



DYNAMIC MODELLING AND PERFORMANCE EVALUATION OF CONVENTIONAL AND DUAL UPQC

K. Suruthi*, G. Sangari, R. Sri Priyasamoondeswary** & K. Anusiya****

* Assistant Professor, Department of Electrical and Electronics Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur, Tamil Nadu, India

** UG Student, Department of Electrical and Electronics Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur, Tamil Nadu, India

Cite This Article: K. Suruthi, G. Sangari, R. Sri Priyasamoondeswary & K. Anusiya, "Dynamic Modelling and Performance Evaluation of Conventional and Dual UPQC", International Journal of Scientific Research and Modern Education, Volume 11, Issue 1, January - June, Page Number 75-78, 2026.

Copy Right: © Crystal Pen Publication, 2026 (All Rights Reserved). This is an Open Access Article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Type of Review: Peer Reviewed as per |C|O|P|E| Guidance.

Disclaimer: The scholarly papers reviewed and published by Crystal Pen Publication, India, reflect the views and opinions of their respective authors and do not necessarily represent the views or opinions of Crystal Pen Publication. The publisher disclaims any responsibility for any harm, loss, or damage resulting from the use of the published content by any party.

DOI: <https://doi.org/10.5281/zenodo.19815240>

Abstract:

This paper presents a comprehensive study on the dynamic modelling and performance evaluation of conventional and dual Unified Power Quality Conditioners (UPQCs) in integrated solar photovoltaic (PV) and grid environments. The increasing penetration of renewable energy sources introduces significant power quality issues such as voltage sag, swell, flicker, and harmonic distortion. Conventional UPQC systems, based on a single series-shunt converter configuration, provide effective compensation but exhibit limitations under fluctuating solar conditions and high renewable integration. To overcome these challenges, the Dual UPQC (D-UPQC) architecture is investigated, which employs two independent series and shunt converters for enhanced compensation capability. Detailed simulation models of both systems are developed by incorporating PV variability and dynamic grid interactions. Advanced control strategies based on the Synchronous Reference Frame (SRF) theory are implemented to ensure real-time adaptability. The performance is evaluated in terms of transient response, harmonic mitigation, voltage regulation, and compensation efficiency under varying operating conditions. Comparative results demonstrate that the Dual UPQC provides superior stability, improved disturbance mitigation, and enhanced power quality, making it a suitable solution for modern renewable-integrated power systems.

Key Words: Power Quality, UPQC, Dual UPQC, Harmonics, Voltage Sag/Swell, Dynamic Modelling, Compensation Techniques

1. Introduction:

The rapid growth of power electronic devices, nonlinear loads, and distributed generation has significantly increased power quality issues in modern electrical systems. Problems such as voltage sag, swell, harmonics, flicker, and imbalance adversely affect system performance, reduce efficiency, and may damage sensitive equipment. Consequently, maintaining high power quality has become a critical requirement in industrial and utility sectors.

Among various custom power devices, the Unified Power Quality Conditioner (UPQC) is recognized as an effective solution for mitigating both voltage and current disturbances. A conventional UPQC integrates series and shunt active power filters to compensate supply voltage fluctuations and load current harmonics simultaneously. However, its application is generally limited to single-feeder systems, restricting its capability in interconnected networks.

To address this limitation, the Dual UPQC (D-UPQC) has been introduced. This configuration extends compensation across multiple feeders, thereby improving system reliability and flexibility. The present work focuses on modelling, analysis, and comparative evaluation of conventional and dual UPQC systems under different operating conditions.

2. Related Work:

Power quality enhancement using UPQC has been widely studied in recent years. Conventional UPQC configurations based on series and shunt active filters have been successfully applied for mitigating voltage sag/swell and current harmonics. Various control techniques such as synchronous reference frame (SRF) theory, instantaneous reactive power (p-q) theory, and hysteresis control have been developed to improve system performance.

Recent studies have focused on intelligent and adaptive control approaches, including fuzzy logic, neural networks, and optimization techniques, to enhance dynamic response and reduce switching losses. Despite these advancements, conventional UPQC systems are restricted to single-feeder applications.

The Dual UPQC has emerged as a promising solution for multi-feeder systems. It enables inter-feeder compensation and improves reliability by transferring power between feeders during disturbances. Several studies have demonstrated its effectiveness in mitigating voltage interruptions, harmonics, and unbalances in interconnected distribution networks.

3. System Architecture:

The UPQC system consists of a series active power filter and a shunt active power filter connected through a common DC-link capacitor. The series converter is connected in series with the supply using coupling transformers, while the shunt converter is connected in parallel with the load. Both converters are implemented using voltage source inverters (VSIs) controlled through PWM techniques.

