ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Volume 12, Issue 5, May 2025

Synergistic Approaches for Mitigation of Harmonic Distortion in Power Systems: A Review

[1] Jagdeep Kaur, [2] Dr. Sarbjeet Kaur Bath

[1] Research Scholar, Department of Electrical Engineering, Giani Zail Singh Campus College of Engineering & Technology, Maharaja Ranjit Singh Punjab Technical University, Bathinda, Punjab, India

[2] Professor, Department of Electrical Engineering, Giani Zail Singh Campus College of Engineering & Technology, Maharaja Ranjit Singh Punjab Technical University, Bathinda, Punjab, India

Corresponding Author Email: [1] jagdeepbrar121@gmail.com, [2] sjkbath.gzsccet@mrsptu.ac.in

Abstract*— This abstract delves into diverse mitigation strategies aimed at alleviating harmonic distortion within power systems. Harmonic distortion poses significant challenges to power infrastructure, leading to equipment overheating, augmented losses, and interference with communication systems. To counteract these adversities, a number of mitigation methods have been developed, encompassing passive and active filters, harmonic isolation transformers, phase-shifting transformers, active front-end converters, pulse width modulation techniques, switching frequency optimization, resonant converters, hybrid solutions, and load management and distribution strategies. Each technique offers distinct advantages and constraints, with the selection contingent upon considerations such as harmonic frequency and magnitude, cost-effectiveness, and specific system requisites. Through the integration of a synergistic array of mitigation measures, power systems can effectively mitigate harmonic distortion, thereby ensuring sustained operational efficiency and reliability.

Keywords: Active filtering techniques, Harmonic isolation transformers, Hybrid mitigation strategies, Passive filtering techniques, Pulse Width Modulation techniques.

I. INTRODUCTION

Harmonic distortion in power systems, caused by nonlinear loads like variable frequency drives and power converters, leads to issues such as voltage distortion, losses, and electromagnetic interference. This paper reviews various mitigation techniques, from passive filters to active control strategies, evaluating their principles, benefits, and limitations to guide the selection of effective solutions for ensuring power system stability and efficiency[1][2].

II. MITIGATION TECHNIQUES

Mitigation of harmonic distortion in power systems is essential to maintain operational efficiency and ensure the reliability of electrical infrastructure. Mitigation techniques are primarily employed to diminish harmonics and enhance system performance [3][4]. Various types of filters, including passive, active, and hybrid filters, are utilized to eradicate harmonics [5][6][7]. Figure 1 illustrates different types of mitigating techniques for harmonic distortion.

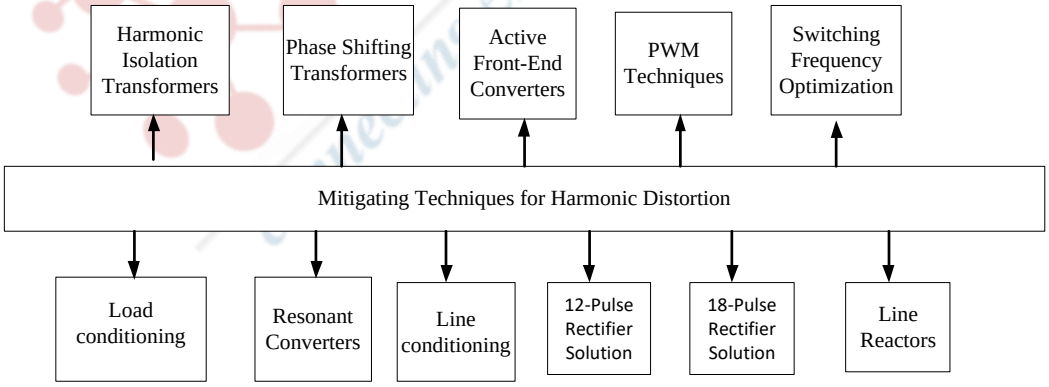


Figure 1. Mitigation Techniques for Harmonic reduction

A range of techniques exist to address this challenge effectively:

