A REVIEW OF HYBRID PASSIVE–ACTIVE FILTERING STRATEGY FOR HARMONIC SUPPRESSION IN GRID-INTERACTIVE SOLAR PHOTOVOLTAIC INVERTER SYSTEMS

Abha Singh[1], Dr. Imran Khan[2]

[1]*Master of Technology, Electrical Engineering (Power System), Azad Institute of Engineering and Technology, Lucknow, India*

[2]*Professor, Department Electrical Engineering , Azad Institute of Engineering and Technology, Lucknow, India*

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Abstract - *The increasing penetration of grid-interactive solar photovoltaic (PV) systems has introduced significant challenges in maintaining power quality due to harmonic distortions generated by inverter switching and nonlinear loads. Harmonics adversely affect system efficiency, equipment reliability, and compliance with international standards such as IEEE-519. Various harmonic mitigation techniques, including passive and active filters, have been widely employed; however, each approach has inherent limitations. Passive filters are cost-effective and simple but lack adaptability, while active filters provide dynamic compensation at the expense of higher complexity and cost. Hybrid passive–active filtering strategies have emerged as a promising solution, integrating the advantages of both methods to achieve effective harmonic suppression with improved efficiency and reduced active component ratings. This review comprehensively examines the principles of harmonic generation in grid-connected PV systems and critically analyzes passive, active, and hybrid filtering techniques. A dedicated focus is placed on hybrid filter topologies, their control strategies, and performance evaluation in terms of total harmonic distortion (THD) reduction, system stability, and implementation feasibility. The review also identifies research gaps and future directions, emphasizing advanced control techniques, adaptive filtering, and integration with smart grids. The study serves as a valuable reference for researchers and engineers aiming to optimize harmonic mitigation strategies in modern PV inverter systems.*

Key Words: Hybrid filtering, Solar PV inverter, Harmonic suppression, Active filter, Passive filter, Power quality, Grid integration

1. INTRODUCTION

1.1 Background of Renewable Energy Integration

The global shift toward sustainable energy has accelerated the adoption of renewable energy sources, with solar photovoltaic (PV) systems being one of the fastest-growing technologies. Grid-connected PV systems provide clean and decentralized electricity generation, reducing dependence on fossil fuels and mitigating environmental impacts (Gupta et al., 2021). The integration of PV systems into modern power networks contributes significantly to energy security, especially in countries promoting renewable energy targets. However, the increasing penetration of PV inverters, which rely heavily on power electronic converters, introduces new challenges in maintaining power quality. The nonlinear behavior of these converters and their interaction with the grid can cause voltage and current distortions, reactive power issues, and potential stability problems, making effective control and mitigation strategies crucial (Bollen and Hassan, 2011).

1.2 Harmonic Issues in Grid-Interactive PV Inverter Systems

Harmonics are a primary concern in grid-connected PV systems due to the switching operations of pulse-width-modulated (PWM) inverters and nonlinear loads connected to the grid. These harmonics manifest as distortions in voltage and current waveforms, often measured in terms of total harmonic distortion (THD). High harmonic levels increase system losses, generate additional heating in transformers and cables, reduce the efficiency of sensitive equipment, and can lead to resonance phenomena within the grid network (IEEE, 2014). Furthermore, harmonics can interfere with protective devices and affect overall grid reliability, highlighting the need for effective harmonic suppression mechanisms in PV inverter applications.

1.3 Importance of Harmonic Mitigation Techniques

To ensure compliance with international power-quality standards such as IEEE-519, harmonic mitigation techniques are essential. Traditional approaches include passive filters, which are simple LC-based circuits designed to suppress specific harmonic frequencies, and active filters, which use real-time control to compensate for harmonic currents dynamically. While passive filters are cost-effective, they lack adaptability to changing harmonic conditions. Active filters offer high performance but are expensive and complex to implement (Akagi et al., 2017). Consequently, researchers have increasingly focused on hybrid filtering systems, which combine the strengths of passive and active approaches to provide efficient harmonic reduction with optimized cost and operational flexibility.

1.4 Hybrid Passive–Active Filtering

Hybrid passive–active filters have emerged as a promising solution for harmonic suppression in grid-connected PV systems. By integrating passive components with active power filters, hybrid strategies can reduce the rating of active elements while maintaining effective suppression across a wider range of harmonics. Passive filters provide initial harmonic attenuation, reducing the burden on the active filter, which then dynamically compensates residual harmonics. This combination achieves high performance in THD reduction, enhances grid stability, and lowers overall implementation costs compared to standalone active filters. The growing research interest in hybrid solutions reflects their potential to meet stringent power-quality requirements in modern solar PV installations (Gupta et al., 2021; Akagi et al., 2017).

