International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

Improvement of Power Quality using UPQC based Proportional Resonant (PR) Controller

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Abstract - The main source of energy used in today's industries is electricity. Disturbances in power quality occur due to changes in voltage and frequency. Power quality problem comes with the use of non-linear loads. Harmonic and power quality disturbances are caused by non-peak loads. If it detects a fault, harmonics are generated for a short period of time and the voltage is seen to be unbalanced. In this paper, UPQC (Unified Power Flow Controller) is introduced which is used to reduce the harmonic. For better improvement the UPQC is controlled by using the Proportional & Integral (PI) Controller and compared this proposed UPQC with the Proportional and Resonant controller (PR). UPQC is simulated using a MATLAB model with a PI controller. THD observed that the proposed UPQC is a strategy based on PI and PR controller. In this UPQC, the voltage distortion is effectively controlled, and a smooth compensated load voltage is obtained.

Keywords: Dynamic voltage restorer, Harmonics, PI controller, Power quality and Power system.

I. INTRODUCTION

Power Quality refers to the consistency of voltage and frequency within a specific range in a steady state, describing the quality of power supply in terms of voltage and current[1]. Electric power production involves three key stages: generation of electricity, transmission of electrical power, and distribution or supply of power to end-users. [2]. The Quality of the Power is disturbed due to the non-linear Loads.

Harmonics refer to changes or distortions in the frequency and voltage waveforms. In power quality issues, harmonics are a significant concern, as they can cause equipment malfunction, power failures, or improper operation due to deviations in frequency or current [3]. The widespread use of automated equipment introduces significant harmonics into shared networks due to nonlinear loads drawing non-sinusoidal currents. As the demand for improved power quality grows, electronic devices often alter voltage, time, or frequency parameters, leading to distorted current waveforms and pulses that can cause power grid failures. Effective harmonic testing and control are crucial. In power systems, harmonics disrupt both voltage and current sources. [4].

Nonlinear loads, such as transformers, laser printers, refrigerators, computers, and televisions, do not draw current proportionally to the applied voltage, resulting in a non-linear relationship between voltage and current. These loads are common in modern power systems [5]. Nonlinear loads, like heavy machinery and certain electronic devices, draw disproportionate currents, even when supplied with a constant voltage. This can create various issues in power systems, as these devices don't have a linear relationship between voltage and current [6]. Harmonic distortion disrupts power quality, particularly during faults, leading to disturbances in system frequency and voltage [7]. In this case, harmonic distortion occurs due to fluctuations or inconsistencies in the voltage supply. [8].FACTS Systems is widely used in the global distribution sectors for compensation of power, stability of voltage and energy efficiency [9], [10]. Harmonics cause damage to resistors, transmission lines, electrical equipment, and electrical short circuits [11].

Harmonics also cause unwanted disturbances in source voltage, source current etc. besides increasing the losses in the system [12]. In previous research works, two types of filters were used to reduce harmonic distortion. Active filtering and passive filtering.Active harmonic filters are electronic devices that remove unwanted harmonics in a network to add negative harmonics to the network. Dynamic filters are often seen in small electronic networks. Active filters are IGBT transistors in active modules and remove various harmonic frequencies [13] [14].

Theory indicates that 5th harmonic voltage measurements tend to increase at night due to harmonic propagation and resonance between coupling coils and shunt capacitors in the transmission network. Harmonics can be recorded and mitigated to reduce pollution in energy distribution networks. It is the responsibility of customers and end-users to ensure the current harmonics generated by their equipment stay within specified limits. [15].

MATLAB and its simulation tools can be highly valuable for monitoring and analyzing energy levels, as well as studying wave patterns and force characteristics, due to their strong computational capabilities. [16]. This study emphasizes modelling power quality issues related to voltage changes and analyzing system efficiency, with a focus on reducing harmonics in a UPQC (Unified Power Flow Controller) using PI control, and compares the results with existing research.

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2. BLOCK DIAGRAM OF THE PROPOSED WORK

In this proposed work, a UPQC-based PI controller is used to control harmonics. A three-phase voltage supply is fed to a transmission line connected to a load, where single-line, double-line, and three-line faults (including line-to-ground faults) are simulated. Fast Fourier Transform (FFT) analysis is then used to measure the Total Harmonic Distortion (THD).

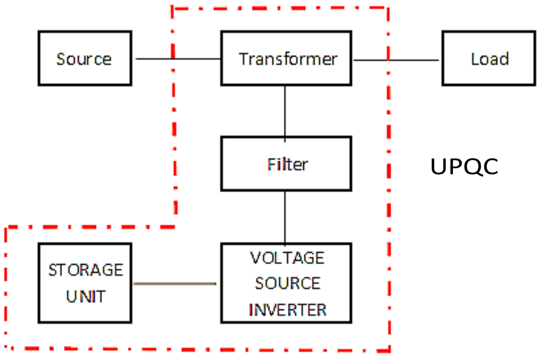

Figure 1: Block diagram of the proposed work

UPQC (Unified Power Flow Controller) is a popular method for power quality compensation, effectively addressing voltage sag and swell by injecting the required voltage to meet load demands, making it a valuable solution for modern industrial applications.

3. UNIFIED POWER FLOW CONTROLLER WITH PI CONTROLLER

The UPQC (Unified Power Flow Controller), a FACTS device, compensates for power quality disturbances like sag, swell, and harmonics on the distribution side, maintaining system stability by injecting voltage through a series transformer. During normal operation, UPQC injects voltage into the transmission line, and when disturbances occur, it calculates the required voltage using PWM technique to protect the load. A controller, particularly a closed-loop PI controller, generates pulses for the Voltage Source Inverter (VSI) switches. The UPQC absorbs or delivers active or reactive power, and during disturbances, this power exchange occurs through the DC link.

