the substantial reduction in neutral current distortion and utility-side 3rd-harmonic currents. Specifically, the proposed method achieves a reduction of more than 97–99% in third-harmonic current on the utility side under balanced conditions, while under unbalanced loading the neutral current total harmonic distortion (THD) is reduced from 438.4% to approximately 49.95%, showing the efficiency of the proposed configuration.

Keyword:- Zigzag transformer, Neutral current, 3rd harmonic, Passive filter, 3-phase 4-wire distribution power system.

I. Introduction

The rapid development of nonlinear loads, basically based on power-electronic devices like adjustable-speed motor drives and silicon-controlled rectifiers, has considerably intensified harmonic distortion in electrical distribution systems [1],[2]. Triplen harmonics (3rd, 9th, 15th, and higher-order elements) are of particular concern in 3-phase 4-wire networks, because they are in phase in all three conductors and instead of canceling, they accumulate in the neutral line[3]. The waveform relation among basic elements and the 3rd-harmonic component they shown in Figure 1, highlighting the characteristic distortion defined by nonlinear loads. Because triplen harmonics are in phase in all three conductors, they accumulate in the neutral line instead of canceling, leading to high neutral current levels, as illustrated in Fig. 2. The harmonic order relationship is given in Eq. (1), which indicates that harmonic components occur at integer multiples of the fundamental frequency. As a result, excessive neutral currents, voltage distortion, overheating of conductors and transformers, and degradation of overall power quality may occur, particularly in low-voltage distribution systems supplying sensitive loads[4], [5]. Studies published in the last few years confirm that neutral current accumulation remains a critical power-quality concern in modern low-voltage distribution networks supplying nonlinear and single-phase loads[6], [7].

$$f_h = h \times f \qquad (1)$$

Where: f_h, h, and f represent the harmonic frequency, the harmonic order, and the frequency, respectively.

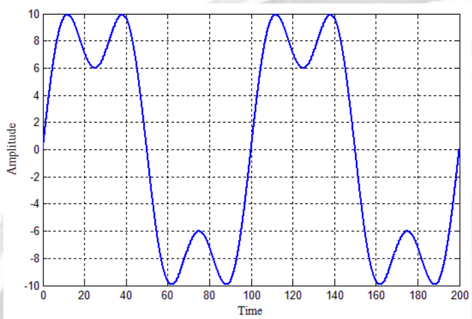


Figure 1. The fundamental frequency signal and 3rd-harmonic order[8].

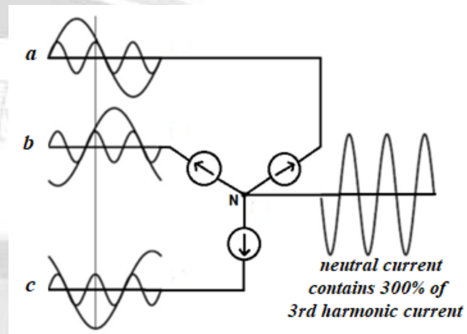


Figure 2. High 3rd harmonics neutral current under nonlinear loads

Various mitigation techniques have been proposed in the literature to address neutral current harmonics. Active power filters can generate compensating currents that effectively cancel harmonic components and can provide excellent performance under dynamic load conditions[8], [9]. Recent investigations have demonstrated that three-phase four-wire shunt active power filters can significantly reduce neutral current distortion at the point of common coupling; however, their implementation is still associated with increased system complexity and cost[10]. However, their application in medium- and high-voltage systems is sometimes restricted by high price, complex control requirements, and reduced economic feasibility[9], [10]. In other words, passive filters show the more economical as well as simpler response for harmonic mitigation and are broadly applied in practice[11], [12], [13]. Such filters are normally composed of inductive and capacitive components tuned to particular harmonic frequencies and offer advantages such as low implementation complexity and high reliability[8], [13]. Current studies on passive-filter model investigates report effective reduction of THD when filters are appropriately tuned, however, system impedance sensitivity as well as resonance concerns are still an issue[14], [15]. Therefore, passive filters might define undesirable resonance with the supply network, their performance also could be sensitive to variations in system impedance [16], [17].

Also, Zigzag transformers have been broadly used in 3-phase 4-wire distribution systems for decreasing neutral current as well as suppressing zero-sequence harmonic elements[17], [18]. Zigzag transformers present a low-impedance path for triplen harmonics due to their winding configuration, letting such elements circulate locally instead of propagating to the side of utility[19]. Present strategy is attractive due to its relatively low cost, simplicity as well as ease of integration into existing distribution systems[16]. Recent modeling and application-oriented studies reaffirm the effectiveness of Zigzag transformers in reducing neutral current distortion under practical nonlinear loading conditions, while also highlighting their limited mitigation capability when used as a standalone solution[20], [21]. However, previous studies have shown that the harmonic mitigation capability of Zigzag transformers alone is limited, and in practical applications, only a partial reduction of third-harmonic currents typically not exceeding 42 -46% can be achieved, particularly under unbalanced load conditions[22], [23]. In addition, passive filters, although widely used, are often affected by resonance issues and sensitivity to system impedance variations, which may limit their performance in practical distribution systems. Furthermore, existing studies do not adequately address the controlled distribution of harmonic currents between the load and the utility. To overcome these limitations, the proposed configuration shown in Fig. 3 integrates a Zigzag transformer with a series passive filter placed in the neutral conductor on the utility side, aiming to suppress triplen harmonics more effectively while avoiding resonance with the upstream network. The main novel contribution of this work lies in an impedance-based strategy for controlling the flow of triplen harmonic currents. Unlike conventional hybrid approaches that primarily focus on direct harmonic filtering, the proposed method introduces a coordinated impedance based strategy to control the flow of triplen harmonic currents. Specifically, the series passive filter is strategically placed in the neutral conductor on the utility side to present high impedance at the third-harmonic frequency, thereby preventing harmonic propagation toward the source and forcing these components to circulate through the Zigzag transformer. This operational principle distinguishes the proposed configuration from existing hybrid solutions and enhances its effectiveness, particularly under unbalanced load conditions. The primary objective of this paper is to develop an effective and low-complexity method for mitigating third-harmonic currents in three-phase four-wire distribution systems by controlling the flow of zero-sequence harmonic components. Specifically, this work aims to limit the propagation of triplen harmonics toward the utility side while forcing their circulation through the Zigzag transformer using a series passive filter installed in the neutral conductor. The main contributions of this work can be summarized as follows:

1. A hybrid Zigzag transformer–series passive filter configuration with the filter installed in the neutral conductor at the utility side.
2. An impedance-based strategy for controlling the path of triplen harmonic currents, preventing their propagation toward the utility and forcing their circulation through the Zigzag transformer.
3. Comprehensive simulation analysis under balanced and unbalanced conditions demonstrating significant reduction in third-harmonic currents and neutral current THD.

JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلـة جـــامعة بـــــابـل للعلـــــوم الهندسية
Vol. 34, No. 2. \ 2026 ISSN: 2616 - 9916

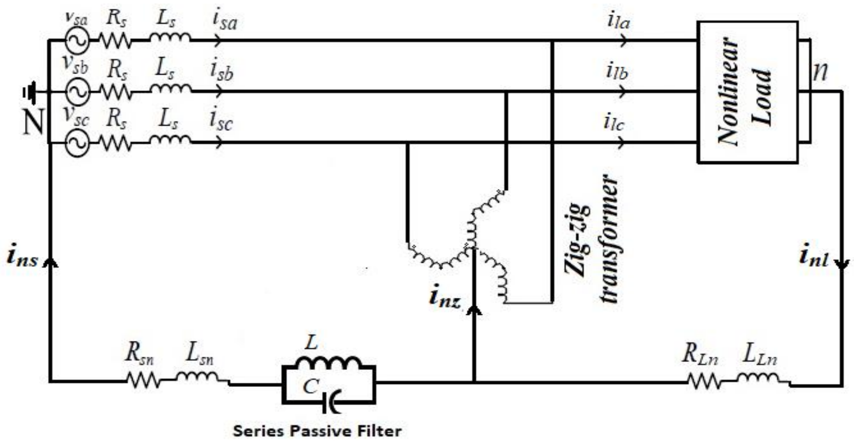


Figure 3. High 3rd-harmonics neutral current under nonlinear loads

II. Basic Analysis

A. Zigzag Transformer Analysis

Zigzag transformer can be single-phase or three-phase transformer with three windings and unique construction as shown in Figure 4(a). Zero-sequence currents for the three-phase (i_{a0} , i_{b0} and i_{c0}) in the three-phase four-wire distribution power system have the same amplitude and phase. They can be given as[17], [18].

$$i_{a0}(t) = i_{b0}(t) = i_{c0}(t) \quad (2)$$

The current of neutral $i_n(t)$ is given by the equation below which represents the sum of harmonic currents of the zero sequence for all phases a, b, and c [14], [17], [18].

$$i_n(t) = 3i_{a0}(t) = 3i_{b0}(t) = 3i_{c0}(t) \quad (3)$$

The output current flowing out from the connection dot of the secondary coil will be equal to the input current passing into the connection dot of the primary coil because the transformer coil turn ratio is 1:1 as shown in Fig.4. Therefore, we have

$$i_{za}(t) = i_{zb}(t) \quad (4)$$

$$i_{zb}(t) = i_{zc}(t) \quad (5)$$

$$i_{zc}(t) = i_{za}(t) \quad (6)$$

Equations (4)–(6) indicate that the currents flowing in the three phases into the three transformers must be equal. This indicates that the Zigzag transformer can provide a path for the zero-sequence current. The phase diagram for Fig. 4(a) is shown in Fig. 4(b), and it can be observed that the voltage across the transformer winding is in phase with the phase voltage of the three-phase distribution power system[24], [25], [26], [27].

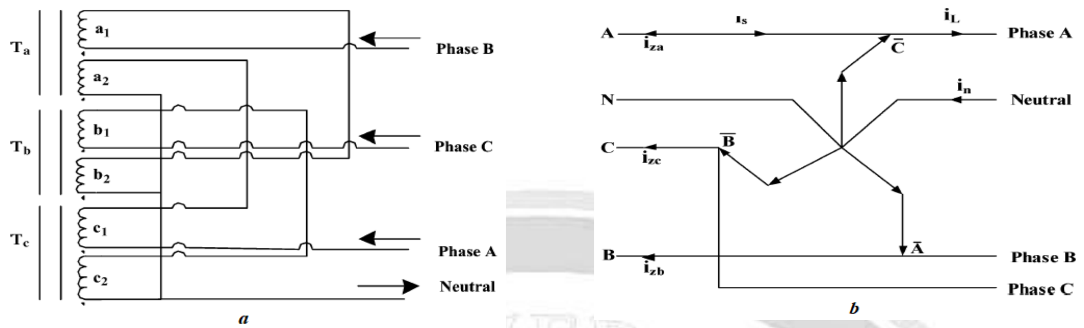


Fig.4. Zigzag transformer. (a) Circuit connection and (b) phase diagram[27].

II-B. Mathematical Model of the Series Passive Filter

The series passive filter employed in this work consists of an inductor L_{sf} and a capacitor C_{sf} connected in parallel and installed in series with the neutral conductor on the utility side, as illustrated in Fig. 3. The purpose of this configuration is to provide a frequency-dependent impedance that restricts the flow of third-harmonic currents toward the utility while allowing fundamental-frequency components to pass with minimal attenuation.

The equivalent impedance of the parallel *LC* filter can be expressed as:

$$Z_{sf}(jw) = \left(\frac{1}{jwL_{sf}} + jwC_{sf}\right)^{-1} \quad (7)$$

Where ω = 2πf is the angular frequency. At the tuning frequency, the inductive and capacitive susceptances cancel each other, resulting in a high impedance characteristic.

The tuning frequency of the filter is defined by:

$$f_t = \frac{1}{2\pi\sqrt{L_{sf}C_{sf}}} \quad (8)$$

In this study, the filter is tuned to the third-harmonic frequency $f_3 = 3f_1$, where f_1 is the fundamental system frequency. At this frequency, the high impedance of the filter prevents third-harmonic currents from flowing toward the utility side and forces them to circulate through the Zigzag transformer, which provides a low-impedance path for zero-sequence components. At the basic frequency, although, the filter impedance stays sufficiently low, ensuring a usual system function with no definition of considerable voltage drop.

