Volume: 5 Issue: 5 Pages: 23-27

Adaptive Harmonic Suppression in Distributed Generation Using Instantaneous Power (p–q) Theory

[*1] MV Subramanyam, [2]N Ramyasri, [3]G Divyasindhu, [4]N Puneeth and [5]V Rajesh

[*1] Assistant Professor, Department of Electrical and Electronics Engineering, Matrusri Engineering College, Hyderabad, Telangana, India.

[2,3,4,5] Students, Department of Electrical and Electronics Engineering, Matrusri Engineering College, Hyderabad, Telangana, India.

Article Info.
E-ISSN: 2583-6528
Impact Factor (QJIF): 8.4
Peer Reviewed Journal
Available online:
www.alladvancejournal.com

Received: 05/April/2026
Accepted: 05/May/2026

***Corresponding Author**
MV Subramanyam
Assistant Professor, Department of Electrical and Electronics Engineering, Matrusri Engineering College, Hyderabad, Telangana, India.

Abstract

The rapid integration of renewable energy sources, such as solar photovoltaic and wind energy, into distributed generation systems has significantly improved sustainability but has also introduced major power-quality challenges. One of the most critical issues is harmonic distortion, which arises primarily from the use of power electronic converters and nonlinear loads. These harmonics distort current and voltage wave forms, leading to increased losses, overheating, and malfunction of sensitive equipment. This paper proposes an effective harmonic mitigation technique based on Instantaneous Reactive Power (PQ) Theory. A hybrid renewable energy system is modelled using MATLAB/Simulink, and harmonic levels are analysed using Fast Fourier Transform (FFT). A Shunt Active Power Filter is implemented to compensate for harmonic components. Simulation results demonstrate a significant reduction in Total Harmonic Distortion (THD) from 5.78% to 1.2%, ensuring compliance with IEEE standards. The proposed approach enhances overall power quality and ensures stable and efficient operation of distributed generation systems.

Keywords: Harmonic Distortion, Power Quality, Distributed Generation, Renewable Energy Systems, Solar Photovoltaic, MATLAB Simulink

1. Introduction

The increasing demand for clean and sustainable energy has accelerated the adoption of renewable energy systems such as solar and wind power. These systems are commonly integrated into power networks through power electronic converters, which introduce non-linearity into the system. As a result, harmonic distortion becomes a significant issue, affecting both current and voltage wave forms. Harmonics can lead to various problems, including increased power losses, overheating of electrical equipment, and reduced lifespan of devices. In addition, they can interfere with communication systems and cause malfunctioning of sensitive loads. Maintaining power quality within acceptable limits is therefore essential for the reliable operation of modern power systems. Standards such as IEEE 519 specify limits for Total Harmonic Distortion to ensure system stability. Among various harmonic mitigation techniques, PQ theory has gained attention due to its ability to detect and compensate for harmonics in real time. It provides a simple and efficient method for improving power quality in distributed generation systems.

2. Literature Survey

Several researchers have investigated harmonic mitigation techniques in distributed generation systems to improve power quality. Early work by Hirofumi Akagi introduced the Instantaneous Reactive Power (PQ) Theory, which became a fundamental approach for real-time harmonic detection and compensation. Later studies focused on the application of Shunt Active Power Filters (SAPF) controlled by PQ theory to eliminate harmonic components effectively.

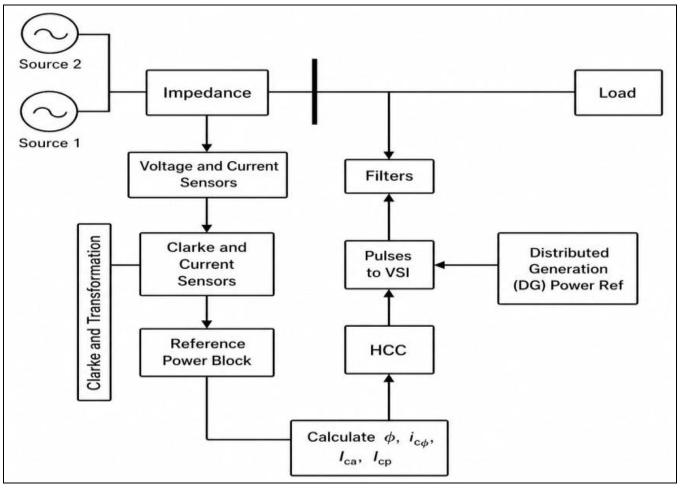
Researchers have also explored alternative control methods, such as synchronous reference frame (SRF) theory, which provides accurate results under balanced conditions but faces limitations during unbalanced or distorted supply conditions. Recent advancements include the integration of intelligent techniques like fuzzy logic and neural networks to enhance harmonic compensation performance.

