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Reactive Power Compensation for Standalone Hybrid Power System Using Facts Devices

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Abstract

Reactive power compensation is essential in hybrid grid-connected systems because power electronic inverters utilized for supplying DC energy into the grid causes a reduction in the overall power factor of the power systems. Due to the ability to provide a reliable and efficient power supply to remote and off-grid areas, hybrid power systems are growing in popularity. It can provide greater opportunities for operational growth by combining economic and technology advancement. To meet the demand for electrical energy in both regular and critical situations, operators must be in charge of the power systems reliable and secure operation. The primary objective of the work is to control the reactive power flow in a grid-connected hybrid renewable energy system (PV-wind-battery). The power quality problems that these systems frequently experience include voltage sags, harmonics, and flicker. A FACTS device Unified Power Quality controller (UPQC) with a Genetic Algorithm based PI controller is suggested to handle these power quality issues. In order to improve the performance of the power system, the proposed optimization approaches are used to tune the UPQC in a multiline transmission system. The model was developed with the help of the MATLAB/Simulink work framework.

Keywords

Hybrid Power Systems, Solar PV System, Wind Energy, Unified Power Quality controller, MATLAB/Simulink, PI controller

Introduction

The rapid growth of renewable energy integration into power systems has brought about a new set of challenges, particularly in maintaining the stability and efficiency of electricity supply. Standalone hybrid power systems, which combine various energy sources such as solar, wind, and conventional generators, are increasingly utilized in remote or off-grid locations where traditional grid connections are not feasible. However, the inherent variability and intermittency of renewable energy sources in these systems create significant difficulties in ensuring stable voltage levels and reliable power quality. One of the critical components in addressing these challenges is the effective management of reactive power.

Reactive power, while not directly responsible for performing work, plays a

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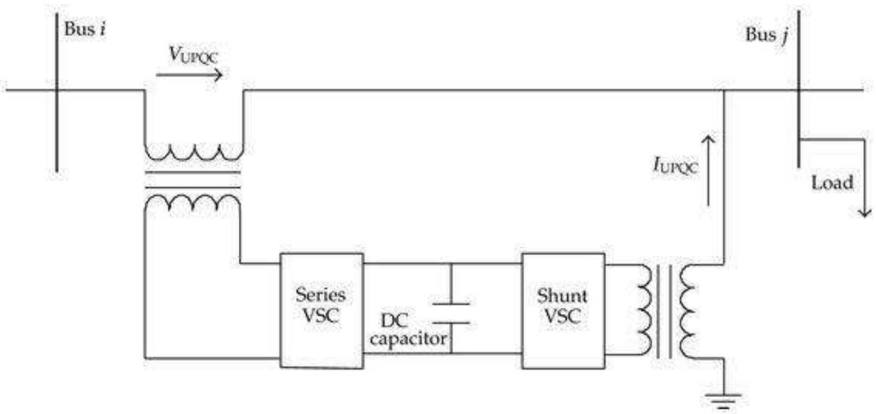
fundamental role in the operation of power systems. It is essential for maintaining the voltage levels necessary for the efficient transmission of active power across the network. Without adequate reactive power compensation, a standalone hybrid power system may suffer from voltage instability, increased power losses, and degraded power quality (Li Chun et al., 2023). These issues can compromise the performance and reliability of the entire system, especially in environments where consistent and high-quality power supply is crucial. The complexity of managing reactive power in standalone hybrid power systems is compounded by the diverse nature of the energy sources involved. Renewable sources like solar and wind are inherently unpredictable and can cause significant fluctuations in power generation. In contrast, conventional generators, such as diesel engines, provide more stable output but can be less efficient and environmentally friendly (Yang Ruiliang et al., 2023). Balancing the interaction between these disparate sources requires advanced technologies that can dynamically adjust to changing conditions in real-time.