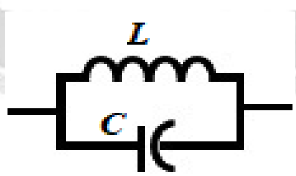


Fig. 5 Series harmonic filter

C. Mathematical Model of the Proposed System

The proposed harmonic mitigation system includes a nonlinear load supplied by a 3-phase 4-wire distribution network, a Zigzag transformer connected in shunt with the load as well as a series passive filter installed in the neutral conductor on the side of utility. The interaction between these components determines the flow of fundamental and harmonic currents within the system. Let the phase currents drawn by the nonlinear load be expressed as:

$$i_a(t) = i_{a1}(t) + \sum_{h=3,9,\dots} i_{ah}(t) \quad (9)$$

$$i_b(t) = i_{b1}(t) + \sum_{h=3,9,\dots} i_{bh}(t) \quad (10)$$

$$i_c(t) = i_{c1}(t) + \sum_{h=3,9,\dots} i_{ch}(t) \quad (11)$$

where $i_{x1}(t)$ represents the fundamental component and $i_{xh}(t)$ denotes the harmonic components of order. For triplen harmonics, the harmonic components are in phase and form zero-sequence currents.

The neutral current can therefore be written as:

$$i_n(t) = i_a(t) = i_b(t) = i_c(t) \quad (12)$$

For triplen harmonic components, this reduces to:

$$i_{n,h}(t) = 3i_{a,h}(t) \quad (13)$$

At the neutral node, the zero-sequence harmonic current is divided between the Zigzag transformer branch and the utility side through the series passive filter. This relationship can be expressed as:

$$i_{n,h}(t) = i_{z,h}(t) + i_{u,h}(t) \quad (14)$$

Where iz,h(t) is the harmonic current circulating through the Zigzag transformer and iu,h(t) is the harmonic current flowing toward the utility.

The current division is governed by the frequency-dependent impedances of the Zigzag transformer $Z_z(h)$ and the series passive filter $Z_{sf}(h)$, such as:

$$i_{u,h}(t) = i_{n,h}(t) \frac{Z_z(h)}{Z_z(h)+Z_{sf}(h)} \quad (15)$$

$$i_{z,h}(t) = i_{n,h}(t) \frac{Z_{sf}(h)}{Z_z(h)+Z_{sf}(h)} \quad (16)$$

At the third-harmonic frequency, the impedance of the series passive filter becomes significantly larger than that of the Zigzag transformer, i.e., $Z_{sf}(3) > Z_z(3)$. Consequently:

$$i_{u,3}(t) \approx 0 \ \ and \ \ i_{z,3}(t) \approx i_{n,3}(t) \quad (17)$$

This condition ensures that third-harmonic currents are effectively prevented from flowing toward the utility and are instead forced to circulate through the Zigzag transformer. At the fundamental frequency, the impedance of the series passive filter remains low, allowing normal current flow without disturbing system operation.

While Fig. 3 presents the theoretical schematic of the system, Fig.6 shows the corresponding MATLAB/Simulink implementation used for simulation studies, showing the implementation of the three-phase source, nonlinear load, Zigzag transformer, and the series passive filter in the neutral conductor. The model is used to evaluate harmonic mitigation under different loading conditions.

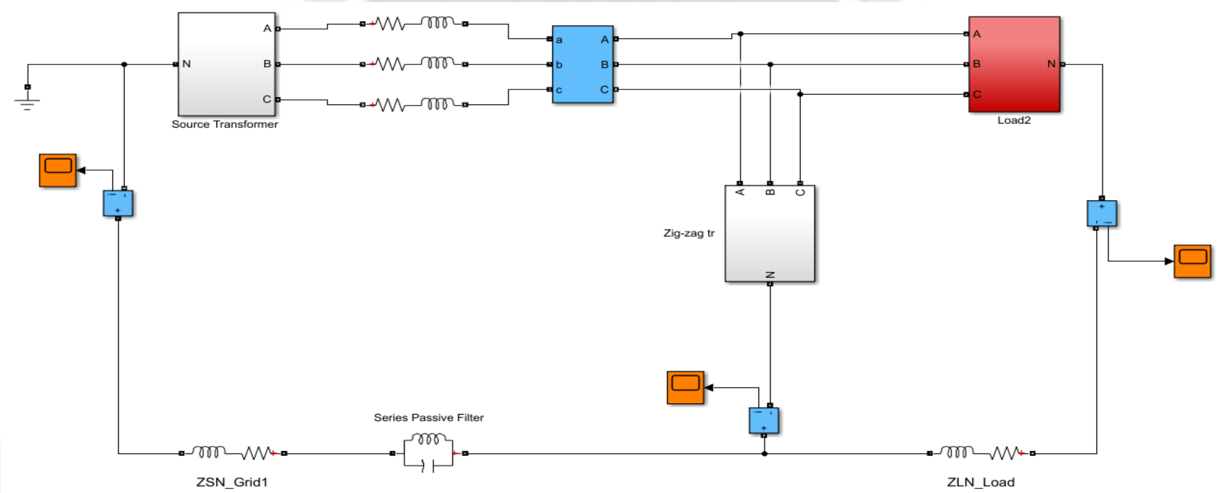


Fig. 6 illustrates the MATLAB/Simulink model

IV. Simulation Results and Discussion

MATLAB/Simulink simulations were performed to assess the performance of the proposed harmonic mitigation under balanced and unbalanced nonlinear load situations. The model of simulation was enhanced applying the parameters of filter, system, load briefed in Table 1. Zigzag transformer as well as Hybrid Zigzag transformer–series passive filter configuration efficiency

separately is evaluated via phase and neutral present waveforms as well as their related harmonic spectra, with specific focus on total harmonic distortion (THD) and 3rd-harmonic magnitude on the utility side.

Table 1

S. No	Parameter	Value
1	Source Transformer	380/220V, 250kVA, 50HZ
2	Balanced Load (R, C)	40Ω, 1500µF
3	Unbalanced Load (R, C)	(40, 30, 20) Ω, 1500µF
4	Z_L (Rs, Ls)	0.02Ω, 0.2mH
5	Z_{LN} (RLN, LLN)	0.005Ω, 0.05mH
6	Z_{SN} (RSN, LSN)	0.015Ω, 0.15mH
7	Series Filter (C_{sf} , L_{sf})	22540 µf, 0.05 mH
8	Z Zig-Zag (RZ, LZ,)	0.521 Ω, 0.276mH,
9	Zm Zig-Zag (RM , LM)	4444 Ω, 4.408H

The parameters listed in Table 1 are selected based on representative values commonly used in low-voltage three-phase four-wire distribution systems. These parameters are chosen to ensure realistic operating conditions and to facilitate a fair evaluation of the harmonic mitigation performance of the proposed configuration.

