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Mitigating Power Quality Issues: A Study On Statcom And Upqc With Enhanced Control Methods

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Abstract: In both commercial and industrial settings, power systems incorporate a diverse array of electrical, electronic, and power electronic equipment. The quality of electrical power in such systems can be significantly impacted by various factors, including harmonic distortion stemming from non-linear loads like thyristor power converters and rectifiers. Additionally, issues like voltage and current flickering due to equipment such as arc furnaces, as well as voltage sag and swell caused by switching loads, can adversely affect the reliable supply of power to sensitive loads. To address these challenges, the Unified Power Quality Conditioner (UPQC) emerges as a custom power device. It comprises shunt and series converters connected in a back-to-back configuration on the DC side, effectively addressing load current and supply-voltage imperfections. The performance of a UPQC system critically hinges on the accuracy and rapidity with which reference signals are derived. In this paper, we present a designed UPQC model featuring a DC link for shunt and series compensation. This design offers the advantage of reducing the likelihood of simultaneous converter malfunction. To optimize UPQC operation, distinct control strategies are developed for the shunt and series converters. The shunt compensation and series compensation within the UPQC model are each realized through the implementation of distinct control methods. Specifically, we employ a Proportional-Integral (PI) controller for shunt compensation, while a hysteresis controller is utilized for series compensation. The hysteresis current control strategy is tailored to maintain harmonic levels below 5 percent, thereby ensuring improved power quality and the reliable operation of sensitive equipment in commercial and industrial settings.

Keywords: STATCOM, UPQC, Hysteresis Controller, PI Controller.

1. Introduction

The global demand for electrical energy has surged dramatically in recent decades, driven by technological advancements, urbanization, and industrial growth. This escalating demand has placed an unprecedented burden on power distribution systems, prompting a need for higher reliability, efficiency, and power quality [1]. In both commercial and industrial applications, maintaining a stable and high-quality power supply is paramount. The quality of electrical power is a multifaceted concern, influenced by various factors such as harmonic distortion, voltage and current flickering, and sag/swell events, which can disrupt sensitive loads and impair the operation of critical equipment.

Power quality issues, including voltage fluctuations, harmonic distortions, and other irregularities, can have detrimental effects on connected loads, leading to equipment malfunction, productivity loss, and increased maintenance costs. Additionally, the proliferation of non-linear loads in modern power systems, such as large thyristor power converters and rectifiers, has exacerbated harmonic contamination issues [2]. In industries that rely on heavy machinery, like arc furnaces, voltage and current flickering caused by abrupt changes in load can further exacerbate power quality challenges. These issues underscore the critical importance of developing effective solutions to enhance power quality and mitigate the impact of disturbances on electrical systems [3].

Over the years, power electronic devices have played a pivotal role in addressing power quality concerns. Among these devices, the STATCOM (Static Synchronous Compensator) and UPQC (Unified Power Quality Conditioner) have emerged as robust and versatile solutions [4]. These custom power devices are designed to address a wide range of power quality problems, including voltage regulation, harmonic mitigation, and load balancing. Their effectiveness hinges on advanced control strategies that ensure swift and accurate response to power quality disturbances [5].

In this research paper, we delve into the application of STATCOM and UPQC in power quality improvement, focusing on the implementation of Proportional-Integral (PI) and hysteresis controllers. The STATCOM and UPQC systems, equipped with these controllers, provide dynamic and efficient solutions for maintaining the quality of power in both commercial and industrial settings [6]. This paper presents an in-depth exploration of the design, operation, and control strategies of these devices, with an emphasis on the advantages of using PI and hysteresis controllers in power quality enhancement.

This research paper endeavours to contribute to the understanding of advanced control strategies in the application of STATCOM and UPQC systems, shedding light on their potential to address power quality challenges effectively and efficiently [7]. Through this investigation, we hope to facilitate the adoption of these custom power devices in practical scenarios, ultimately leading to more stable, reliable, and high-quality power supplies for a wide range of applications.

1.1. Power Quality Challenges

A. Harmonic Distortion

Harmonic distortion is a primary concern affecting power quality. Harmonics are multiples of the fundamental frequency of the power supply and are introduced into the system by non-linear loads. Non-linear loads include devices that do not have a linear relationship between voltage and current, such as rectifiers and power converters. These devices draw current in short pulses, which leads to the distortion of the voltage waveform. Harmonic distortion can cause overheating in equipment, increased power losses, and even the malfunction of sensitive electronic devices [8].