2. HARMONIC GENERATION IN GRID-CONNECTED SOLAR PV SYSTEMS

2.1 Structure of Grid-Interactive PV Inverter Systems

Grid-connected PV systems are designed to convert solar energy into usable AC electricity and inject it into the utility grid. The system typically consists of a PV array, power conditioning units, DC–DC converters, and a grid-connected inverter with output filters. These components work together to regulate voltage, control power flow, and ensure compliance with grid standards (Gupta et al., 2021). Understanding the architecture is essential for analyzing harmonic generation and developing effective mitigation strategies.

2.1.1 PV Array and Power Conditioning Unit

The PV array is composed of multiple solar modules connected in series and parallel to achieve the required voltage and current levels. The power conditioning unit (PCU) ensures the maximum power point tracking (MPPT) to extract optimal power under varying solar irradiance and temperature conditions. This stage also provides basic voltage regulation before the power reaches the DC–DC converter, but it contributes minimally to harmonic generation.

2.1.2 DC–DC Converter Stage

The DC–DC converter, typically a buck, boost, or buck–boost topology, regulates the voltage level from the PV array to match the inverter input requirements. Switching operations in the DC–DC stage introduce high-frequency components in the DC link, which may propagate to the AC side if not properly filtered. Although these harmonics are usually at higher frequencies, they can interact with the inverter control and the grid, affecting overall system quality (Bollen and Hassan, 2011).

2.1.3 Grid-Connected Inverter and Output Filter

The grid-connected inverter converts the regulated DC voltage into synchronized AC power suitable for the grid. Pulse-width modulation (PWM) techniques are commonly used to generate sinusoidal output, but they inherently produce switching harmonics. To minimize harmonic injection into the grid, LC or LCL output filters are employed, attenuating high-frequency components while maintaining voltage quality. The design of these filters plays a critical role in reducing total harmonic distortion (THD) and ensuring grid compliance.

2.2 Sources of Harmonics in PV Inverter Systems

Harmonics in grid-connected PV systems originate from multiple sources, including switching operations, nonlinear loads, and grid interactions. These distortions are critical to analyze because they affect system efficiency and reliability (Akagi et al., 2017).

2.2.1 Switching Harmonics in PWM Inverters

PWM inverters operate by rapidly switching power electronic devices to synthesize an AC waveform. These switching actions introduce high-frequency harmonics into the current and voltage waveforms, the magnitude and frequency of which depend on the switching frequency, modulation scheme, and inverter topology. Without proper filtering, these harmonics can propagate into the grid and nearby loads.

2.2.2 Nonlinear Load Effects

Nonlinear loads, such as computer power supplies, LED lighting, and motor drives, draw current in abrupt pulses rather than smooth sinusoidal waves. When connected to a PV inverter system, these loads distort the current waveform, which may interact with inverter harmonics and exacerbate total harmonic distortion in the network.

2.2.3 Grid Impedance Interaction

The interaction between the inverter output and the grid impedance can amplify certain harmonic frequencies, leading to resonance conditions. Weak grid connections, long feeders, and reactive components in the network can all influence harmonic magnitudes and distribution, complicating harmonic suppression strategies.

2.3 Impact of Harmonics on Power System Performance

The presence of harmonics in grid-connected PV systems can have several detrimental effects on both system components and overall power quality.

2.3.1 Increased Power Losses

Harmonic currents increase resistive losses in conductors, transformers, and inverter components. These losses reduce overall system efficiency and may lead to increased operational costs.

2.3.2 Equipment Stress and Thermal Effects

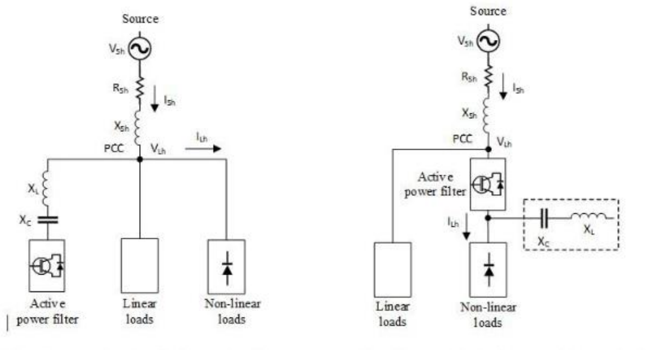
Power electronic devices, transformers, and other connected equipment experience additional thermal stress due to harmonic currents. Overheating can accelerate insulation aging, reduce lifespan, and even cause premature failures in sensitive devices.