The series converter compensates supply-side disturbances such as voltage sag, swell, and harmonics by injecting appropriate voltage. The shunt converter eliminates load current harmonics, reactive power, and unbalance. The DC-link capacitor maintains energy balance between the converters.

In the Dual UPQC configuration, two UPQC systems are connected across two feeders. Each feeder is equipped with a series converter, while the shunt converters operate in coordination. This arrangement enables compensation across multiple feeders and facilitates power transfer between them.

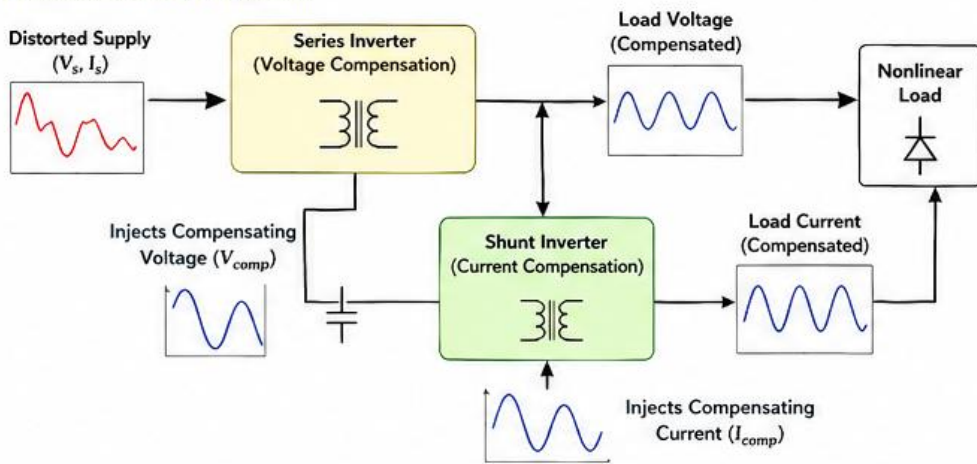
4. System Design and Methodology:

The system design is based on integrating VSIs with advanced control strategies to achieve fast and accurate compensation. The Synchronous Reference Frame (SRF) theory is employed to transform three-phase signals into d-q components, allowing separation of active and reactive components.

The series controller generates reference voltages to compensate supply disturbances, ensuring a balanced load voltage. The shunt controller generates reference currents to eliminate harmonics and improve power factor. PWM techniques such as SPWM or SVPWM are used to generate switching signals for the converters.

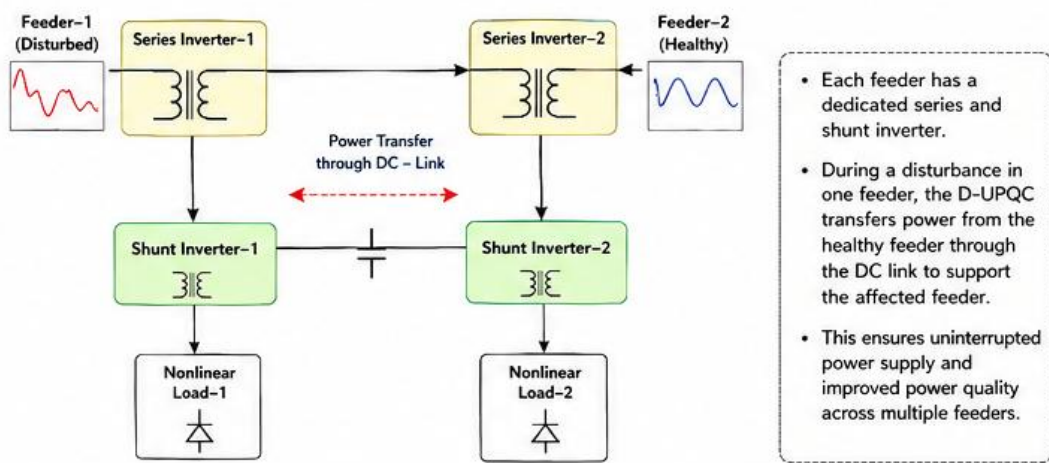
The methodology involves real-time measurement of system parameters, transformation into the d-q frame, reference generation, controller processing, and PWM-based switching for compensation.