Flexible AC Transmission Systems (FACTS) devices have emerged as a key solution for managing these challenges in modern power systems. FACTS devices, including Static Var Compensators (SVC), Static Synchronous Compensators (STATCOM), and Unified Power Flow Controllers (UPFC), offer dynamic and real-time control over reactive power (M S Aarthi et al., 2023). By integrating FACTS devices into standalone hybrid power systems, operators can achieve better voltage regulation, reduce power losses, and improve overall system stability, even in the face of fluctuating renewable energy inputs. One of the primary advantages of FACTS devices is their ability to provide immediate response to changes in power system conditions. For example, when there is a sudden drop in renewable energy generation due to weather changes, FACTS devices can quickly compensate by adjusting the reactive power flow to stabilize voltage levels (Ramchandra Adware et al., 2022). This capability is particularly valuable in standalone hybrid power systems, where maintaining stable voltage is critical for the proper functioning of connected loads and the overall system's resilience.



The Unified Power Quality Conditioner (UPQC) is a sophisticated device designed to enhance power quality by addressing both voltage and current-related issues in an electrical system. It combines two key components: a Series Active Power Filter (APF) and a Shunt Active Power Filter (APF). The Series APF is connected in series with the power line and primarily compensates for voltage disturbances such as sags, swells, and harmonic distortions by injecting a voltage in real-time that corrects these issues before they reach the load (Xiangpei Gu et al., 2023). On the other hand, the Shunt APF, connected in parallel with the load, focuses on mitigating current-related problems like reactive power imbalance, harmonic currents, and load unbalance by injecting compensating currents. This dual functionality allows the UPQC to provide comprehensive power quality improvement.

The operation of the UPQC is governed by a unified control strategy that continuously monitors the power quality parameters within the system. When the control system detects any disturbances, it generates reference signals for both the Series and Shunt APFs (Yang Ruiliang et al., 2023). These signals determine the appropriate compensating voltages and currents that need to be injected into the system. The Series APF ensures that the voltage delivered to the load is stable and free of distortions, while the Shunt APF ensures that the current drawn from the supply is balanced, sinusoidal, and in phase with the voltage, thereby improving the overall power factor and reducing harmonic pollution. In the Unified Power Quality Conditioner (UPQC) system, both feedforward and feedback control strategies are employed to enhance the effectiveness of power quality improvement.

Feedforward control in the UPQC is used primarily in the Series Active Power Filter (Series APF) to anticipate and mitigate voltage disturbances before they affect the load. For instance, if a voltage sag or swell is detected on the supply side, the feedforward control mechanism can immediately inject a compensating voltage into the system, ensuring that the load voltage remains stable and unaffected by the disturbance (M.R. Shaktisinh et al., 2013). This proactive approach enables the UPQC to respond quickly to potential issues, minimizing the impact on sensitive equipment connected to the system.

Feedback control is crucial in the Shunt Active Power Filter (Shunt APF) of the UPQC, where it is used to continuously monitor and adjust the current to maintain optimal power quality. The feedback control system measures the actual current flowing through the load and compares it with the desired reference current. If any deviations are detected, the system adjusts the Shunt APF to inject compensating currents that correct issues such as harmonic distortions, reactive power imbalance, or load unbalance. This reactive approach allows the UPQC to maintain high power quality by correcting errors as they occur, even when disturbances are unpredictable or not fully accounted for by the feedforward control (K. T. Tan et al., 2013). The combination of both control strategies in the UPQC ensures comprehensive and dynamic power quality management, providing both fast response and robust error correction.