2.1 Passive Filters

Passive filters, made of inductors, capacitors, and resistors, are used to reduce specific harmonic frequencies in power systems. These cost-effective filters include low pass, high pass, band pass, notch, and tuned filters, each designed to target different harmonic ranges [36][37]. While they are efficient for certain applications, they may not cover a broad range of harmonics and are often used in conjunction with active methods for enhanced performance [8][9][10]. Table 1

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Volume 12, Issue 5, May 2025

discusses the roles, benefits, and limitations of passive filters, particularly shunt passive filters, which are cost-effective, easy to install, and suitable for systems with budget constraints. Effective implementation requires careful analysis, expert consultation, and regular maintenance to ensure optimal performance.

Table: 1. Comparison between different types of passive filters

Passive Filter Type	Function	Advantages	Limitations
Low Pass Filters[20][39]	These filters permit the transmission of low-frequency signals while suppressing higher-frequency components.	They are characterized by a straightforward design and are particularly effective in mitigating high frequency harmonics within power systems.	However, their efficacy diminishes when it comes to addressing low-order harmonics.
High Pass Filters[5]	High pass filters facilitate the passage of high frequency signals while inhibiting low frequency ones.	They excel in mitigating low order harmonics, offering a robust solution for such issues.	Nonetheless, they may exhibit limited effectiveness in attenuating high frequency harmonics.
Band Pass Filters[6]	These filters selectively allow signals within a specified frequency range to pass through while attenuating frequencies outside this band.	They provide precise suppression of specific harmonic frequencies, enhancing power quality significantly.	Their design complexity and limited effectiveness in addressing broadband harmonics are notable drawbacks.
Tuned Filters/Notch Filter[1][38]	Tuned filters maximize attenuation at predetermined harmonic frequencies through resonance effects. Notch filters are engineered to attenuate specific frequencies.	They offer unparalleled efficiency at specific harmonic frequencies, ensuring effective harmonic suppression.	Yet, their reliance on precise tuning for each targeted frequency poses a considerable challenge.
Passive Harmonic Filters[7][8]	These filters integrate various filter types to simultaneously address multiple harmonics.	They provide comprehensive harmonic mitigation across a spectrum of frequencies, significantly enhancing power quality.	Their complex design and configuration, coupled with higher costs, may present practical challenges.
Series Passive Filters [3]	Series filters are interconnected with the load to reduce harmonic currents directed towards it.	They directly mitigate harmonic currents flowing into the load, thereby improving power quality.	However, they may introduce voltage drop and impact the performance of connected load.
Shunt Passive Filters [4][5][6]	Shunt filters are connected in parallel with the load, offering an alternative path for harmonic currents.	By diverting harmonic currents away from the load, they effectively reduce voltage distortion and enhance power quality.	Careful sizing and placement are essential to avoid resonance issues and ensure optimal performance.

2.2 Active Filters

Active filters utilize power electronic components to generate corrective harmonic currents that counteract those produced by nonlinear loads. Offering dynamic response capabilities as discussed in Table 2, they can manage a wide array of harmonic distortions.

Table 2: Comparison between different types of Active Filters

Active Filter Type	Function	Advantages	Limitations
Active Harmonic Filters (AHFs)/12][13]	Generate compensating currents to mitigate harmonic distortions	Wide frequency range, built in protection features, customization options	Higher initial cost, complex installation and setup, maintenance requirements for power electronics components

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Volume 12, Issue 5, May 2025

Active Filter Type	Function	Advantages	Limitations
Active Power Filters (APFs)[47] [14][33][34]	Neutralize harmonic currents from non-linear loads in real time.	Effective across a wide range of frequencies and loads, compatibility with retrofitting applications	Higher initial cost, maintenance needs for power electronics components, complexity in control algorithms and tuning parameters.
PWM(Pulse Width Modulation) converters[17][18]	Utilize high- frequency switching to minimize harmonic distortion	Efficient in power conversion, widely applicable, reduced harmonic content in output	Complex design and control algorithms, higher switching losses and costs, limited effectiveness with non-linear loads
Active Voltage Conditioners (AVCs)[19]	Regulate voltage level and mitigate fluctuations	Stable voltage supply, effective in reducing anomalies, suitable for critical environments.	Higher initial cost, Complexity in design and integration, limited effectiveness with non-linear loads.
Hybrid Active Power Filters[9][10][11][15][39]	Integrate passive and active technology for comprehensive mitigation	Comprehensive harmonic reduction, component flexibility, suitable for low and high-order harmonics.	Higher initial cost, maintenance requirements for power electronics components, complexity in design and integration.