B. Voltage and Current Flickering

Voltage and current flickering, often referred to as voltage or current fluctuations, result from rapidly changing loads, such as arc furnaces, welding machines, and large motors. These fluctuations can lead to visible and perceptible effects in lighting systems, causing discomfort to occupants and potentially damaging equipment. In extreme cases, flicker can be a safety hazard and can disrupt industrial processes [9].

C. Voltage Sag and Swell

Voltage sag, also known as a dip, and voltage swell are transient disturbances characterized by sudden drops or increases in voltage levels. Voltage sags are typically caused by short-circuits, faults, or the starting of large motors, while voltage swells can result from sudden load removal or capacitor switching. These disturbances can disrupt the operation of sensitive equipment, causing mis-operation, data loss, and reduced equipment lifespan [10].

Addressing these power quality challenges requires sophisticated solutions that can detect disturbances and respond rapidly to correct them. This is where custom power devices like STATCOM and UPQC, equipped with advanced control strategies, come into play.

1.2. Custom Power Devices: STATCOM and UPQC

A. STATCOM (Static Synchronous Compensator)

The STATCOM, or Static Synchronous Compensator, is a power electronic device that plays a crucial role in enhancing power quality by providing voltage support, regulating voltage levels, and mitigating voltage fluctuations. It is essentially a shunt-connected device that can inject or absorb reactive power as needed to maintain stable voltage conditions in the electrical grid [11].

The key component of a STATCOM is the Voltage Source Converter (VSC), which is a power electronic device capable of generating a sinusoidal voltage of variable magnitude and frequency. By adjusting the output of the VSC, the STATCOM can effectively compensate for voltage variations, harmonics, and flicker.

B. UPQC (Unified Power Quality Conditioner)

The Unified Power Quality Conditioner (UPQC) is a more comprehensive custom power device that combines the functionalities of both series and shunt compensation in a single unit. It consists of a shunt converter and a series converter, both connected back-to-back on the DC side. The shunt converter is responsible for mitigating current-related issues, such as harmonic distortion, while the series converter addresses voltage-related problems, including sag/swell and flicker [12,13].

The UPQC is designed to provide complete and coordinated control over power quality problems, making it a versatile solution for improving power quality in complex electrical systems. Its ability to handle multiple power quality issues simultaneously sets it apart from other custom power devices.

1.3. Control Strategies for Power Quality Enhancement

The performance of STATCOM and UPQC systems in power quality improvement significantly depends on the control strategies employed. These control strategies determine how accurately and swiftly the devices can respond to power quality disturbances and correct them to ensure a stable and high-quality power supply.

In this research paper, we focus on two distinct control strategies for enhancing power quality: Proportional-Integral (PI) control and hysteresis control. These strategies are applied to both the shunt and series converters within the UPQC system, allowing for comprehensive control and mitigation of power quality issues.

A. Proportional-Integral (PI) Control

The PI controller is a common and well-established control strategy used in power electronics. It is a feedback control system that continuously adjusts the output based on the error signal, which represents the difference between the desired and actual values. The PI controller comprises two main components: the proportional (P) term, which provides an immediate response to the current error, and the integral (I) term, which accumulates and corrects any long-term errors.

B. Hysteresis Control

Hysteresis control is a robust and nonlinear control strategy that is well-suited for applications where a quick response is required. It operates by continuously comparing the controlled variable to predefined upper and lower bounds (hysteresis bands). If the variable falls outside these bounds, the control action is triggered to bring it back within the bands.

In the context of power quality improvement, hysteresis control is particularly effective in managing fast-changing disturbances, such as harmonics and voltage flicker. It offers a swift response to deviations from the desired values, making it a valuable choice for maintaining power quality within acceptable limits.

1.4. Research Objectives

The primary objective of this research paper is to investigate and compare the performance of STATCOM and UPQC systems with PI and hysteresis controllers in the context of power quality improvement. We aim to achieve the following specific research goals:

1. Design and model STATCOM and UPQC systems with a focus on the implementation of PI and hysteresis controllers.

2. Evaluate the effectiveness of these control strategies in addressing common power quality challenges, including harmonic distortion, voltage flicker, and sag/swell events.

3. Compare the response times, accuracy, and robustness of PI and hysteresis controllers in mitigating power quality issues.