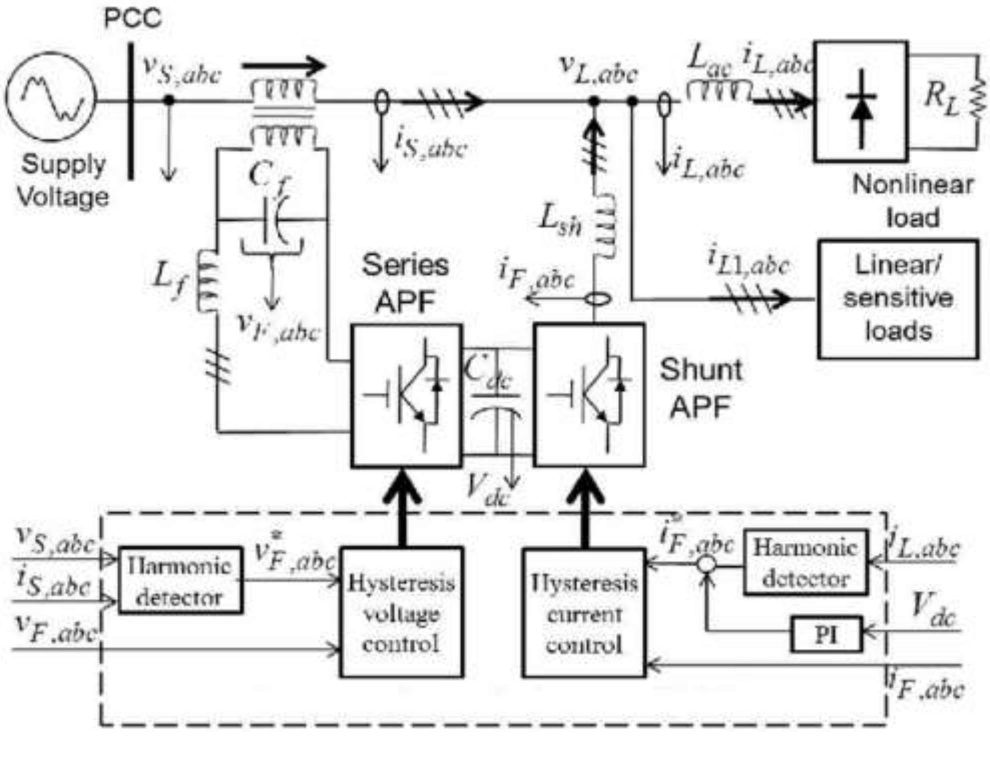


Figure 2. Proposed Methodology of UPQC System with Grid Connected

Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a nature-inspired optimization algorithm that mimics the social behaviour of birds or fish to solve complex problems in multidimensional search spaces. Introduced by Russell Eberhart and James Kennedy in 1995, PSO consists of a group of particles, each representing a potential solution to an optimization problem. These particles move through the search space, adjusting their positions based on two key factors: their own best-known position (personal best) and the best-known position of the entire swarm (global best). This collaborative approach allows the swarm to converge toward optimal solutions over several iterations, making PSO particularly effective for nonlinear and multidimensional optimization tasks (Lakshmi D et al., 2023). The operation of PSO involves several steps. Initially, a swarm of particles is randomly initialized within the search space. Each particle evaluates its fitness based on an objective function that measures how well it solves the optimization problem. The algorithm updates the velocity and position of each particle according to predefined equations that incorporate the particle's personal best and the global best.

PSO has been widely adopted in various fields, including engineering, finance, artificial intelligence, and machine learning, due to its simplicity, flexibility, and effectiveness. Its ability to handle complex, multimodal, and constrained optimization problems makes it a valuable tool for researchers and practitioners. Moreover, PSO's minimal parameter tuning requirements make it accessible for users with varying levels of expertise. Overall, Particle Swarm Optimization is a powerful optimization technique that leverages collective intelligence to efficiently explore solution spaces and find high-quality solutions across a broad spectrum of applications.