In summary, each active filter technique offers distinct advantages tailored to specific application requirements, playing a pivotal role in enhancing power quality by mitigating harmonic distortions in electrical systems shows in table 2 [13,14].

2.3 Harmonic Isolation Transformers

These transformers block harmonic currents from reaching sensitive loads by providing electrical isolation and low-impedance paths for high-frequency harmonics [37]. With features like high K-factor, shielding, and filtering, they improve power quality, regulate voltage, and protect sensitive equipment in systems with non-linear loads. By adjusting the phase angle between input and output, these transformers help mitigate specific harmonics, manage power flow, balance loads, and regulate voltage. They are widely used in power transmission and distribution systems to enhance grid stability and performance.

2.4 Active Front-End Converters

Active Front-End (AFE) converters are advanced devices that regulate power flow between AC and DC systems while minimizing harmonics and improving power factor. Commonly used in motor drives and energy storage, they support bidirectional power flow, regenerative braking, and active harmonic filtering for enhanced efficiency and grid compliance. The 12-pulse rectifier uses two 6-pulse bridges and a phase-shifting transformer to cancel 5th and 7th harmonics, reducing input current THD to around 10%. It mainly introduces 11th and 13th harmonics, offering improved harmonic performance over standard rectifiers.whereas; the 18-pulse rectifier uses three phase-shifted 6-pulse bridges and a multi-phase transformer to eliminate 5th–13th harmonics, reducing THD to about 5%. It ensures IEEE-519 compliance, with 17th and 19th harmonics as the dominant residuals [16][17].

2.5 PWM Techniques

Pulse-width modulation (PWM) shapes converter output by high-frequency switching of devices such as IGBTs or MOSFETs, varying pulse widths to set the desired average voltage or current while suppressing harmonics. Approaches like sinusoidal or space-vector PWM, selective harmonic elimination, and random PWM let engineers target specific harmonic orders for cleaner, application-tailored waveforms[18][26][27].

2.6 Switching Frequency Optimization

Optimizing the switching frequency in power electronic devices helps reduce high-order harmonics and improve efficiency. This balance minimizes losses, manages EMI and thermal effects, and enhances overall system performance in converters and inverters [28][29].

2.7 Resonant Converters

Resonant converters operate at frequencies where impedance is minimized, reducing switching losses and effectively mitigating harmonics. By using resonant components like inductors and capacitors, they achieve high efficiency and low electromagnetic interference in power conversion[18][30][31[35].

2.8 Hybrid Solutions

Hybrid harmonic mitigation solutions combine passive and active filters or other methods like phase-shifting transformers and resonant converters to effectively reduce harmonic distortion. This approach leverages the strengths of each technique to provide comprehensive, adaptable, and efficient harmonic suppression across a wide frequency range.

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Volume 12, Issue 5, May 2025

2.9 Line Reactors and Load Management

Line reactors, when connected in series with non-linear loads like adjustable speed drives, provide a cost-effective solution for reducing harmonic distortion by introducing inductive reactance and absorbing voltage transients. By adjusting impedance relative to load current, they mitigate harmonic currents and enhance power quality, typically maintaining optimal impedance levels between 3% and 6%.Effective load management and distribution minimize harmonic distortion by balancing loads across phases, with mitigation techniques chosen based on harmonic characteristics, cost, and system needs [32].