2.3.3 Power Quality Degradation

Harmonics distort voltage and current waveforms, affecting the quality of power delivered to end-users. Poor power quality can result in malfunctioning of sensitive equipment, misoperation of protection devices, and noncompliance with international standards such as IEEE-519.

3. OVERVIEW OF HARMONIC MITIGATION TECHNIQUES

Harmonic mitigation in grid-connected PV systems is essential to maintain power quality and comply with standards such as IEEE-519. Various techniques have been developed, primarily categorized into passive filtering, active filtering, and hybrid solutions, each having distinct mechanisms, advantages, and limitations (Akagi et al., 2017; Gupta et al., 2021).



(a) Config.1: APF in series with shunt passive filter (b) Config.2: Combined series APF and shunt passive filter

Figure-1: Classification of Harmonic Filter Types

3.1 Passive Filtering Techniques

Passive filters are the earliest and most widely used approach for harmonic suppression. They consist of inductors (L), capacitors (C), and sometimes resistors (R) arranged to provide a low-impedance path for targeted harmonic frequencies, thereby reducing harmonic currents injected into the grid. Passive filters are simple, reliable, and cost-effective, but their compensation is fixed and limited to designed harmonic orders.

3.1.1 Single-Tuned Passive Filters

Single-tuned passive filters are designed to resonate at a specific harmonic frequency, commonly the 5th or 7th harmonic. By providing a low-impedance path at the tuned frequency, they divert the harmonic current away from the grid. While effective for dominant harmonics, they do not address multiple or higher-order harmonics and may lead to resonance if not carefully designed (Bollen and Hassan, 2011).

3.1.2 Double-Tuned Filters

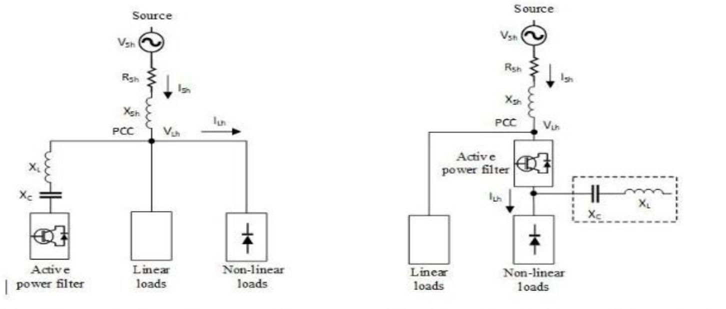
Double-tuned filters are configured to target two specific harmonic frequencies simultaneously, often the 5th and 7th harmonics. This configuration improves harmonic suppression over single-tuned filters, but the design becomes more complex and may still be ineffective against harmonics beyond the tuned orders.

3.1.3 LCL Filters for Grid-Connected Inverters

LCL filters, widely used in modern PV inverters, consist of a series combination of two inductors separated by a capacitor. LCL filters provide broadband attenuation of switching harmonics from pulse-width-modulated (PWM) inverters while maintaining low losses. They are particularly effective in high-power PV systems and offer better performance than simple LC filters, but they require damping resistors or active damping methods to prevent resonance (Akagi et al., 2017).

3.2 Active Power Filtering Techniques

Active power filters (APFs) dynamically detect and compensate harmonic currents in real time. They use power electronics and control algorithms to inject currents that cancel out harmonics, improving voltage and current waveforms. Active filtering offers adaptability across multiple harmonic orders, but it is costlier and more complex than passive solutions.



(a) Config.1: APF in series with shunt passive filter (b) Config.2: Combined series APF and shunt passive filter

Figure-2: Shunt and Series Active Filter Diagrams

3.2.1 Shunt Active Power Filters (SAPF)

Shunt APFs are connected in parallel with the load and inject compensating currents to cancel harmonic components. They are widely used for industrial and renewable energy applications because they effectively reduce THD under varying load conditions.

3.2.2 Series Active Power Filters

Series APFs are connected in series with the supply and inject compensating voltage to cancel harmonics. While less common than shunt filters, they are suitable for voltage-sensitive applications and can correct voltage distortions as well as current harmonics.