Additionally, several works have demonstrated the effectiveness of MATLAB/Simulation-based modelling for analyzing Total Harmonic Distortion (THD) and validating control strategies. Although these methods provide significant improvements, challenges remain in terms of real-time implementation, cost, and adaptability. Therefore, PQ theory-based approaches continue to be widely preferred due to their simplicity, fast response, and effectiveness in improving power quality in renewable energy-based distributed systems.

3. Proposed Work

The proposed system consists of a hybrid renewable energy source, including solar photovoltaic and wind energy connected to a distributed generation system. The generated power is fed to the grid through power electronic converters, which introduce harmonic distortions due to nonlinear characteristics. To analyse these harmonics, a Fast Fourier Transform (FFT) block is used. An Instantaneous Reactive Power (PQ) Theory-based controller is implemented to detect and compute the harmonic components present in the system. Based on this, a Shunt Active Power Filter (SAPF) is employed to inject compensating currents and eliminate harmonics. This improves the overall power quality by reducing Total Harmonic Distortion (THD) and ensures stable and efficient operation of the system.

A. Block Diagram



Power Source

The sources represent the three-phase utility grid along with distributed generation (DG) units supplying electrical power to the system. These include inverter-based renewable energy sources such as solar PV and wind energy. Due to power electronic interfaces and nonlinear loads, the source currents often become distorted, introducing harmonic components into the grid.

Transmission Line Impedance

This block models the real-time characteristics of the transmission line, including resistance and inductance between the source and the point of common coupling (PCC). It plays an important role in voltage drop, harmonic propagation, and maintaining overall system stability.

Load Unit

The load block represents nonlinear consumer loads such as rectifiers, adjustable speed drives, and power electronic devices. These loads draw non-sinusoidal currents even when supplied with sinusoidal voltage, leading to harmonic distortion and reduced power quality.

Voltage and Current Measurement

This block continuously monitors the three-phase voltages and currents at the PCC. The measured signals act as real-time inputs for harmonic detection and control. Accurate measurement is essential for proper compensation.

Clarke Transformation Unit

This unit converts three-phase (abc) voltages and currents into two-axis stationary reference frame (α-β) components. This simplifies analysis by removing phase dependency and enables instantaneous power calculation, forming the basis of PQ theory.

Reference Unit

This block computes instantaneous active (p) and reactive (q) power using α-β components. The total power is divided into average and oscillating parts, where the oscillating component corresponds to harmonic and reactive power that must be compensated.

Reference Compensating Current Generation

Based on calculated p and q values, this block generates reference compensating currents (i*ca, i*cb, i*cc). These currents are used to eliminate harmonic and reactive components, ensuring improved power quality.

Hysterisis Current Controller

This controller compares the actual compensating current with the reference current and produces switching signals. It offers fast response, simplicity, and high accuracy, making it suitable for real-time applications.

Gating Signals to VSI

This block sends switching pulses generated by the HCC to the Voltage Source Inverter (VSI). The VSI injects compensating currents into the system to cancel harmonics and reactive power components.