III. CONCLUSION

In summary, the mitigation of harmonic distortion in power systems is imperative to uphold operational efficiency, preserve equipment integrity, and ensure uninterrupted power supply. The array of mitigation techniques explored in this manuscript provides a comprehensive toolkit for addressing harmonic challenges across various operational contexts. While each technique boasts distinct advantages and constraints, their collective application enables tailored solutions that align with specific system requirements and operational constraints. By considering factors such as harmonic frequency, magnitude, cost-effectiveness, and system dynamics, power system stakeholders can prudently select and integrate appropriate mitigation strategies. Whether through passive filtering, active control methodologies, or hybrid approaches, the overarching objective remains consistent: mitigating harmonic distortion to uphold the quality and reliability of power delivery. As power systems evolve and encounter new challenges, ongoing research and innovation in harmonic mitigation techniques are pivotal.

IV. FUTURE WORK

Despite advancements in harmonic mitigation, further research is needed in areas like advanced filtering techniques, integration of renewable energy, and smart grid technologies to address emerging challenges. Additionally, exploring machine learning, AI, cost-effective solutions, and cyber security in harmonic mitigation can enhance system performance and sustainability.

REFERENCES

[1] Saad, T., et al. "Sizing passive filters for mitigation of harmonics in a low voltage network containing solar PV units." *Franklin Open* 10 (2025): 100220.

[2] Neku, Sinethemba, and Sandile Phillip Koko. "A Recent Review of Passive Filters as Used in Solar Photovoltaic-Based Systems to Mitigate Harmonics." *2025 15th International Renewable Energy Congress (IREC)*. IEEE, 2025.

[3] Okuo, Michael Ozaveshe, Oluseun Ibrahim Adebisi, and Olubunmi Adewale Akinola. "Assessment of the effect of series passive filter on harmonic distortion-power losses relationship in an electricity distribution network." *ITEGAM-JETIA* 11.52 (2025): 156-164.

[4] Nour, Ahmed MM, and Ahmed A. Helal. "A voltage sensorless technique for a shunt active power filter adopting band pass filter under abnormal supply conditions." *Electric Power Systems Research* 238 (2025): 111133.

[5] Upanya, M., et al. "Harmonic Mitigation Using Active and Passive Filters." *2025 International Conference on Sustainable Energy Technologies and Computational Intelligence (SETCOM)*. IEEE, 2025.

[6] Saad, T., et al. "Sizing passive filters for mitigation of harmonics in a low voltage network containing solar PV units." *Franklin Open* 10 (2025): 100220.

[7] Setamkesh, Saeid, Ali Karimi, and Mohsen Rahimi. "Harmonic Mitigation in Power Systems With High Wind Sources Penetration by Placing Passive Filters Considering Resonance Issues: A Case Study of the Sistan Power Grid." *IET Renewable Power Generation* 19.1 (2025): e70031.

[8] Gaiceanu, Marian, et al. "Power Quality Improvement with Three-Phase Shunt Active Power Filter Prototype Based on Harmonic Component Separation Method with Low-Pass Filter." *Energies* 18.3 (2025): 556. []Göttsberger, Christoph, et al. "A generic observer-based control system for three-phase parallel active power filters." *Authorea Preprints* (2025).

[9] Al-Barashi, Maged, et al. "Magnetic Integrated Multi-Trap Filters Using Mutual Inductance to Mitigate Current Harmonics in Grid-Connected Power Electronics Converters." *Energies* 18.2 (2025): 423.

[10]Foster, Joao GL, et al. "Finite Control Set Model Predictive Control Applied to Multilevel Hybrid Active Power Filter." *IEEE Transactions on Industrial Electronics* (2025).

[11] Morán, Luis, Juan Dixon, and Miguel Torres. "Active filters." *Power Electronics Handbook*. Butterworth-Heinemann, 2024. 1301-1341, doi: 10.1016/B978-0-323-99216-9.000 35-4.

[12] Rezapour, Hamed, et al. "Enhancing power quality and loss optimization in distorted distribution networks utilizing capacitors and active power filters: A simultaneous approach." *International Journal of Electrical Power & Energy Systems* 155 (2024): 109590,doi: 10.1016/j.ijepes. 2023.109590.