A. Case 1: Zigzag Transformer Only

1) Balanced Load Condition

Zigzag transformer presents partial triplen harmonic suppression under balanced nonlinear loading, where providing a low-impedance way for zero-sequence currents. As Figure 7 shows, the peak 3rd-harmonic current at the phase of load obtains nearly 10.95 A, as the load-side neutral current gets 32.84 A. On the utility side of the related phase and neutral 3rd-harmonic currents are in turn decreased to 7.01 A and 21.04 A, showing the reduction of nearly 36%. The harmonic spectra shown in Figure 8 validates that; however, the Zigzag transformer attenuates the 3rd-harmonic element, a considerable harmonic distortion level stays injected into the network of utility.

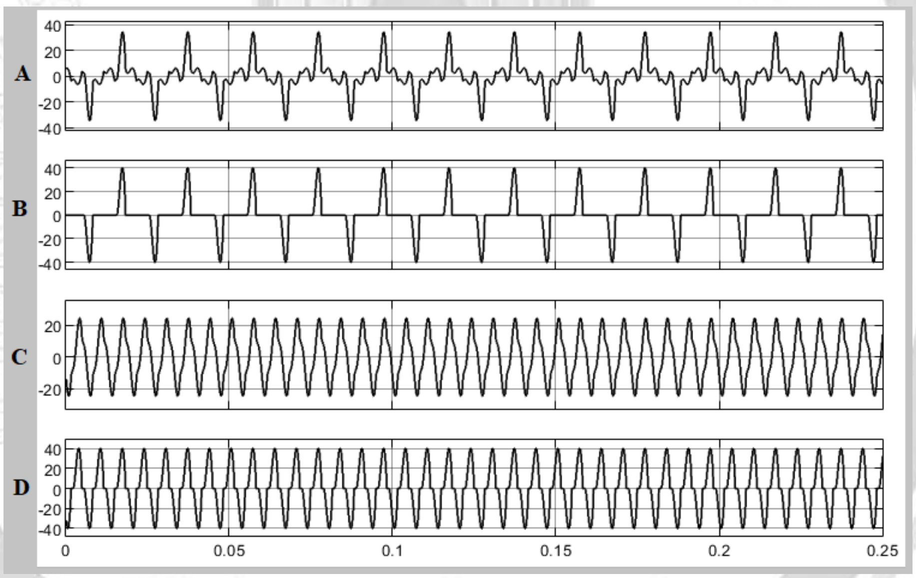
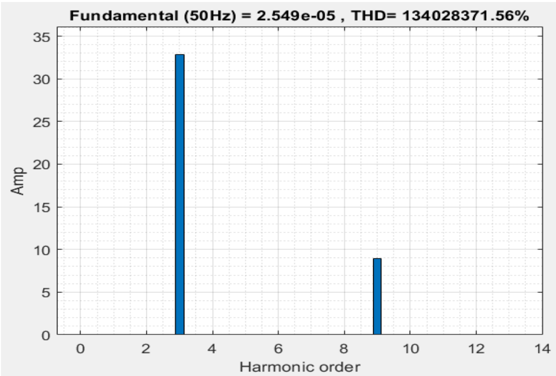
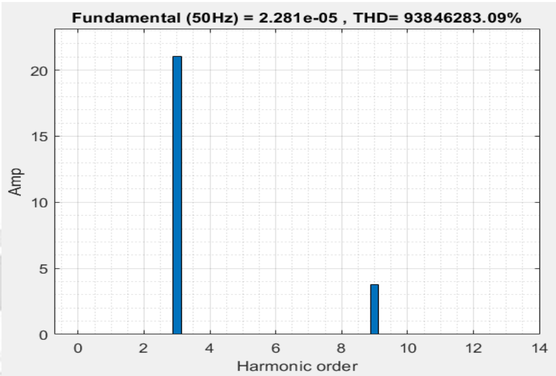


Fig. 7. Result of simulation with the balanced nonlinear load: (A) load current-phase a, (B) current on the utility side (C) the side of utility neutral current, (D) load neutral current side

ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلــة جـــامعة بـــــابــل للعلــــــوم الهندسية
Vol. 34, No. 2. \ 2026
ISSN: 2616 - 9916



(a)



(b)

Figure 8 illustrates the current spectrum under balanced load, (a) on load neutral side, (b) on the neutral side of utility

2) Unbalanced Load Condition

The zero-sequence currents’ accumulation causes the substantial increment in neutral current magnitude as the load does not become balanced. Figure 9 shows the peak 3rd-harmonic current at the load-side neutral develops to 45.82 A, while the load current around 10.93 A. On the utility side, the Zigzag transformer decreases the phase and neutral 3rd-harmonic currents in turn to 6.64 A and 29.35 A, related to reductions of nearly 39% and 36%. The harmonic spectra in Figure 10 illustrate that the neutral current THD is decreased from 449.37% on the side of load to 324.2% on the utility side, showing restricted ability of mitigation under unbalanced operating situations.