4. Analyze the advantages and limitations of each control strategy in different operational scenarios.

5. Provide insights into the practical implementation and real-world applicability of STATCOM and UPQC systems for power quality enhancement.

By addressing these objectives, we aim to contribute to the growing body of knowledge in the field of power quality improvement and provide valuable insights for engineers, researchers, and practitioners working in the power electronics and electrical engineering domains.

2. Control methods in UPQC System

The Unified Power Quality Conditioner (UPQC) is a comprehensive custom power device comprising three integral components: the series active power filter, the shunt active power filter, and energy storage capacitors. These components work synergistically to enhance power quality in electrical distribution systems.

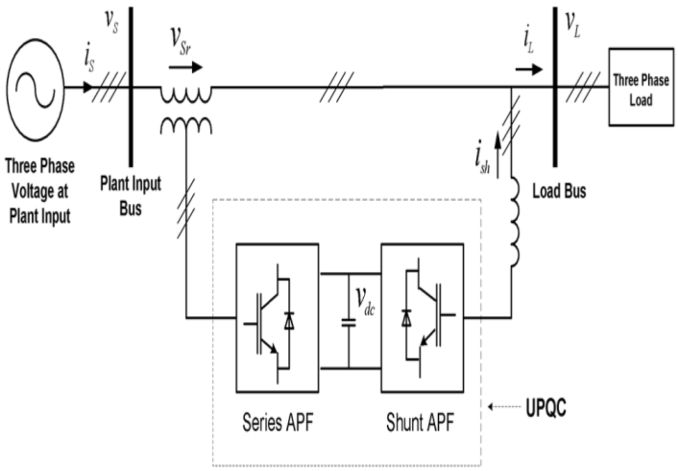

Fig 1. UPQC Circuit Diagram

The series active power filter, interconnected with the grid and the load through a coupling transformer, serves a vital role in load voltage regulation and power supply voltage sag compensation. In its controlled voltage source mode, the series active power filter ensures that the load voltage maintains the desired amplitude, thereby preventing fluctuations that can adversely affect sensitive equipment. By injecting or absorbing reactive power as needed, it effectively mitigates voltage disturbances, contributing to a stable and high-quality power supply.

On the other hand, the shunt active power filter is directly connected to the load and primarily focuses on compensating load currents. It continuously monitors the load current and counteracts any disturbances or harmonics, ensuring that the load operates smoothly and without disruptions.

The coupling of these two active power filters is facilitated by energy storage capacitors in the DC-link. These capacitors store energy and allow for seamless energy transfer between the series and shunt active power filters, enabling them to coordinate their efforts in real-time to address power quality issues.

By integrating these components, the UPQC provides a comprehensive solution for mitigating power quality challenges, including voltage sag, harmonic distortion, and current fluctuations. It offers a versatile and efficient means of maintaining a stable and high-quality power supply, safeguarding sensitive equipment, and enhancing the reliability of electrical distribution systems.

3. Control of Active Power Filter Using Pulse Width Modulation (PWM)

The primary objective of an active power filter (APF) is to generate compensatory currents within the power system to counteract the current harmonics produced by nonlinear loads. This corrective action leads to the establishment of sinusoidal line currents and a unity power factor in the input power system. As depicted in Figure 2, a three-phase active power filter is typically configured in parallel with a nonlinear load. It comprises essential components, including a power converter, a DC-link capacitor (C_2), and a filter inductor (L_2).

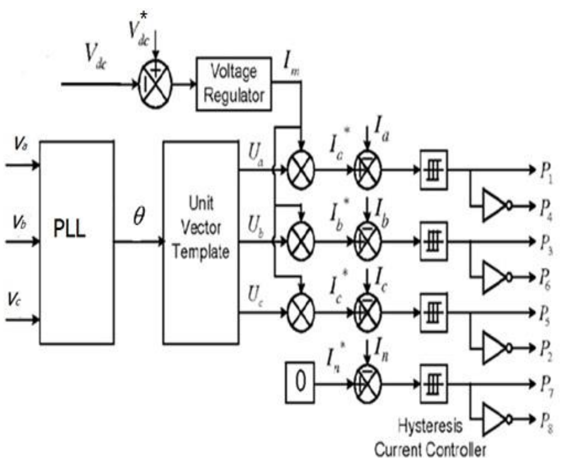

Fig 2. UPQC Shunt Controller

In essence, the active power filter counters the current harmonic components originating from nonlinear loads by producing equivalent yet opposite harmonic currents at the point where it connects with the nonlinear load. This process results in a reduction of the initial distortion and the rectification of the power factor. The inductor plays a critical role in voltage boosting when combined with the DC-link capacitor and serves as a low-pass filter for the line current of the active power filter.