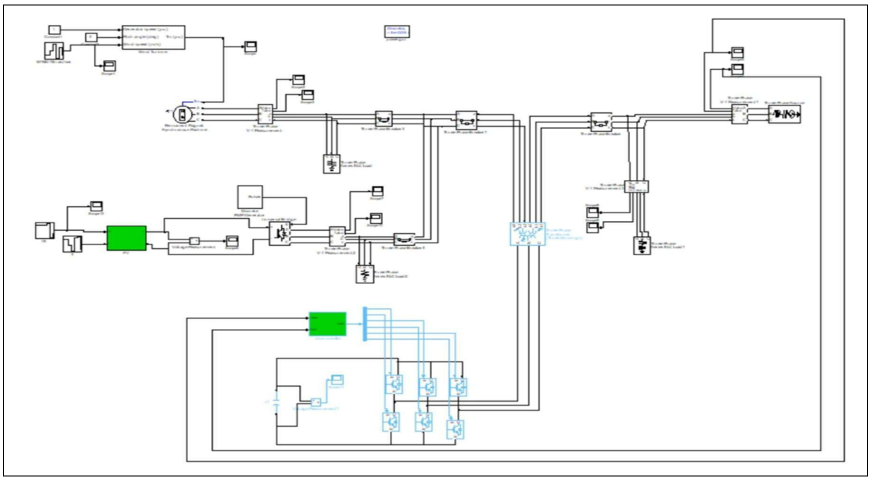
Filtering Unit

Filters (such as LC or LCL) are used to smooth the inverter output currents and reduce high-frequency switching harmonics. This ensures only the required compensating currents are delivered to the grid.

DG Power Reference Unit

This block provides the active power reference for the distributed generation unit. It helps coordinate between power injection and harmonic compensation, ensuring stable operation and compliance with grid standards.

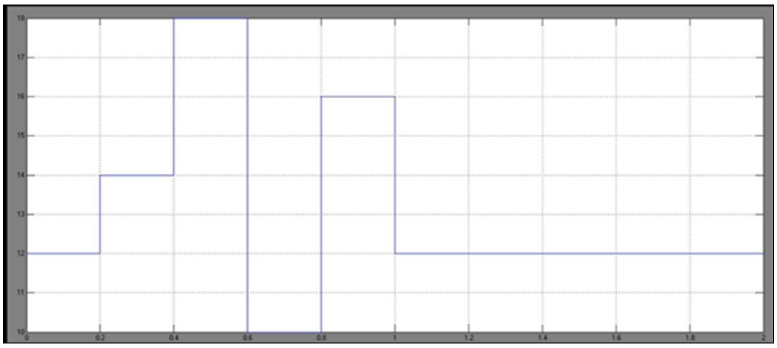
B. Circuit Diagram



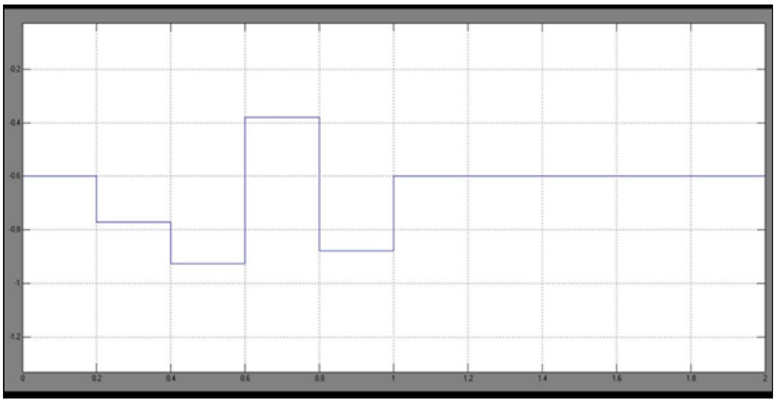
4. Result

The performance of the proposed harmonic mitigation technique is evaluated using MATLAB/Simulink simulations. The system is analyzed under two different conditions: without compensation and with PQ theory-based compensation. In the absence of compensation, the system exhibits significant harmonic distortion due to the presence of nonlinear loads and inverter-based renewable sources. The Total Harmonic Distortion (THD) is measured using FFT analysis and is found to be 5.78%, which exceeds the acceptable limit defined by IEEE standards. After implementing the PQ theory-based Shunt Active Power Filter, a substantial improvement is observed. The THD is reduced to 1.2%, indicating effective elimination of harmonic components. Additionally, the current waveform becomes smooth and nearly sinusoidal, and reactive power is minimized. These results clearly demonstrate that the proposed method successfully enhances power quality, reduces losses, and ensures stable system operation under varying load conditions.