3.2.3 Unified Power Quality Conditioner (UPQC)

UPQC combines series and shunt APFs to simultaneously correct voltage and current harmonics, reactive power, and unbalance. This configuration provides comprehensive power quality improvement, making it suitable for sensitive renewable energy grids.

4. HYBRID PASSIVE–ACTIVE FILTERING STRATEGIES

Hybrid passive–active filters have emerged as an effective solution for harmonic mitigation in grid-connected PV inverter systems. By combining passive components with active power electronics, hybrid filters leverage the strengths of both approaches: passive filters provide initial harmonic attenuation at low cost, while active filters dynamically compensate for residual harmonics and adapt to changing load conditions. This integration reduces the rating and cost of the active components while maintaining high harmonic suppression capability across a wide frequency spectrum (Gupta et al., 2021).

4.1 Concept of Hybrid Harmonic Filtering

The concept of hybrid harmonic filtering is based on the complementary behavior of passive and active filters. Passive filters, typically tuned LC networks, are designed to suppress dominant harmonics such as the 5th and 7th orders. Active filters, usually voltage-source or current-source converters, inject compensating currents or voltages to cancel remaining harmonics in real time. This combination allows the active filter to operate at a reduced rating, lowering cost and losses, while ensuring effective total harmonic distortion (THD) reduction even under variable load or grid conditions (Akagi et al., 2017).

4.2 Hybrid Filter Configurations

Hybrid filter topologies are categorized based on how the passive and active elements are connected with respect to the grid and load.

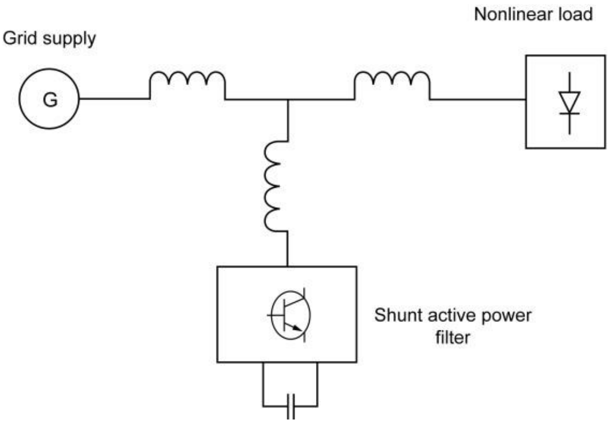


Figure-3: Hybrid Parallel Filter Topology

4.2.1 Series Hybrid Active Power Filter

In series hybrid filters, the active filter is connected in series with the load or grid to inject compensating voltage, while passive components are connected in parallel to attenuate specific harmonic currents. This configuration improves voltage quality and reduces THD effectively, particularly in sensitive loads.

4.2.2 Parallel Hybrid Active Power Filter

Parallel hybrid filters connect the active filter in parallel with the load, typically alongside passive LC networks. The passive filter handles dominant harmonics, while the active filter compensates higher-order or variable harmonics dynamically. This arrangement is widely used for grid-connected PV inverters because it reduces the active power rating while maintaining high harmonic suppression.

4.2.3 Series–Parallel Hybrid Filter Structures

Series–parallel hybrid structures integrate both series and parallel compensation strategies. Passive tuned filters are combined with voltage-source converters to manage current and voltage harmonics simultaneously. This configuration offers comprehensive harmonic mitigation, high adaptability, and improved dynamic response, making it suitable for high-power PV systems and weak-grid conditions (Gupta et al., 2021).

4.3 Control Strategies for Hybrid Filters

Effective control strategies are critical to the performance of hybrid filters. Various control methods are applied depending on system requirements, grid conditions, and desired harmonic mitigation.

4.3.1 Instantaneous Reactive Power (p–q) Theory

The p–q theory decomposes three-phase currents into instantaneous active and reactive components. The active filter uses this information to inject compensating currents that cancel the harmonic and reactive portions, improving grid current quality.

4.3.2 Synchronous Reference Frame (SRF) Control

SRF control transforms three-phase currents into a rotating reference frame (dq0), separating harmonic components from the fundamental. Active filters then inject compensating currents to eliminate these harmonics effectively. This method is widely used in grid-connected PV systems due to its robustness and accuracy.