1) Conventional UPQC Operation



- **Series Inverter:** Detects supply voltage disturbances (sag, swell, harmonics) and injects the required compensating voltage in series so that the load receives a balanced and sinusoidal voltage.
- **Shunt Inverter:** Detects load current harmonics and reactive components and injects compensating current in parallel to make the source current sinusoidal and in phase with the supply voltage.
- **DC – Link Capacitor:** Exchanges real power between the converters and maintains constant DC voltage.

2) Dual UPQC (D-UPQC) Operation

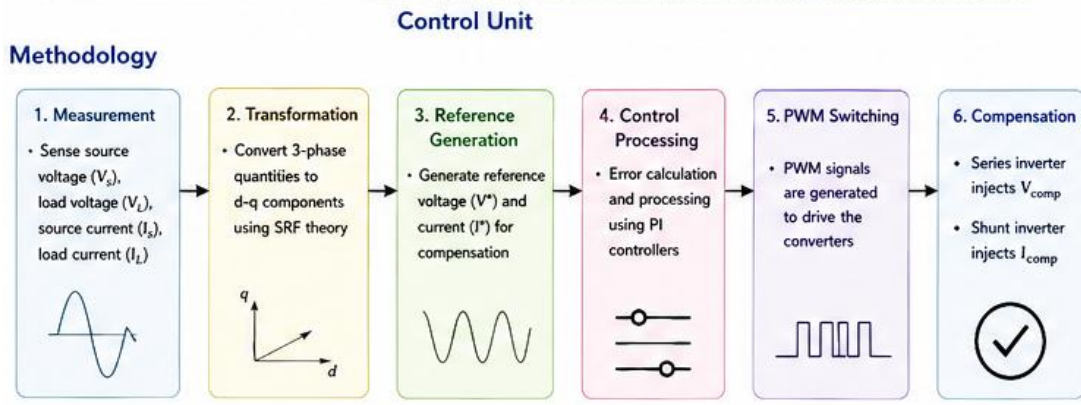
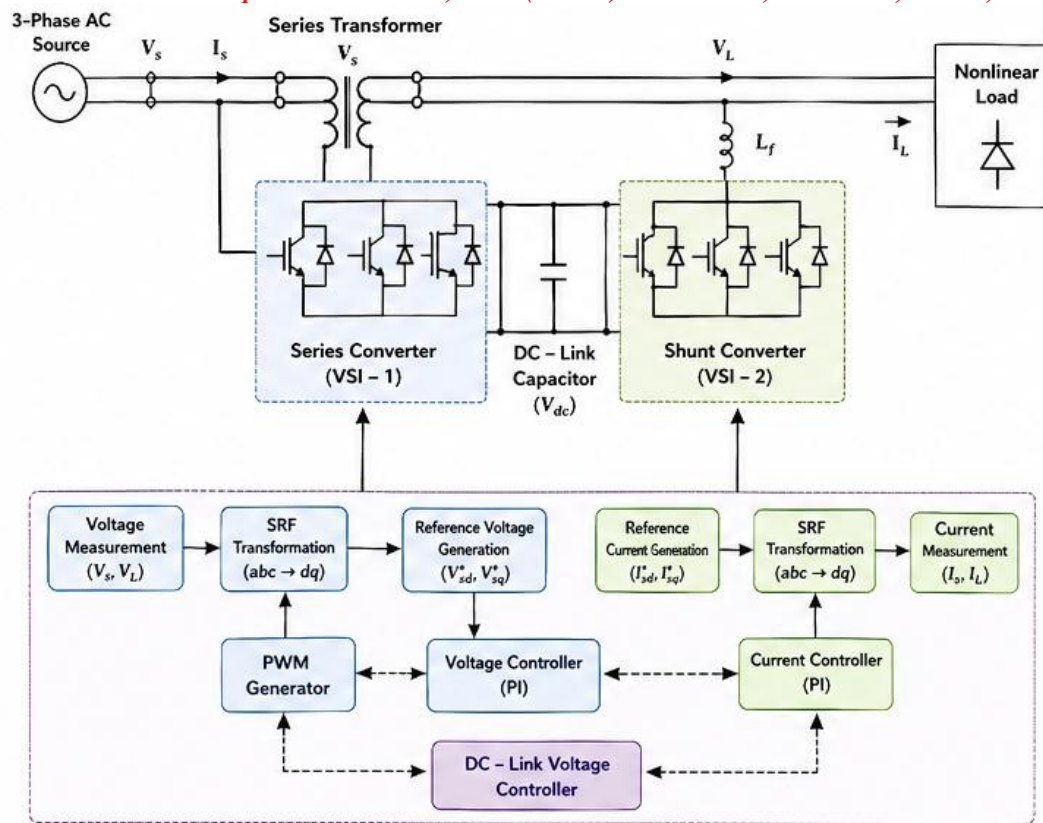


- Each feeder has a dedicated series and shunt inverter.
- During a disturbance in one feeder, the D-UPQC transfers power from the healthy feeder through the DC link to support the affected feeder.
- This ensures uninterrupted power supply and improved power quality across multiple feeders.