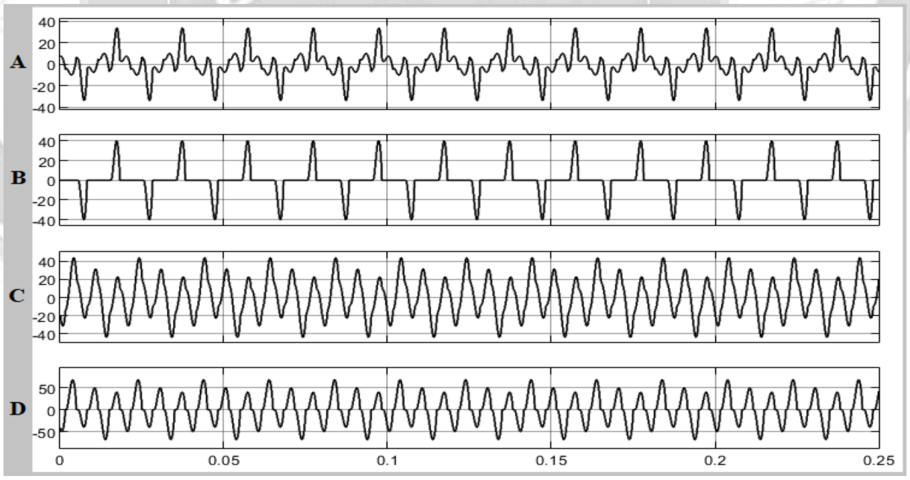
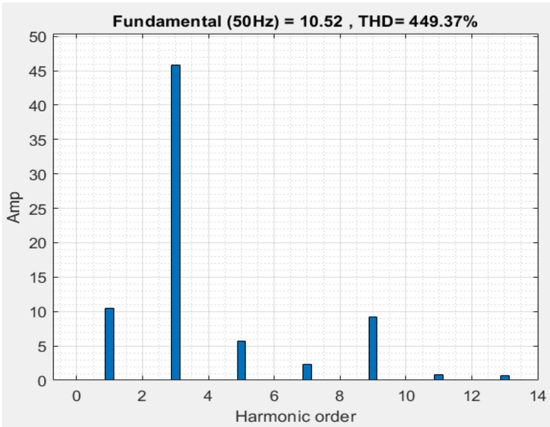
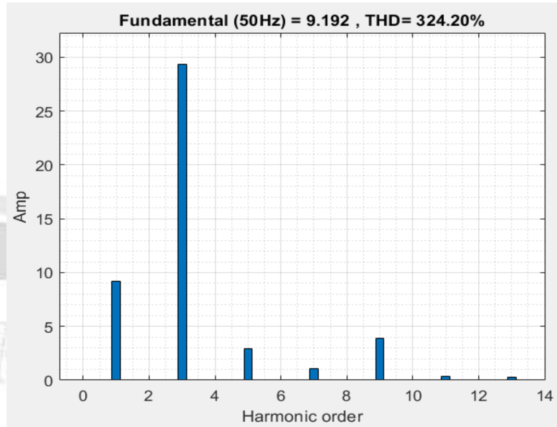


Fig. 9. Result of simulation with the unbalanced nonlinear load: (A) load current-phase a, (B) current on the utility side (C) utility neutral current side, and (D) load neutral current side





(a) (b)

Fig.10 illustrates the current spectrum under unbalanced load, (a) on load neutral side, (b) on neutral side of utility

B. Case 2: Zigzag Transformer with Series Passive Filter

1) Balanced Load Condition

The series passive filter addition considerably improves the performance of harmonic mitigation. Figure 1 1shows that as the load-side 3rd-harmonic phase and neutral currents stay high at nearly 10.61 A and 31.84 A, the phase of utility-side as well as neutral third-harmonic currents are in turn decreased to around 0.1 A and 0.031 A. It relates to a reduction exceeding 97–99% in comparison to the Zigzag-only configuration. The harmonic spectra in Figure 12 validate that the series passive filter efficiently limits triplen harmonic propagation to the utility and forces them to circulate in the Zigzag transformer.

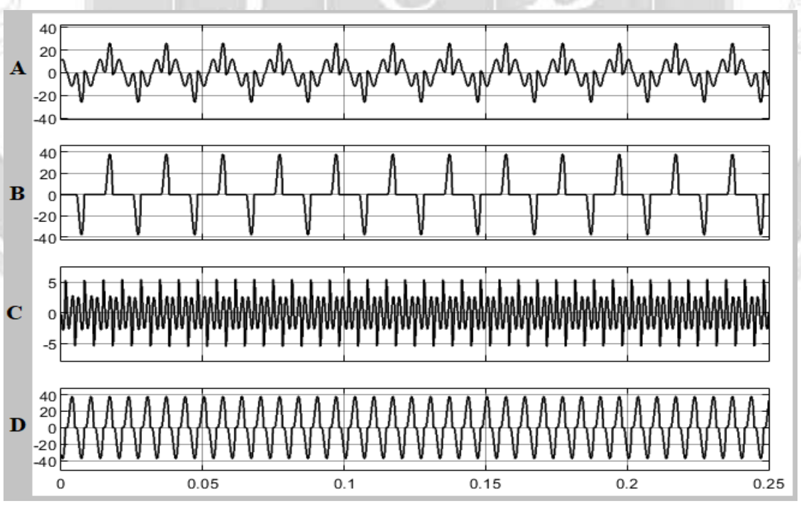
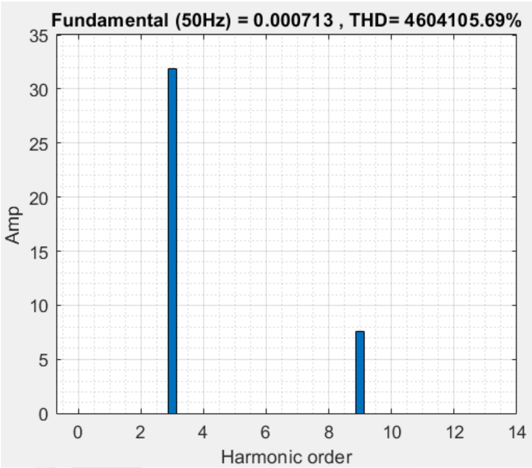
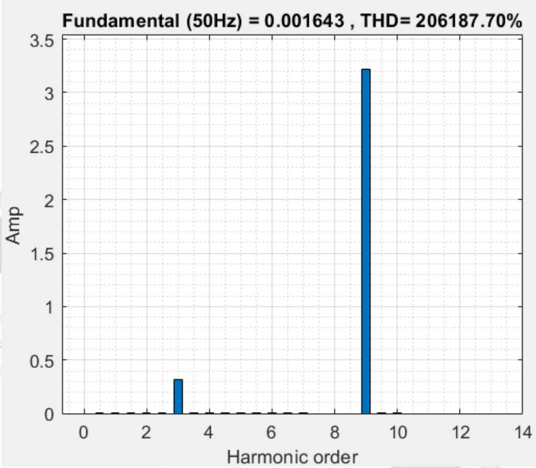


Fig. 11. Result of simulation with the balanced nonlinear load: (A) load current-phase a, (B) current on the utility side (C) neutral current side of utility, (D) load neutral current side





(a) (b)

Fig.12 shows the current spectrum under balanced load, (a) on the load neutral side and (b) on the utility neutral side

2) Unbalanced Load Condition

Under unbalanced nonlinear load conditions, the proposed hybrid configuration maintains strong harmonic suppression capability. As illustrated in Fig. 13, despite the high load-side third-harmonic neutral current, the utility-side neutral current magnitude is significantly reduced. The corresponding harmonic spectra in Fig. 14 reveal that the neutral current THD at the utility side is reduced from 438.4% at the load side to approximately 49.95%, demonstrating the robustness of the proposed method under severe unbalanced operating conditions.