4. Series Control Configuration

The algorithm put forward in this study relies on the estimation of reference supply currents. This approach shares similarities with the control algorithm used for a shunt compensator, such as the Distribution Static Synchronous Compensator (DSTATCOM), which is commonly employed to regulate terminal voltage for both linear and nonlinear loads, as described in [6]. In essence, the control algorithm proposed for the regulation of Dynamic Voltage Restorer (DVR) is graphically illustrated in Figure 3.

The basis of the algorithm's operation centres on the accurate estimation of reference supply currents. It is important to note that this methodology draws parallels with the control techniques applied in regulating terminal voltage for both linear and nonlinear loads, as evidenced in existing literature [6]. The depicted control algorithm serves as a visual representation of the approach adopted for the precise control and management of the Dynamic Voltage Restorer (DVR) system.

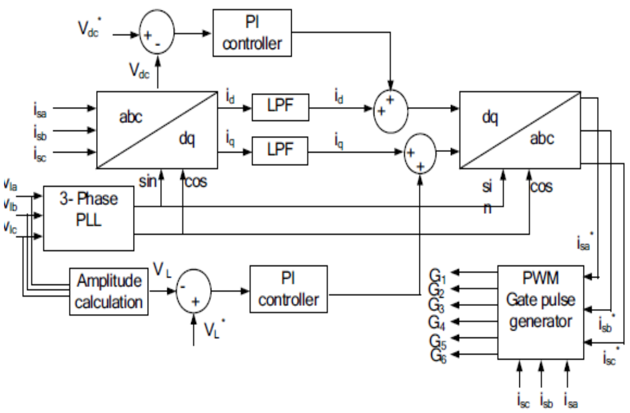

Fig 3. Dynamic Voltage Restorer Control Method

5. MATLAB Simulation for Creating a UPQC

To assess the operational effectiveness of the suggested UPQC, a 3-phase electrical system is employed. In this setup, a PI controller is utilized for reference signal generation for the UPQC. Its performance is then evaluated and compared with a controller based on hysteresis, all simulated using the MATLAB software.

The Simulink model for STATCOM and the obtained THD results are as shown in Figures 4-7.