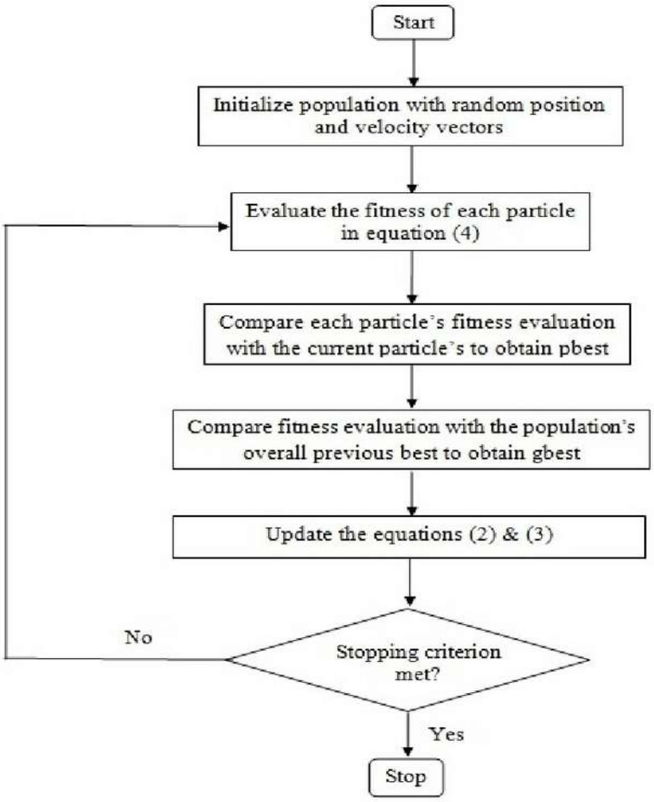


Figure 3. Flow Chart of Particle Swarm Optimization

Simulation Results

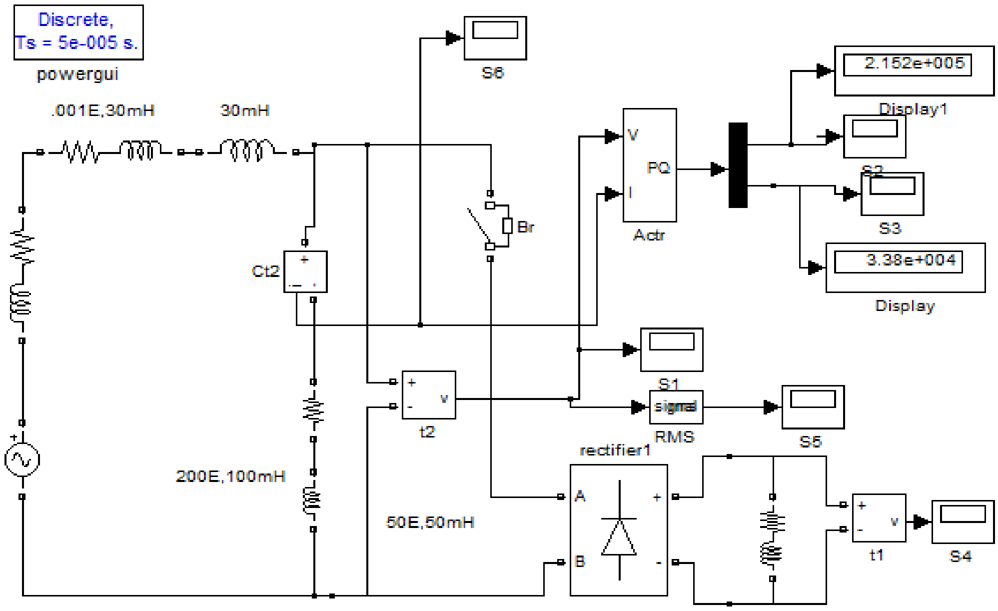


Figure 4. Simulation without UPQC controller

Figure 4 represents the simulation diagram grid connected system without controller and their corresponding load voltage and current waveform variations are also mentioned in Figure 5 and 6. In the output current and voltage waveforms without controller there will be a high THD.