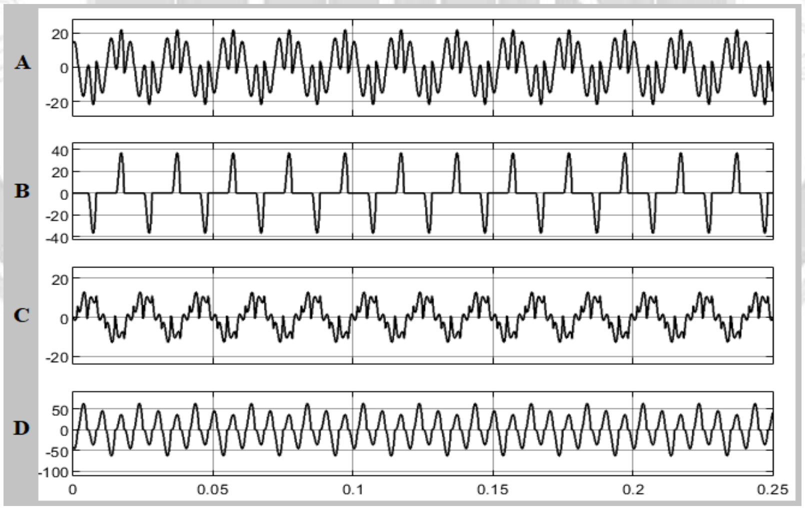
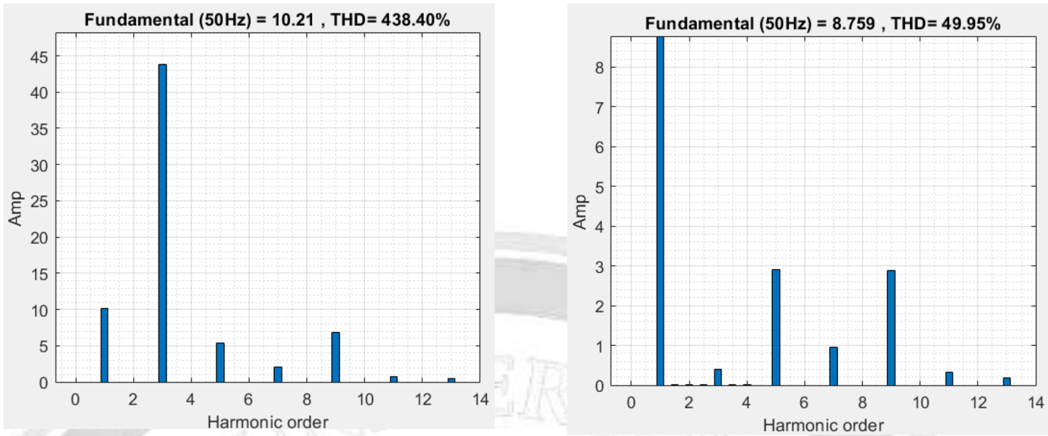


Fig. 13. Simulation result with the unbalanced nonlinear load: (A) load current-phase a, (B) current at utility side, (C) utility neutral current side, and (D) load neutral current side



(a) (b)

Fig.14 shows the current spectrum under unbalanced load, (a) on load neutral side and (b) on utility neutral side

C. Comparative Performance Analysis

The comparative assessment of the two configurations clearly shows the hybrid Zigzag transformer–series passive filter strategy superiority. When the Zigzag transformer alone achieves the moderate reduction in 3rd-harmonic current and neutral current THD, especially under balanced loading, its performance deteriorates under unbalanced situations. In contrast, the series passive filter inclusion leads to a drastic reduction in 3rd-harmonic current magnitude and neutral current distortion on the side of utility, as evidenced by Figures 11-14. Such quantitative outcomes validate that the offered configuration presents the highly efficient response to mitigate triplen harmonics in 3-phase 4-wire distribution systems.

It should be noted that under balanced loading conditions, the fundamental component of the neutral current is inherently close to zero. As a result, the calculated THD values may appear excessively high, since THD is defined relative to the fundamental component. Therefore, in this case, the THD index does not accurately reflect the actual level of harmonic distortion, and the absolute magnitude of the neutral current provides a more meaningful indicator of performance. Under unbalanced conditions, the THD reaches 449.37% at the load side, is reduced to 324.2% on the utility side with the Zigzag transformer, and significantly lowered to 49.95%, using the proposed method. According to IEEE 519 recommendations, current THD limits at the point of common coupling are typically below 5% for low-voltage systems. Although the Zigzag transformer alone does not satisfy these limits, the proposed configuration demonstrates a consistent and substantial improvement in THD reduction across all operating conditions.

It should also be noted that under unbalanced nonlinear loading conditions, the neutral current contains a significant contribution from triplen harmonics (particularly the third harmonic), which are zero-sequence components. These harmonics from each phase are in phase and therefore add arithmetically in the neutral conductor, resulting in a neutral harmonic current that can reach approximately three times the corresponding phase harmonic component.

Consequently, the neutral current may exhibit relatively high harmonic content compared to individual phase currents. When combined with a relatively small fundamental component in the neutral conductor, this leads to very high THD values, which reflect the accumulation of harmonic currents rather than any inaccuracy in the simulation model.

V. Discussion

The simulation results show that harmonic mitigation efficiency in 3-phase 4-wire distribution systems significantly relies on the characteristic of the neutral current impedance path. When only a Zigzag transformer is used, 3rd-harmonic and other triplen elements are partially suppressed because of the low-impedance path accessibility for zero-sequence currents. This mechanism accounts for the observed reduction in 3rd-harmonic current magnitude and neutral current THD on the utility side under balanced loading situations. However, the mitigation capability of the Zigzag transformer alone becomes limited under unbalanced nonlinear loads, as evidenced by the relatively high residual neutral current distortion.