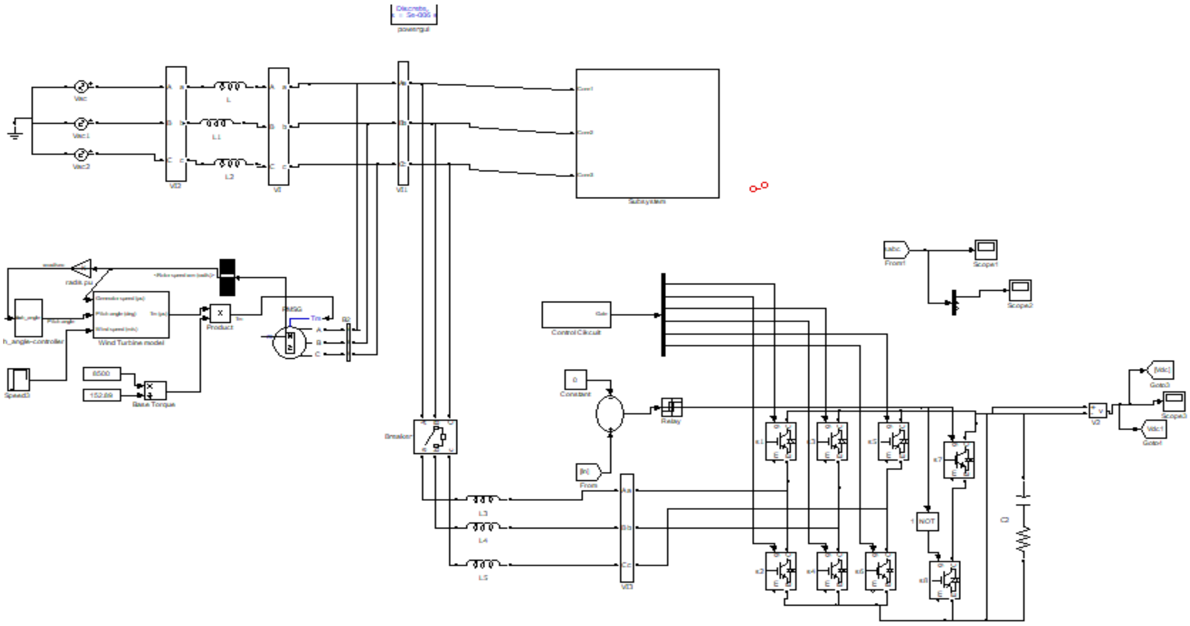

Fig 4. STATCOM Simulink model

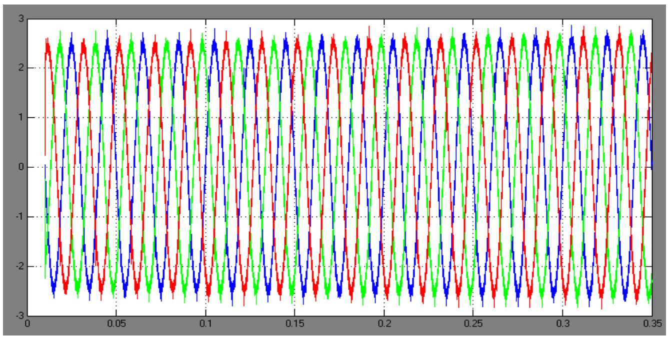

Fig 5. Regulating Source Current with a STATCOM Equipped with a PI Controller

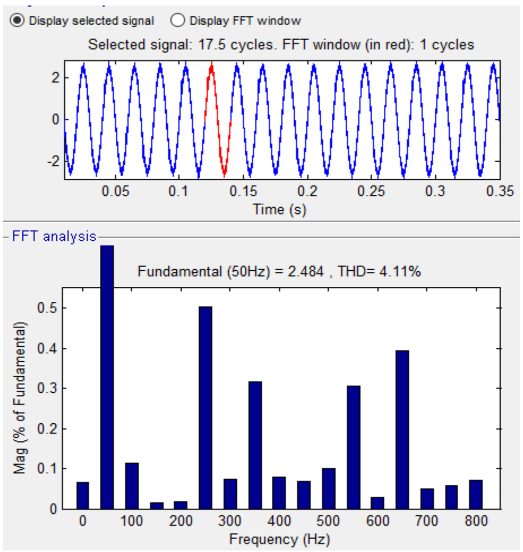

Fig 6. THD in a STATCOM System with a PI Controller

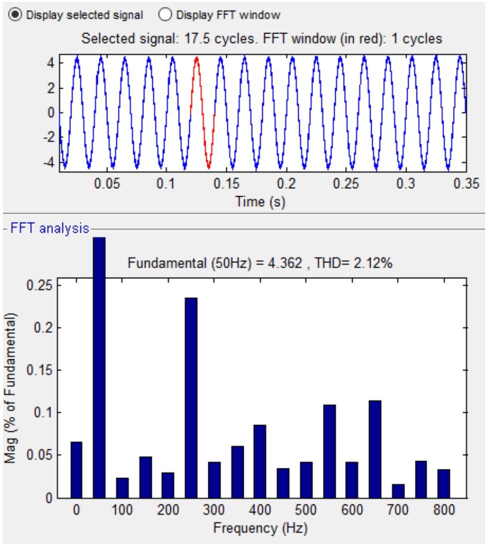

Fig 7. THD in a STATCOM System with a Hysteresis Controller

After employing UPQC using the Simulink model in Figure 8, the results obtained are illustrated in Figures 10-13.