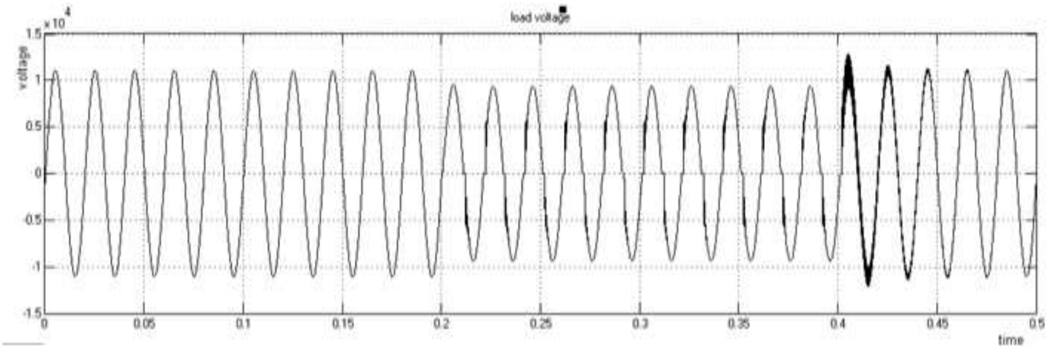


Figure 5. Load voltage without controller

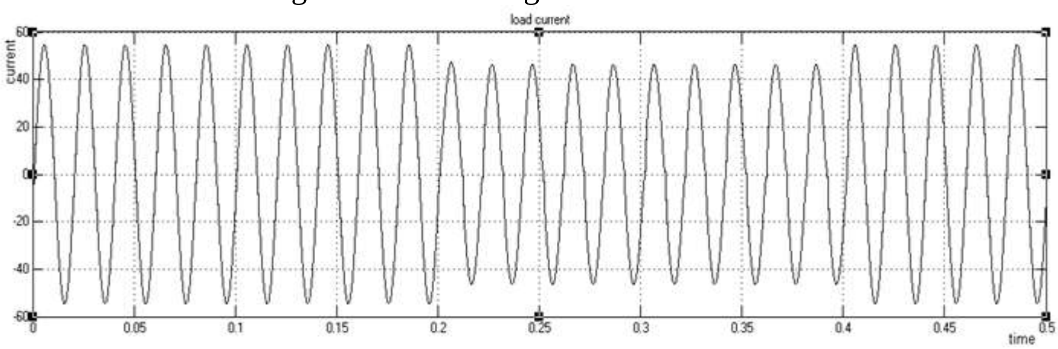


Figure 6. Load current without controller

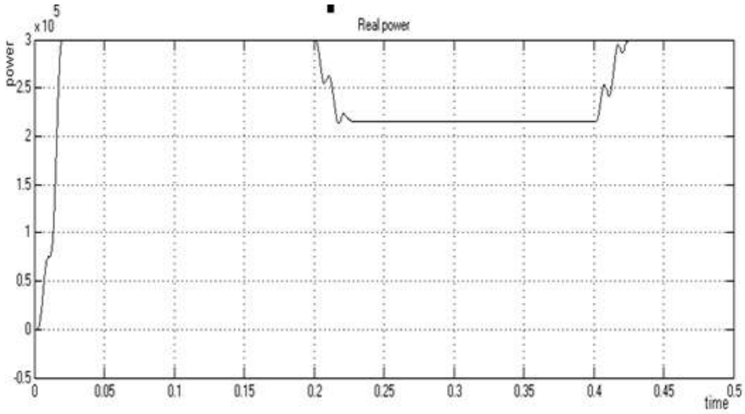


Figure 7. Real Power without controller

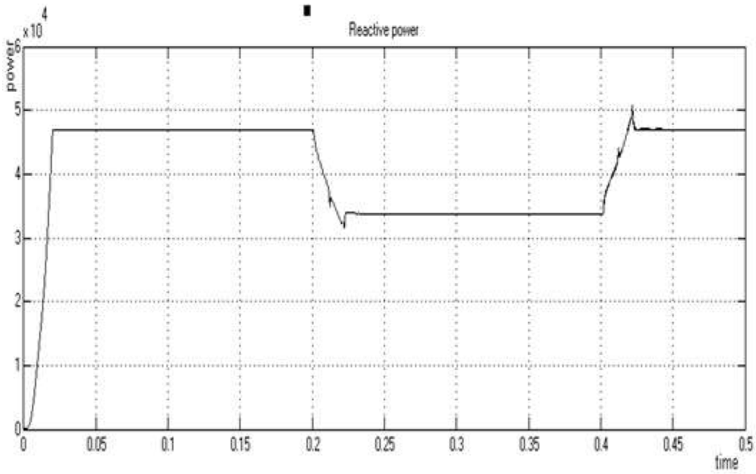


Figure 8. Reactive Power without controller

Figure 7 and 8 represents real and reactive power of grid connected system without controller.