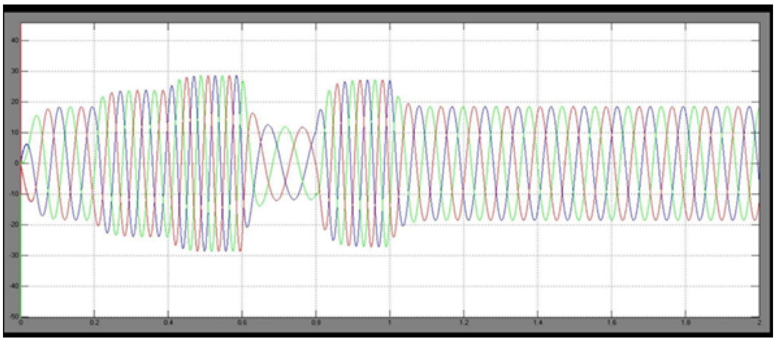
C. Outputs



Input Wind Speed vs Time

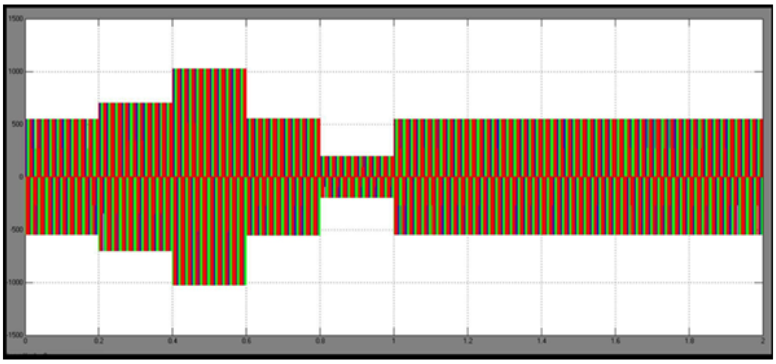


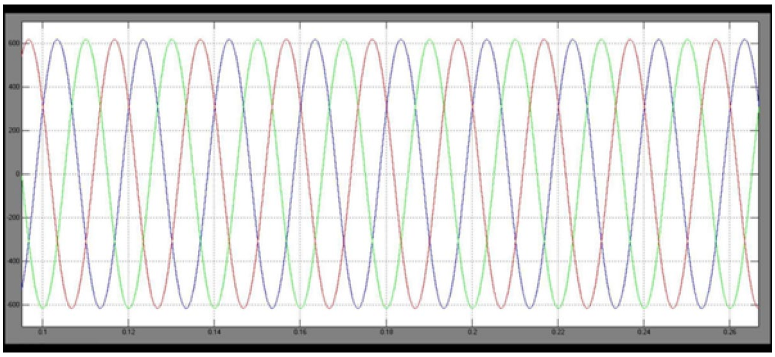
PSMG Input Torque vs Time



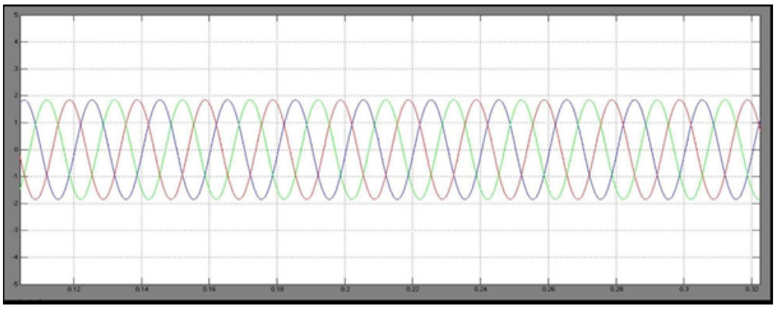
PV Inverter Voltage vs Time

After Harmonics Reduced the Grid Voltage vs Time

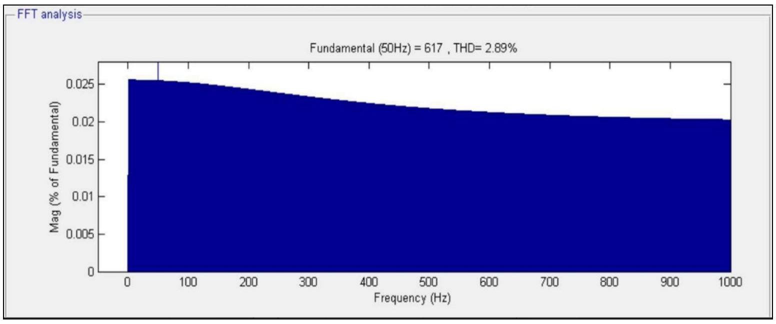




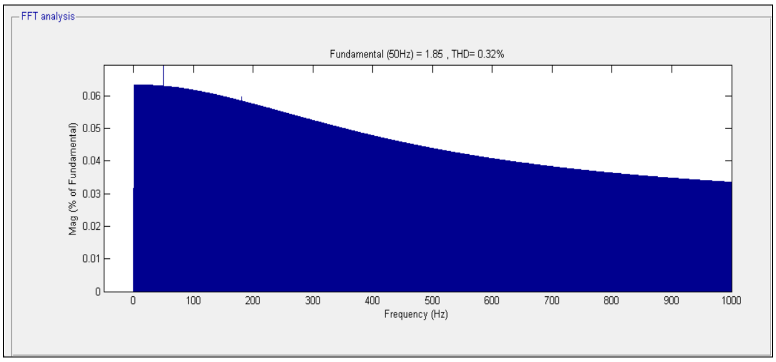
Grid voltage Vs Time



Grid current Vs Time



Grid Voltage THD



Grid Current THD

Conclusion

This paper presents an efficient approach for harmonic analysis and mitigation in distributed generation systems using PQ theory. The method effectively identifies and compensates for harmonic components in real time, resulting in improved power quality. Simulation results confirm a significant reduction in Total Harmonic Distortion from 5.78% to 1.2%, demonstrating the effectiveness of the proposed technique. The use of a Shunt Active Power Filter controlled by PQ theory ensures fast response and accurate compensation under both balanced and unbalanced conditions. This approach is particularly suitable for modern renewable energy systems, where harmonic distortion is a common issue. Furthermore, the method contributes to reducing power losses and improving system reliability. Future work can focus on implementing this technique in real-time hardware using DSP or FPGA platforms, as well as integrating advanced control strategies such as artificial intelligence for further performance enhancement.

5. Future Scope

- Implementation of the proposed system in real-time using hardware platforms such as DSP or FPGA.
- Integration of artificial intelligence and machine learning techniques for adaptive harmonic detection.
- Extension of the system to handle unbalanced and rapidly varying load conditions.