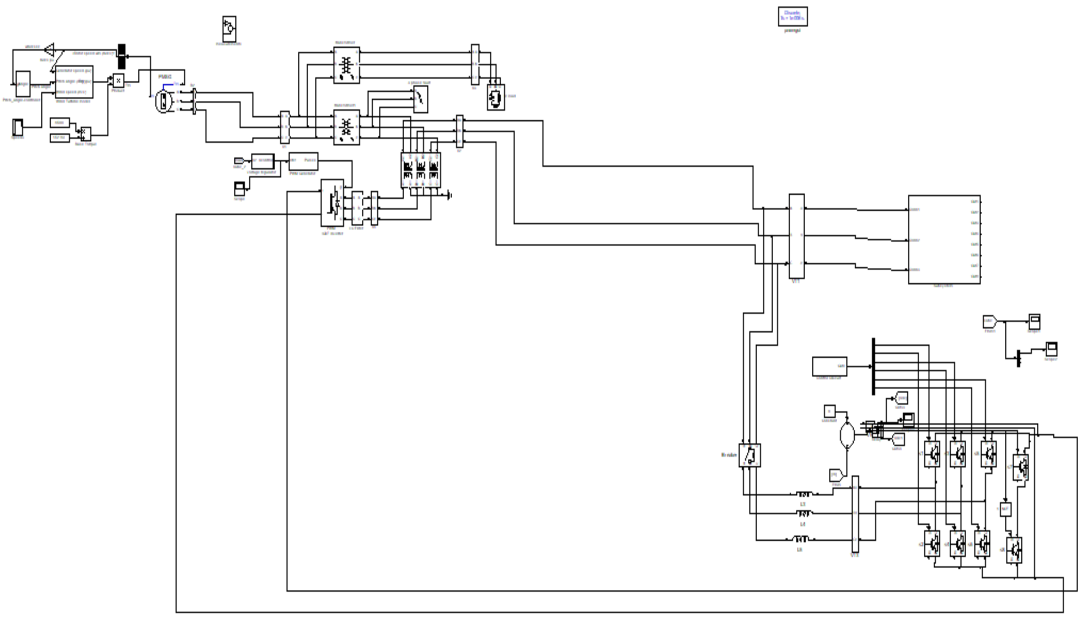

Fig 8. Simulation Model of a System Incorporating UPQC Using Simulink

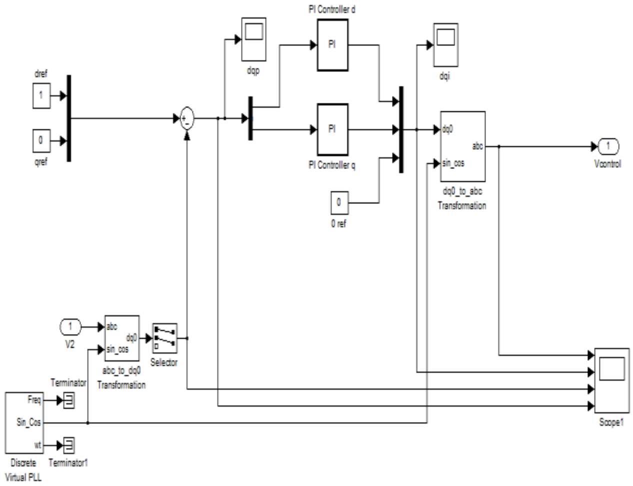

Fig 9. Series APF Control

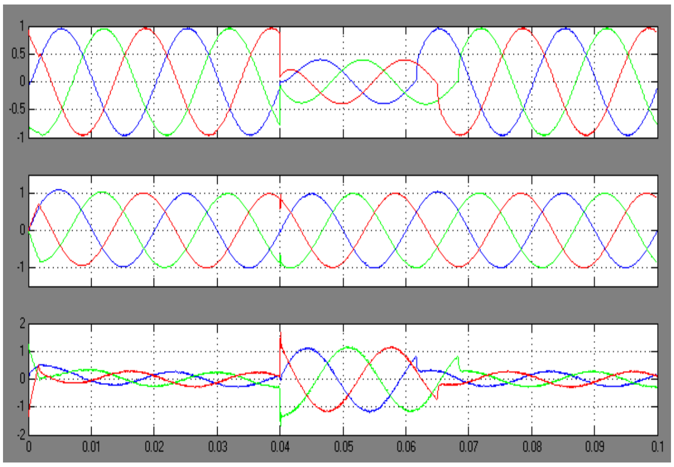

Fig 10. Compensation for a Three-Phase Voltage Fault Using a Series Active Power Filter