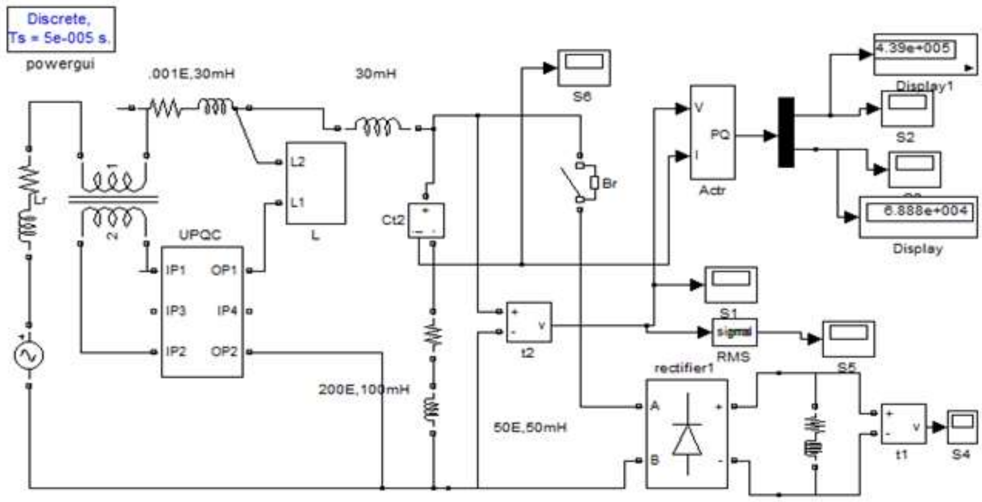


Figure 9. Simulation with UPQC controller

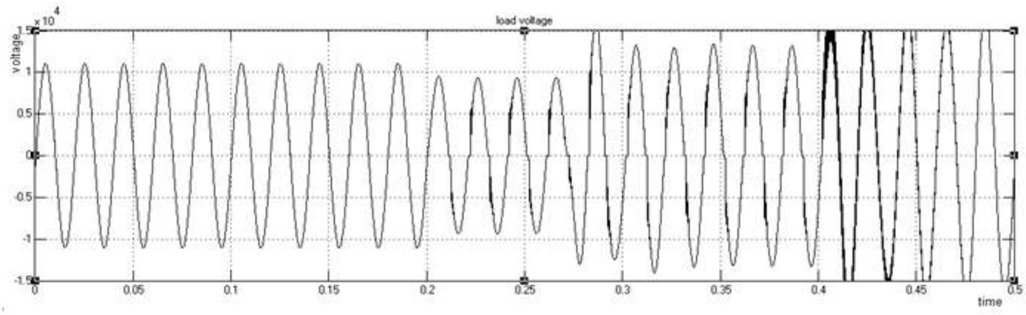


Figure 10. Load voltage with controller

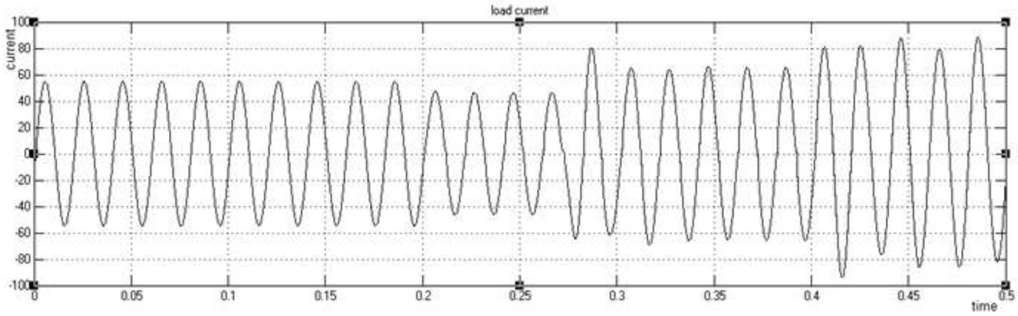


Figure 11. Load current with controller

Figure 9 represents the simulation diagram grid connected system with controller and their corresponding load voltage and current waveform variations are also mentioned in Figure 10 and 11. In the load current and voltage waveforms with controller the THD is reduced to 50 %.