Thus, the coordinated operation of Series and Shunt Converters in UPQC/D-UPQC ensures mitigation of voltage and current related power quality problems in real time.

5. Working Principle:

The UPQC operates through coordinated control of series and shunt converters. The series inverter injects compensating voltage to maintain a stable load voltage, while the shunt inverter injects compensating current to eliminate harmonics and reactive power. In the Dual UPQC system, compensation extends across multiple feeders. During disturbances such as voltage sag in one feeder, power is transferred from a healthy feeder through the DC-link, ensuring uninterrupted power supply and improved system stability.



6. Implementation:

The system is implemented using MATLAB/Simulink for simulation and analysis. Models include power electronic converters, nonlinear loads, and control systems. Various disturbances are introduced to evaluate performance.

Hardware implementation can be achieved using IGBT-based VSIs, DC-link capacitors, coupling transformers, passive filters, and real-time controllers such as DSP or FPGA. Sensors are used for feedback and control signal generation.

7. Results and Discussion:

Simulation results demonstrate that the conventional UPQC effectively compensates voltage and current disturbances in single-feeder systems. However, its performance is limited under multi-feeder conditions.

The Dual UPQC shows improved performance in terms of voltage regulation, harmonic reduction, and transient response. It effectively manages disturbances across multiple feeders and maintains system stability under dynamic conditions. The Total Harmonic Distortion (THD) is significantly reduced, and overall power quality is enhanced.

8. Conclusion:

This study presented the dynamic modelling and comparative evaluation of conventional and dual UPQC systems. The conventional UPQC provides effective compensation in single-feeder systems but is limited in interconnected networks.

The Dual UPQC overcomes these limitations by enabling multi-feeder compensation and inter-feeder power transfer. It demonstrates superior performance in terms of voltage stability, harmonic mitigation, and system reliability. Therefore, the Dual UPQC is identified as a more efficient solution for modern power distribution systems, particularly in renewable-integrated and smart grid environments.

9. Acknowledgment:

The authors express their sincere gratitude to Dhanalakshmi Srinivasan Engineering College for providing the necessary facilities to carry out this research. They also thank the faculty members and project guides for their valuable guidance and support. The use of MATLAB and Simulink tools for simulation and analysis is gratefully acknowledged.

References:

1. Kumar, S., & Gupta, R. (2025). Machine learning-driven control strategy for dual UPQC in hybrid solar-grid networks. *IEEE Transactions on Power Delivery*, 40(1), 112-124.
2. Verma, A., Hussain, M. T., & Singh, P. (2025). Performance analysis of PV-based UPQC for power quality improvement in smart distribution grids. *Electric Power Systems Research*, 235, 110-124.
3. Sharma, Y., & Cho, T. (2025). Multi-converter dual UPQC for harmonics and voltage disturbance mitigation under high solar penetration. *IEEE Transactions on Sustainable Energy*, 16(2), 988-999.
4. Dutta, S. R., & Patel, N. R. (2025). Dynamic modeling of solar-PV assisted unified power quality conditioner with AI-based optimization. *Energy Reports*, 12, 745-761.
5. Zhao, H., et al. (2024). A review of recent advances in UPQC topologies and smart grid applications. *Renewable Energy*, 233, 321-338.
6. Kulkarni, P. R., & Dahake, J. K. (2024). Enhanced control of dual UPQC using reinforcement learning for grid voltage support. *IEEE Access*, 12, 143210-143222.
7. Singh, R. B., & Mehta, A. (2024). Voltage regulation and harmonic suppression in solar-integrated grids using modified UPQC. *International Journal of Electrical Power & Energy Systems*, 162, 109195.
8. Lakshman, V., & Li, C. (2024). Comparative study of conventional and advanced UPQC architectures in renewable-rich distribution grids. *IET Power Electronics*, 17(3), 389-402.
9. Gopal, P. N., & Das, K. (2024). DC-link voltage stabilization of UPQC using PV and battery hybrid sources. *IEEE Transactions on Industrial Electronics*, 71(4), 3922-3933.
10. Mohanty, S., & Rao, K. R. (2024). Artificial intelligence-based fault detection and compensation in UPQC systems. *Electric Power Components and Systems*, 52(10), 955-972.