4.3.3 Hysteresis Current Control

Hysteresis current control is a feedback method that regulates the output current of active filters within a defined hysteresis band. It ensures fast dynamic response and high accuracy in compensating harmonics, though it may generate variable switching frequencies.

4.3.4 Artificial Intelligence and Adaptive Control

Recent research explores AI-based and adaptive control strategies for hybrid filters. Techniques such as neural networks, fuzzy logic, and adaptive algorithms enable real-time identification and suppression of harmonics under varying load and grid conditions, enhancing the flexibility and performance of hybrid systems (Akagi et al., 2017).

5. LITERATURE REVIEW OF HYBRID PASSIVE–ACTIVE FILTERING FOR PV SYSTEMS

Hybrid passive–active filtering strategies have been extensively studied over the past two decades to address the limitations of standalone passive or active filters in grid-connected PV systems. The literature highlights the evolution of these techniques, their application in renewable energy systems, and ongoing technological advancements aimed at improving power quality, reducing total harmonic distortion (THD), and enhancing system stability (Gupta et al., 2021).

5.1 Early Research on Hybrid Harmonic Filters

Early studies on hybrid harmonic filters focused on integrating passive LC networks with active compensators to achieve efficient suppression of low- and high-order harmonics. Akagi et al. (2017) demonstrated that combining a tuned passive filter with a shunt active filter could significantly reduce harmonic currents without requiring a high-rated active filter. Similarly, Bollen and Hassan (2011) analyzed hybrid topologies for industrial power systems, showing that hybrid solutions could mitigate resonance issues associated with purely passive filters while maintaining simplicity and cost-effectiveness. These foundational works established hybrid filtering as a practical solution for diverse power quality problems.

5.2 Hybrid Filters for Grid-Connected Renewable Energy Systems

Recent research has extended hybrid filtering concepts to renewable energy-based microgrids. Studies have shown that integrating passive filters with active power filters in grid-connected solar and wind systems enhances voltage and current quality, reduces THD, and supports compliance with international standards. For instance, Gupta et al. (2021) reviewed multiple hybrid configurations for hybrid microgrids, demonstrating superior harmonic mitigation and improved system reliability compared to standalone filters. These findings highlight the applicability of hybrid filters in modern renewable energy infrastructures where power generation is variable and dynamic.

5.3 Hybrid Filtering in Solar PV Inverter Applications

In solar PV inverter applications, hybrid filters are employed to address harmonics generated by pulse-width-modulated (PWM) inverters and nonlinear loads. Numerous simulation and experimental studies focus on THD reduction, showing that hybrid topologies can maintain grid current THD below 5%, which aligns with IEEE-519 recommendations. Topologies such as series, parallel, and series-parallel hybrids have been tested under different load conditions, demonstrating effective suppression of both dominant and higher-order harmonics (Akagi et al., 2017; Gupta et al., 2021).

5.4 Performance Comparison of Different Hybrid Filter Designs

Comparative studies of hybrid filters have evaluated performance in terms of THD reduction, cost, efficiency, and dynamic response. Series-parallel hybrid filters often achieve the lowest THD levels, while parallel hybrids balance cost and performance effectively. Simulation analyses and laboratory experiments consistently show that hybrid configurations outperform standalone passive or active filters, especially under variable load and weak-grid conditions. Performance tables in several studies highlight that careful design and tuning of passive elements, combined with precise active control, are critical for achieving optimal results (Bollen and Hassan, 2011).

5.5 Research Trends and Technological Developments

Emerging trends in hybrid filtering research include AI-based harmonic detection, adaptive and predictive control, and integration with smart grids. Artificial intelligence techniques, such as neural networks and fuzzy logic, are increasingly used for real-time identification and compensation of harmonics under varying operating conditions. Advanced inverter modulation strategies, including selective harmonic elimination and multilevel inverters, are also being integrated with hybrid filters to enhance performance. These developments aim to provide more flexible, efficient, and intelligent harmonic mitigation solutions in next-generation PV and distributed generation systems (Gupta et al., 2021).

6. PERFORMANCE EVALUATION AND COMPARATIVE ANALYSIS

Performance evaluation of harmonic mitigation techniques is essential for selecting suitable solutions for grid-connected PV systems. Metrics such as total harmonic distortion (THD), cost, efficiency, power losses, and dynamic stability provide a comprehensive assessment of filter effectiveness. Comparative analysis of passive, active, and hybrid filters highlights their strengths and limitations under varying operational conditions (Gupta et al., 2021).