The series passive filter introduction basically alters the harmonic current distribution in the system. Through providing a high impedance at the 3rd-harmonic frequency in the neutral conductor on the utility side, the filter efficiently limits triplen harmonic currents from propagating to the source. Therefore, such harmonic components are diverted through the Zigzag transformer which provides a low-impedance circulation path. This coordinated function defines the substantial reduction in third-harmonic current magnitude and neutral current THD observed under both balanced and unbalanced operating situations.

The quantitative outcomes validate that the proposed hybrid configuration not only develops harmonic suppression under nominal operating situations but also keeps strong performance under strict load imbalance. The drastic reduction in utility-side neutral current distortion shows that the offered strategy addresses the inherent limitation of conventional Zigzag transformer-based mitigation approves, specifically in systems with high nonlinear and asymmetrical loads' penetration.

In order to further evaluate the effectiveness of the proposed method, a comparison with existing harmonic mitigation techniques is considered. Active power filters (APFs) are widely recognized for their high harmonic compensation capability and excellent dynamic performance; however, they require complex control strategies and involve higher implementation costs. Passive filters, although simple and economical, are sensitive to system impedance variations and may introduce resonance issues. Zigzag transformers alone provide only partial mitigation of triplen harmonics, particularly under unbalanced load conditions. In contrast, the proposed hybrid Zigzag transformer–series passive filter configuration combines the advantages of simplicity and improved harmonic suppression by controlling the path of harmonic currents through impedance shaping. This results in enhanced mitigation performance without the complexity associated with active filtering solutions.

Table 2

S. No	Method	Harmonic Reduction	Complexity	Cost	Performance under Unbalance
1	Zigzag Transformer	Moderate	Low	Low	Weak
2	Passive Filter	Moderate- High	Low	Low	Sensitive
3	Active Power Filter	Very High	High	High	Strong
4	Proposed Method	High (Targeted Very High for triplen harmonics)	Medium	Medium	Strong

VI. Conclusions

The Present study examined a hybrid harmonic mitigation strategy for 3-phase 4-wire distribution systems through the integrated use of a Zigzag transformer and a series passive filter. The Zigzag transformer was connected in parallel with the load, while the passive filter was installed in series with the neutral conductor on the utility side of to selectively limit third-harmonic currents.

Simulation results obtained using MATLAB/Simulink under balanced and unbalanced nonlinear load conditions show that the Zigzag transformer alone offers limited harmonic mitigation, especially under load imbalance. In contrast, the proposed hybrid configuration achieves a significant reduction in 3rd-harmonic current magnitude and neutral current total harmonic distortion on the utility side. The results confirm that forcing triplen harmonics to circulate via the Zigzag transformer while preventing their propagation to the utility is the efficient approach to improve power quality.

The proposed approach offers a practical, low-complexity solution for neutral current harmonic mitigation without introducing resonance issues or adversely affecting fundamental-frequency operation. These features make the proposed configuration well suited for application in modern distribution networks with a high penetration of nonlinear loads.

References

[1] J. Wang and B. He, “Novel step-up topologies of zigzag autotransformer,” *Electronics (Switzerland)*, vol. 10, no. 24, Dec. 2021, doi: 10.3390/electronics10243071.

[2] X. Mu *et al.*, “A Novel Shunt Zigzag Double-Tap Low-Harmonic Multi-Pulse Rectifier Based on a Three-Stage Power Electronic Phase-Shifting Transformer,” *Sensors*, vol. 24, no. 17, Sep. 2024, doi: 10.3390/s24175564.

[3] S. Khuttiyaboot and N. Leeprechanon, “dSPACE Based Series Active Filter for Harmonics Mitigation in a Neutral Conductor for 3P4W Distribution System,” *Journal of Clean Energy Technologies*, vol. 2, no. 4, pp. 343–348, 2014, doi: 10.7763/jocet.2014.v2.152.

[4] N. Kumar Yadav, "Harmonics Distortion in Distribution Systems: A Review of Non-Linear Load Effects and Solutions," 2024.

[5] R. Omar, A. Ahmad, M. Sulaiman, and R. O., "Triplen Harmonics Mitigation 3 Phase Four-Wire Electrical Distribution System Using Wye-Zig-Zag Transformers."

[6] M. Popescu, A. Bitoleanu, M. Linca, and C. V. Suru, "Improving power quality by a four-wire shunt active power filter: A case study," *Energies (Basel).*, vol. 14, no. 7, Apr. 2021, doi: 10.3390/en14071951.

[7] S. Freitas, L. C. Oliveira, P. Oliveira, B. Exposto, J. G. Pinto, and J. L. Afonso, "New Topology of a Hybrid, Three-Phase, Four-Wire Shunt Active Power Filter," *Energies (Basel).*, vol. 16, no. 3, Feb. 2023, doi: 10.3390/en16031384.

[8] *2016 17th International Conference on Harmonics and Quality of Power*. IEEE, 2016.

[9] S. T. Jafrodi, M. Ghanbari, M. Mahmoudian, A. Najafi, E. M. G. Rodrigues, and E. Pouresmaeil, "A novel control strategy to active power filter with load voltage support considering current harmonic compensation," *Applied Sciences (Switzerland)*, vol. 10, no. 5, Mar. 2020, doi: 10.3390/app10051664.

[10] M. M. Ishaya, O. R. Adegboye, E. B. Agyekum, M. F. Elnaggar, M. M. Alrashed, and S. Kamel, "Single-tuned passive filter (STPF) for mitigating harmonics in a 3-phase power system," *Sci. Rep.*, vol. 13, no. 1, Dec. 2023, doi: 10.1038/s41598-023-47614-7.

[11] *2015 Modern Electric Power Systems*. IEEE, 2015.

[12] E. Normanyo, "Journal of Engineering Mitigation of Harmonics in a Three-Phase, Four-Wire Distribution System using a System of Shunt Passive Filters," *International Journal of Engineering and Technology*, vol. 2, no. 5, 2012.

[13] Z. A. Memon, M. A. Uquaili, and A. Unar, "Harmonics Mitigation of Industrial Power System Using Passive Filters."