- Use of advanced filter designs such as hybrid active power filters and multilevel inverters.
- Integration with smart grid systems for improved monitoring and control.
- Inclusion of energy storage systems to enhance reliability and stability.
- Reduction of switching losses and improvement in overall system efficiency.
- Cost optimization for large-scale practical applications.
- Enhancement of control strategies for faster and more accurate compensation.
- Ensuring compliance with advanced and evolving power quality standards.

References

1. Hirofumi Akagi, Kanazawa Y, Nabae A. “Instantaneous Reactive Power Compensators Comprising Switching Devices Without Energy Storage Components,” IEEE Transactions on Industry Applications. 1984; 20(3):625-630.
2. IEEE, “IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems,” IEEE Std 519-2014, 2014.
3. Singh B, Al-Haddad K, Chandra A. “A Review of Active Filters for Power Quality Improvement,” IEEE Transactions on Industrial Electronics. 1999; 46(5):960-971.
4. El-Habrouk M, Darwish MK, Mehta P. “Active Power Filters: A Review,” IEE Proceedings-Electric Power Applications. 2000; 147(5):403-413.
5. Akagi H. “New Trends in Active Filters for Power Conditioning,” IEEE Transactions on Industry Applications. 1996; 32(6):1312-1322.
6. Carrasco JM *et al.*, “Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey,” IEEE Transactions on Industrial Electronics. 2006; 53(4):1002-1016.
7. Rahmani S *et al.*, “A Combination of Shunt Hybrid Power Filter and Thyristor-Controlled Reactor for Power Quality,” IEEE Transactions on Industrial Electronics. 2014; 61(5):2152-2164.
8. Mohan N, Undeland TM, Robbins WP. Power Electronics: Converters, Applications, and Design, 3rd ed, 2003.