6.1 Harmonic Reduction Performance (THD Analysis)

Total harmonic distortion (THD) is the primary indicator of power quality improvement in PV inverter systems. Passive filters effectively suppress targeted low-order harmonics but are less adaptable to changes in load or grid conditions. Active filters provide dynamic compensation across multiple harmonic orders, achieving THD levels typically below 5%, meeting IEEE-519 standards. Hybrid filters combine both approaches, offering efficient suppression of both dominant and higher-order harmonics while minimizing the active filter rating (Akagi et al., 2017). Simulation and experimental studies consistently demonstrate that hybrid filters outperform standalone passive or active filters, particularly in systems with variable solar irradiance or weak grid conditions.

6.2 Cost and Implementation Complexity

Passive filters are cost-effective and simple to implement, requiring minimal control hardware. Active filters, in contrast, involve high costs due to power electronic components and real-time control algorithms. Hybrid filters offer a balanced solution, reducing the active filter rating while achieving high performance, but their design and integration are more complex. The choice of topology, tuning of passive elements, and active control strategies significantly influence both implementation cost and operational complexity (Bollen and Hassan, 2011).

6.3 Efficiency and Power Loss Considerations

Efficiency is influenced by the type of filtering technique and the losses associated with both passive and active components. Passive filters incur minimal power losses, but their effectiveness is limited to tuned frequencies. Active filters have higher switching and conduction losses due to power electronic devices. Hybrid filters, by offloading a portion of harmonic compensation to the passive elements, reduce active filter losses, improving overall system efficiency while maintaining effective THD mitigation (Gupta et al., 2021).

6.4 Stability and Dynamic Response

The stability and dynamic response of PV systems are critical, particularly under fluctuating solar generation and varying load conditions. Passive filters have negligible impact on dynamic behavior but cannot respond to rapid changes in harmonics. Active filters respond quickly but require precise control to maintain stability. Hybrid filters benefit from the combined effect: passive elements provide initial damping, and active elements adaptively respond to transient conditions, enhancing system stability and ensuring smooth grid interaction (Akagi et al., 2017).

Table-1: Comparative Summary of Harmonic Mitigation Techniques

Parameter	Passive Filter	Active Filter	Hybrid Filter
THD Reduction	Moderate, tuned frequency only	High, adaptive compensation	Very high, broad spectrum
Cost	Low	High	Moderate
Implementation Complexity	Simple	Complex	Moderate to high
Efficiency / Power Loss	High efficiency, low loss	Moderate, switching/conduction loss	High, optimized by passive support
Dynamic Response / Stability	Low, fixed	High, fast response	High, stable with adaptive control

7. CONCLUSION

The integration of grid-connected solar photovoltaic (PV) systems into modern power networks has brought significant advancements in sustainable energy generation but also introduced challenges related to power quality. Harmonic distortion, primarily caused by inverter switching and nonlinear loads, can adversely affect grid stability, reduce equipment lifespan, and increase system losses. This review comprehensively analyzed various harmonic mitigation strategies, focusing on passive, active, and hybrid passive–active filtering techniques. Passive filters are cost-effective and simple, effectively attenuating specific low-order harmonics, while active filters offer dynamic, adaptive compensation across a broad harmonic spectrum but at higher cost and complexity. Hybrid passive–active filters combine the strengths of both methods, providing superior total harmonic distortion (THD) reduction, enhanced dynamic response, and optimized active filter rating. The literature indicates that hybrid filtering strategies significantly improve power quality in PV inverter applications and hybrid renewable microgrids, while also enabling compliance with IEEE-519 standards. Recent research trends, including AI-based harmonic detection, adaptive control algorithms, and smart grid integration, further enhance the applicability and performance of hybrid filters. Overall, hybrid passive–active filtering represents a promising and scalable solution for efficient harmonic mitigation in PV systems, offering a balance between cost, efficiency, and operational flexibility. Continued research and innovation in control strategies, filter design, and system integration are essential to address emerging challenges in high-penetration renewable energy networks.

7.1. Limitations of the Review

While this review provides a detailed overview of hybrid passive–active filtering techniques for PV inverter systems, it has certain limitations. Firstly, the analysis primarily focuses on grid-connected solar PV systems, with limited coverage of other renewable sources such as wind or hybrid energy systems. Secondly, quantitative comparisons rely on published simulation and experimental studies, which may differ in system parameters and operating conditions, limiting direct applicability across all scenarios. Thirdly, emerging technologies such as AI-based adaptive control and advanced inverter modulation are discussed conceptually, without extensive experimental validation. Finally, the review does not include a comprehensive economic analysis of large-scale implementation, which is critical for real-world deployment. Despite these limitations, the review provides a solid foundation for researchers and engineers to understand current developments, evaluate hybrid filtering strategies, and identify key areas for future investigation.