[13] Amini, Behnam, Hasan Rastegar, and Mohammad Pichan. "An optimized proportional resonant current controller based genetic algorithm for enhancing shunt active power filter performance." *International Journal of Electrical Power & Energy Systems* 156 (2024): 109738,doi: 10.1016/j.ijepes. 2023.109738.

[14] Hajbani, Vadood, Adel Zakipour, and Mahdi Salimi. "A novel Lyapunov-based robust controller design for LCL-type shunt active power filters using adaptive sliding-mode backstepping approach." *e-Prime-Advances in Electrical Engineering, Electronics and Energy* 5 (2023): 100200,doi: 10.1016/j.prime.2023.100200.

[15] Huang, Ta-Wei, et al. "Current-Fed Phase-Shifted Full-Bridge Converter with Secondary Harmonic Current Reduction for Two-Stage Inverter in Energy Storage System." *IEEE Transactions on Power Electronics* (2023),doi: 10.1109/TPEL.2023.3282911.

[16] Du, Qingxiao, et al. "Open-Phase Fault Research on the

Parallel-Connected 40-Pulse Rectifier with Multi-Output Auto-Connected Phase-Shifting Transformer." *IEEE Journal of Emerging and Selected Topics in Power Electronics* (2023),doi: https://doi.org/10.1109/JESTPE.2023.3247731.

[17] Zhaksylyk, Assel, et al. "Review of Active Front-End Rectifiers in EV DC Charging Applications." *Batteries* 9.3 (2023): 150,doi:10.3390/batteries9030150.

[18] Djabali, Sarah, Abdelkarim Ammar, and Aissa Kheldoun. "Harmonics mitigation of AC-to-DC converters using PWM rectifier with enhanced model predictive control approach." *Power Electronics Converters and their Control for Renewable Energy Applications*. Academic Press, 2023. 55-75, doi: 10.1016/B978-0-323-91941-8.00003-2.

[19] Sekiguchi, Takaya, and Keiji Wada. "Active Power Decoupling Control for Single-phase Power Conditioning Systems Focusing on Harmonic Voltage." *IEEJ Journal of Industry Applications* (2023),doi: 10.1541/ieejjia.22009573.

[20] Elmi, Yonis, and Diaa Salman. "Simulation Model for Passive Harmonic Filters Using Matlab/Simulink: A Case Study." *Journal of Power and Energy Engineering* 11.3 (2023): 1-14,doi: 10.4236/jpee.2023.113001.

[21] Aljarrah, Rafat, et al. "Application of Passive Harmonic Filters in Power Distribution System with High Share of PV Systems and Non-Linear Loads." *International Journal of Renewable Energy Research (IJRER)* 13.1 : 401-411, Vol. 13, No.1, March, 2023.

[22] Ishaya, Meshack Magaji, et al. "Single-tuned passive filter (STPF) for mitigating harmonic in a 3-phase power system." (2023), doi: 10.21203/rs.3.rs-2409880/v1.

[23] Sahoo, Buddhadeva, Mohammed M. Alhaider, and Pravat Kumar Rout. "Power quality and stability improvement of microgrid through shunt active filter control application: An overview." *Renewable Energy Focus* (2023),doi: 10.1016/j.ref.2022.12.006.

[24] Jean-Pierre, Garry, et al. "An Expanded Lyapunov-Function Based Control Strategy for Cascaded H-Bridge Multilevel Active Front-End Converters." *IEEE Open Journal of Power Electronics* 4 (2023): 117-127,doi: 10.1109/OJPEL.2023.3239414.

[25] Chatterjee, Shantanu, and Abhijit Das. "A review on technological aspects of different PWM techniques and its comparison based on different performance parameters." *International Journal of Circuit Theory and Applications* 51.5 (2023): 2446-2498,doi: 10.1002/cta.3513.