[14] L. Gumilar, I. A. Wicaksono, A. N. Afandi, A. A. A. Samat, and Q. A. Sias, "Investigation of the usage of zigzag transformers to reduce harmonics distortion in distribution systems," *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, vol. 14, no. 2, pp. 138–149, 2023, doi: 10.14203/j.mev.2023.v14.138-149.

[15] A. M. Elkholy, A. V. Chasov, and D. I. Panfilov, "Statistical approach to non-invasive modeling of zigzag transformers using variable impedance," *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 14, Dec. 2025, doi: 10.1016/j.prime.2025.101135.

[16] *2017 International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT)*. IEEE, 2017.

[17] I. F. Mohamed, S. H. E. Abdel Aleem, A. M. Ibrahim, and A. F. Zobaa, " Optimal Sizing of C -Type Passive Filters under Non-Sinusoidal Conditions ," *Energy Technology & Policy*, vol. 1, no. 1, pp. 35–44, Jan. 2014, doi: 10.1080/23317000.2014.969453.

[18] N. M. Tabatabaei, M. Abedi, N. S. Boushehri, and A. Jafari, "IJTPE Journal MULTIPULSE AC-DC CONVERTERS FOR HARMONIC REDUCTION," *International Journal on "Technical and Physical Problems of Engineering" (IJTPE) Issue*, vol. 18, pp. 210–219, 2014, [Online]. Available: www.iotpe.com

[19] J. C. Olivares-Galvan, M. A. Corona-Sánchez, R. Ocon-Valdez, J. L. Hernandez-Avila, R. Escarela-Perez, and D. A. Aragon-Verduzco, "3D Finite Element Models of Zigzag Grounding Transformer for Zero-Sequence Impedance Calculation," *Applied System Innovation*, vol. 9, no. 2, Feb. 2026, doi: 10.3390/asi9020041.

[20] "IEEE Standard for Harmonic Control in Electric Power Systems," May 13, 2022, *IEEE, Piscataway, NJ, USA*. doi: 10.1109/IEEESTD.2022.9848440.

[21] N.-C. Yang and S.-T. Zeng, "Three-phase power flow solution for multi-grounded four-wire residential networks considering neutral grounding," *Energy Build.*, vol. 323, p. 114784, Nov. 2024, doi: 10.1016/j.enbuild.2024.114784.

[22] "Electrical Power Systems Quality, Second Edition."

[23] C. Gagarin Irianto, R. Setiabudy, and C. Hudaya, "Design of Delta Primary-Transposed zigzag Secondary (DTz) Transformer to Minimize Harmonic Currents on the Three-phase Electric Power Distribution System," 2010.

[24] *2013 Annual IEEE India Conference*. IEEE, 2013.

[25] *The Third International Conference on Deregulation and Restructuring and Power Technologies : DRPT 2008 : April 6-9, 2008, International Conference Hotel of Nanjing*. Southeast University Press, 2008.

[26] *International Conference on Electrical, Control and Computer Engineering 2011*. IEEE, 2011.

[27] B. Singh, P. Jayaprakash, T. R. Somayajulu, and D. P. Kothari, "Reduced rating VSC with a zig-zag transformer for current compensation in a three-phase four-wire distribution system," *IEEE Transactions on Power Delivery*, vol. 24, no. 1, pp. 249–259, 2009, doi: 10.1109/TPWRD.2008.2005398.

ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلـة جـــامعة بـــــابـل للعلـــــوم الهندسية
Vol. 34, No. 2. \ 2026 ISSN: 2616 - 9916

تخفيف التوافقية الثالثة في أنظمة توزيع القدرة الكهربائية ثلاثية الطور رباعية الأسلاك بالاعتماد على محول متعرج مع مرشح غير فعال .

ظافر معيوف داحس

قسم التقنيات الكهربائية، المعهد التقني، الجامعة التقنية الجنوبية، ناصرية

Eng.dafer@stu.edu.iq

الخلاصة:

إن الاستخدام الواسع للأحمال غير الخطية في أنظمة التوزيع ثلاثية الطور رباعية الأسلاك يؤدي إلى ظهور تيارات توافقية كبيرة من الرتبة الثالثة تتجمع في الموصل المحايد وتؤدي إلى تدهور جودة القدرة الكهربائية. تبحث هذه الدراسة في نموذج هجين للتخفيف من هذه المشكلة، يجمع بين محول متعرج موصول على التوازي مع الحمل، ومرشح توالي غير فعال يتم تركيبه في موصل الحياد من جهة مصدر التغذية.

تكمن حداثة المنهج المقترح في التحكم بمسار تيار موصل الحياد من خلال تشكيل الممانعة المعتمدة على التردد، بحيث يتم منع مركبات التوافقية الثالثة من الانتقال باتجاه مصدر التغذية وإجبارها بدلا من ذلك على الدوران الى الحمل عبر المحول المتعرج .تم ضبط المرشح الغير فعال ليظهر ممانعة عالية عند تردد التوافقية الثالثة مما يحد من انتشار التوافقيات الثلاثية باتجاه الشبكة، ويوجه هذه التوافقيات مرة أخرى عبر المحول المتعرج.

أثبتت نتيجة المحاكاة المنفذة باستخدام بيئة ماتلاب في ظل أحمال غير خطية متوازنة وغير متوازنة ، قدرة النموذج المقترح على تحقيق انخفاض واضح في تشوه تيار موصل الحياد وتيارات التوافقية الثالثة من جهة مصدر التغذية وبشكل خاص . تحقق الطريقة المقترحة خفضاً يزيد على 97–99% في تيار التوافقية الثالثة من جهة مصدر التغذية في حالة الأحمال المتوازنة أما في حالة الأحمال غير المتوازنة، فقد انخفض التشوه التوافقي الكلي لتيار موصل الحياد من 438.4% إلى ما يقارب 49.95% مما يبين كفاءة النموذج المقترح في تحسين جودة القدرة وتقليل تأثير التوافقيات في أنظمة التوزيع رباعية الأسلاك.

الكلمات الدالة:– محول متعرج (زكزاك) ، تيار الحياد، التوافقية الثالثة، المرشح غير الفعال، نظام توزيع القدرة الكهربائية ثلاثي الطور رباعي الأسلاك.