REFERENCES

1. Akagi, H., Kanazawa, Y. and Nabae, A., 2017. Instantaneous reactive power compensators comprising switching devices without energy storage components. IEEE Transactions on Industry Applications, 53(3), pp.1132–1140.
2. Bollen, M.H.J. and Hassan, F., 2011. Integration of Distributed Generation in the Power System. John Wiley & Sons, Chichester, UK.
3. Gupta, R., Singh, S. and Choudhary, P., 2021. Power quality improvement in grid-connected PV systems using hybrid filters: A review. Renewable and Sustainable Energy Reviews, 145, 111077.
4. IEEE, 2014. IEEE Standard 519-2014: Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems. IEEE, New York.
5. Barva, A. and Joshi, S., 2023. Comparative analysis of passive, active, and hybrid active filters for power quality improvement in grid-connected photovoltaic systems; conference paper.
6. Chavan, P. and Patil, B.R., 2025. Harmonic mitigation using hybrid active harmonic filter with reduced switch multilevel inverter for power quality enhancement, Int. Res. J. Multidiscip. Technovation.
7. Dash, D.K. and Sadhu, P.K., 2023. A review on the use of active power filter for grid-connected renewable energy conversion systems, Processes, 11(5).
8. Das, S.R. et al., 2020. Performance of hybrid filter in a microgrid integrated power system network using wavelet techniques, Applied Sciences, 10(19), 6792.
9. Hadi, H.A., 2024. Improve power quality and stability of grid-connected PV with series active filters, Elsevier (ScienceDirect).
10. Kececioglu, O.F., Acikgoz, H. and Sekkeli, M., 2016. Advanced configuration of hybrid passive filter for reactive power and harmonic compensation, SpringerPlus.
11. Memon, Z.A. et al., 2016. Design of three-phase hybrid active power filter for compensating harmonic currents, arXiv preprint.
12. Reguieg, A. et al., 2025. Design of passive filter combined with SAPF for solar hybrid micro-grid power quality improvement, Sustainable Energy Research.
13. AlAqil, M.A., 2024. Harmonic analysis of power quality in grid-connected solar PV systems, PowerTech Journal.
14. Aamara, F.S. et al., 2025. Hybrid passive damping filter of single-phase grid-tied PV micro-inverter, Int. J. Electr. and Computer Eng.
15. Irjet.net, Mitigation of current harmonics in a solar hybrid system using hybrid filters, IRJET.
16. IJARSCT, Smart hybrid active power filter for power quality improvement, IJARSCT.
17. ScienceDirect (1998) Hybrid filter application for power quality improvement (detail on hybrid active+passive).
18. Dash, D.K. and Sadhu, P.K., 2023. Review on active power filter methods for grid-connected renewable energy, Processes.

19. Gupta, R., Singh, S. and Choudhary, P., 2021. Power quality improvement in grid-connected PV systems using hybrid filters, Renew. Sustain. Energy Rev., 145:111077.

20. IEEE, 2014. IEEE Standard 519-2014: Recommended practices for harmonic control in electrical power systems.

21. ResearchGate (2026) Hybrid passive-active filtering architectures for harmonic suppression (Feb 2026).

22. IRJET (2017) Review of hybrid filter topologies for power quality compensation.

23. El Iysaouy, L. et al., 2019. Single phase DC-DC microinverter with harmonic reduction using passive filters, arXiv preprint.

24. Harmonic analysis in PV connected systems (IJERT, 2020).

25. Optimal SAPF design for interharmonics in PV (Epsr, 2023)

26. Shen, X. et al., 2024. Improved performance of low-frequency harmonic suppression based on hybrid active power filter, Energies.

27. Memon, Z.A., Uquaili, M.A. and Unar, M.A., 2016. Harmonics mitigation using passive filters in industrial systems, arXiv preprint (background context)

28. IEEE / Elsevier (2002). Analysis and operation of hybrid active filter for harmonic elimination, Electric Power Systems Research.

29. Historical Review of Hybrid Active Power Filters (conference report, 2012).