[26] Ruiz-Gonzalez, Antonio, et al. "Pulse-width modulation technique with harmonic injection in the modulating wave and discontinuous frequency modulation for the carrier wave for multilevel inverters: An application to the reduction of acoustic noise in induction motors." *IEEE Access* (2023), doi: 10.1109/ACCESS.2023.3269593.

[27] Krithiga, G., et al. "Optimization of switching angles for selective harmonic elimination in cascaded h-bridge multilevel inverters employing artificial intelligence techniques–a mini review." *International Journal of Engineering Technologies and Management Research* 10.1 (2023): 1-16.,doi: 10.29121/ijetmr.v10.i1.2023.1278.

[28] Zhang, Siyan, et al. "Chaotic ant colony algorithm-based frequency-optimized random switching frequency SVPWM control strategy." *Journal of Power Electronics* (2023): 1-15,doi: 10.1007/s43236-023-00664-6.

[29] Pashaei, Mohammadreza, Mohammadhesam Hasanisadi, and Farzad Tahami. "Comprehensive Conducted Emission Analysis of the Three-Phase and Single-Phase LLC Resonant Converters for EV Application." *IEEE Transactions on Electromagnetic Compatibility* (2023),doi: 10.1109/TEMC.2023.3280362.

[30] Cheng, Yujie, et al. "Fundamental harmonic amplitude-frequency hybrid modulation strategy for half-bridge LLC resonant converters." *CPSS Transactions on Power Electronics and Applications* (2023),doi: 10.24295/CPSSTPEA.2023.00016.

[31] Jiao, Dong, Hao Wen, and Jih-Sheng Lai. "LLC Resonant Converter Based Single-stage Inverter with Multi-resonant Branches using Variable Frequency Modulation." *2023 IEEE Applied Power Electronics Conference and Exposition (APEC)*. IEEE, 2023,doi: 10.1109/APEC43580.2023.10131127.

[32] Arif, Yahya Chusna. "Implementation Of Hybrid Filter For Harmonics Reduction In Non-Linear Loads." *Eduvest-Journal of Universal Studies* 3.2 (2023), doi:10.59188/eduvest.v3i2.751.

[33] CAZACU, Emil, et al. "Active Power Filter Solution to the Harmonic Issues Caused by a Nonlinear Industrial Load." *2023 10th International Conference on Modern Power Systems (MPS)*. IEEE, 2023,doi: 10.1109/MPS58874.2023.10187576.

[34] Patel, Ms Manisha, et al. "Extenuation Harmonic Using Hybrid Filter.", International Journal of Advances in Engineering and Management (IJAEM) Volume 5, Issue 3 March 2023, pp: 20-24 www.ijaem.net ISSN: 2395-5252.

[35] Ram, Atma, Paras Ram Sharma, and Rajesh Kumar Ahuja. "Harmonics Mitigation Using Proportional–Resonant Controller-Based DSTATCOM in Distribution System." *Recent Developments in Electrical and Electronics Engineering: Select Proceedings of ICRDEEE 2022*. Singapore: Springer Nature Singapore, 2023. 131-143.

[36] Abood, Salam B., and Thamir M. Abdul-Wahhab. "Investigation of Harmonic Reduction Using Passive Filters in a Distribution Network in Basra City." *IOP Conference Series: Materials Science and Engineering*. Vol. 1067. No. 1. IOP Publishing, 2021, doi: 10.1088/1757-899X/1067/1/012124.

[37] Wang, Jingfang, et al. "A novel 18-pulse rectifier based on the 9-phase isolated phase-shifting transformer." (2025).

[38] Fahmi, M. I., et al. "Harmonic reduction by using single-tuned passive filter in plastic processing industry." *IOP Conference Series: Materials Science and Engineering*. Vol. 308. No. 1. IOP Publishing, 2018,doi: 10.1088/1757-899X/308/1/012035

[39] Bagwari, Ashish. "Voltage harmonic reduction using passive filter shunt passive-active filters for non-linear load." *2017 7th international conference on communication systems and network technologies (CSNT)*. IEEE, 2017,doi: 10.1109/CSNT.2017.8418524.