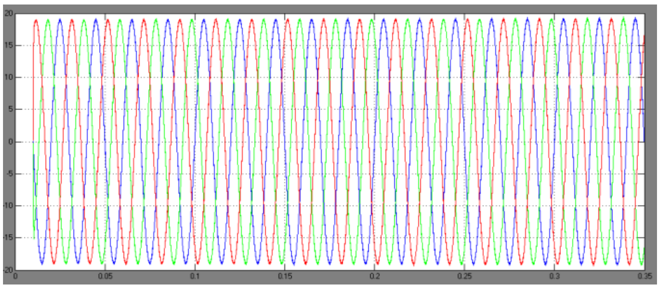

Fig 11. Regulating Source Voltage with a UPQC Employing a PI Controller

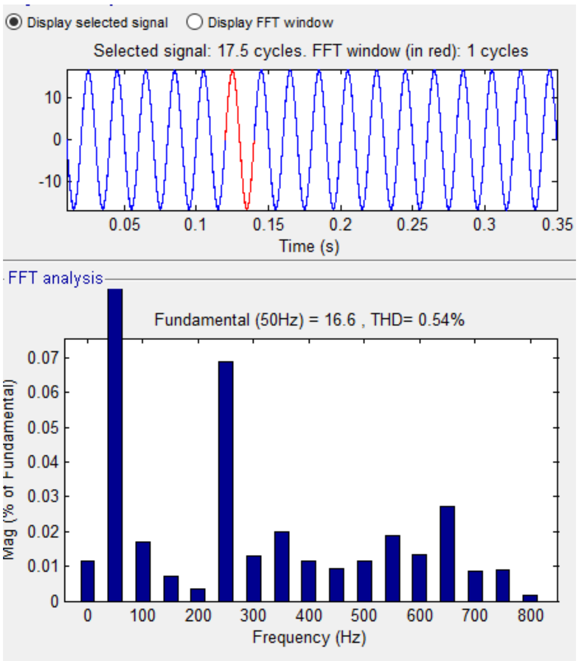

Fig 12. THD in a UPQC System with a PI Controller

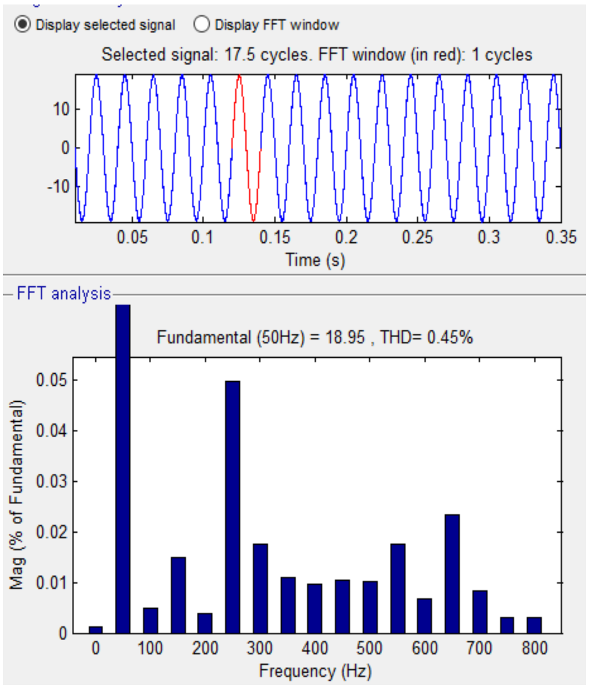

Fig 13. THD in a UPQC System with a Hysteresis Controller

The THD values obtained by implementing all the controllers are tabulated in Table 1.

Table 1: Final THD Values obtained

STATCOM using PI Controller	4.11	UPQC using PI Controller	0.54

STATCOM using Hysteresis Controller	2.12	UPQC using Hysteresis Controller	0.45

6. Conclusion

This research paper primarily focuses on investigating Power Quality issues and their mitigation through the use of a Wind-Powered Unified Power Quality Conditioner (UPQC). The outcomes derived from this study offer valuable insights into the performance of various controllers employed for enhancing power quality within distribution systems. The primary controllers utilized for power quality enhancement are the Proportional-Integral (PI) and Hysteresis-based controllers. When comparing the responses obtained, it becomes evident that the PI controller offers distinct advantages in terms of flexibility.

The paper delves into the utilization of Pulse Width Modulation (PWM) and hysteresis controllers for the reduction of harmonics in the power system. Upon a comparative analysis of these techniques, it becomes evident that hysteresis control outperforms PWM in delivering superior results in harmonic reduction.

The findings of this study contribute significantly to the understanding of power quality improvement techniques and emphasize the effectiveness of specific controllers, particularly in the context of Wind-Powered Unified Power Quality Conditioners (UPQC).

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