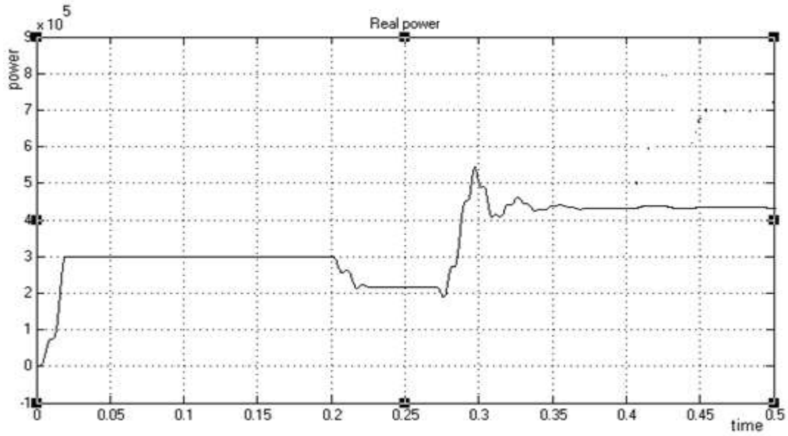


Figure 12. Real Power with controller

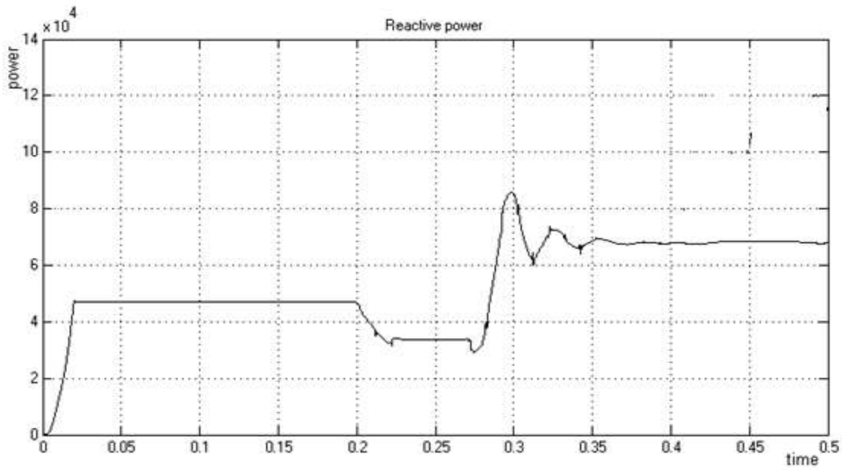


Figure 13. Reactive Power with controller

Figure 12 and 13 represents real and reactive power of grid connected system with controller.

Table 1 represents the measurements of THD for with and without controller. From the table, it is inferred that 50% of reduction in THD occurred by using the UPQC controller.

Table 1. Measurements of total harmonic distortion (THD) for Grid connected System.

Parameter	Without UPQC Controller	With UPQC Controller
THD value	9.72%	4.9%

Conclusion

In this study, a Unified Power Quality Conditioner (UPQC) has been controlled using a model-based approach. The suggested loop shape also offers a practical way to keep the supply voltage from fluctuating at a high frequency while yet maintaining adequate control performance. The study's findings indicate a methodical approach to the control design of the Unified Power Quality Conditioner (UPQC), offering a comprehensive answer to a number of power quality issues like load demand variations, voltage sag and swell compensation, power correction in a microgrid system. It is concluded that this paper has demonstrated a systematic approach to the control design of UPQC, providing an overall solution to a variety of power quality problems encountered in a power distribution system. The Power Quality issues can be minimized by other advanced methods, and we can obtain a better solution, which gives improved voltages and reduction of harmonics within a fraction of seconds.

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