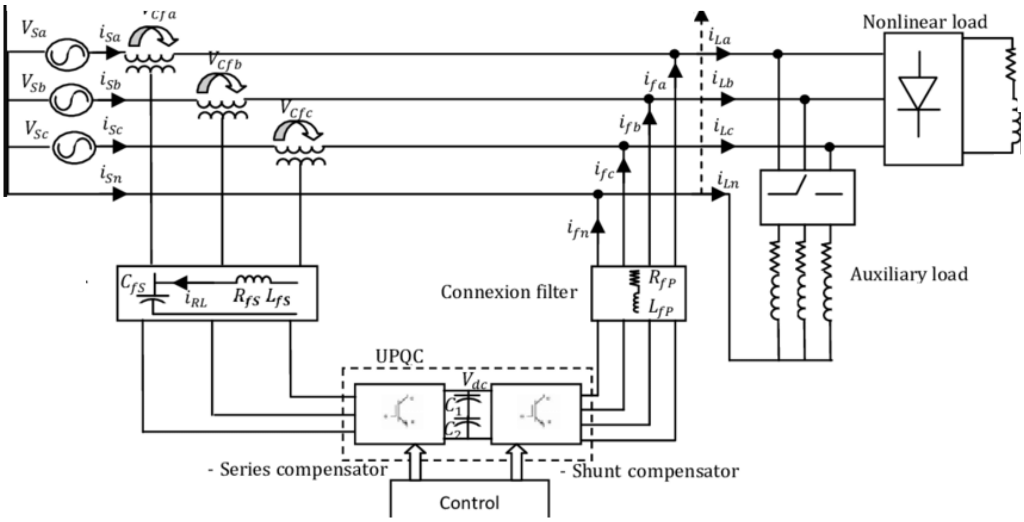

Figure 2: UPQC with PI controller

In this work, the controller is a crucial component of the UPQC, utilizing equations to transform the three-phase ABC coordinates to the dq0 coordinate system.

$$V_d = 2/3[V_a sinwt + V_b \sin\left(wt - \frac{2\pi}{3}\right) + V_c \sin\left(wt + \frac{2\pi}{3}\right) \qquad (1)$$

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$$V_q = 2/3[V_a coswt + V_b \cos\left(wt - \frac{2\pi}{3}\right) + V_c \cos\left(wt + \frac{2\pi}{3}\right) \quad (2)$$

$$V_0 = 2/3[V_a + V_b + V_c \quad (3)$$

When occur the disturbance the coordinate DQ, which is calculated by the reference value of DQ and again converter to ABC. On the other hand, PLL (Phase Locked Loop) is used for frequency measurement.

Here the PI controller input is Error. The Error is the DQ voltage reference value and actual value. The Equation is follow,

$$error_d(t) = V_{dref} - V_d \quad (4)$$

$$error_q(t) = V_{qref} - V_q \quad (5)$$

The PI controller processes the d-axis and q-axis errors, and the output in ABC coordinates is then fed to the PWM, which generates suitable pulses for the VSI's IGBT switches.

4. DISCUSSION OF RESULTS

This section presents simulation results and discusses the effectiveness of PI control for UPQC, with the process implemented and simulated using MATLAB/Simulink.

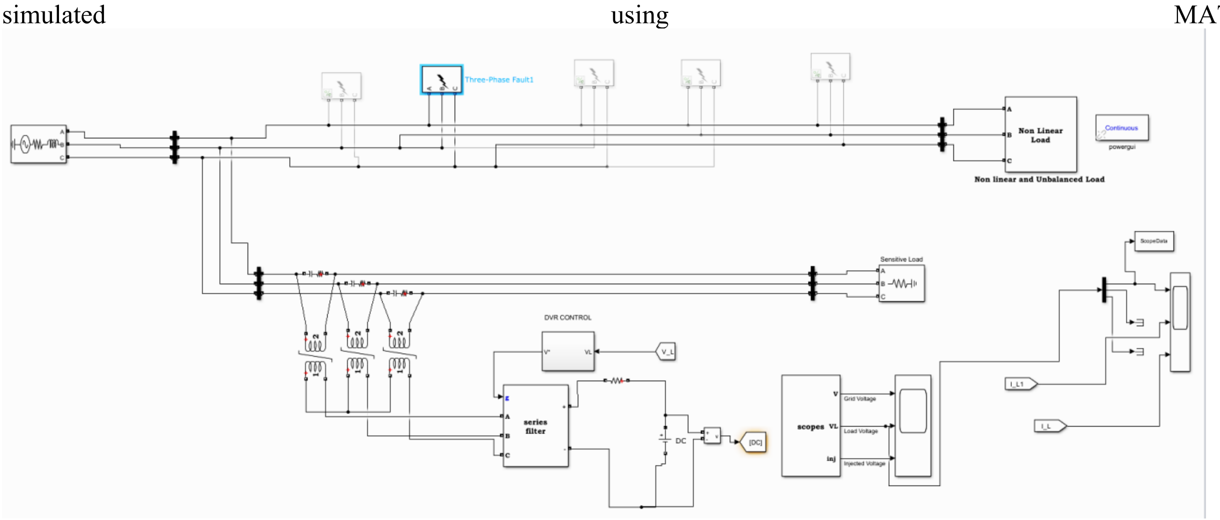

Figure3: Simulation of grid connected system using UPQC-PI controller

Figure 3 illustrates a modern grid system utilizing a UPQC, with a PI controller implemented to enhance control and performance of the device connected to the UPQC.

4.1 Control Algorithm:

This article discusses a system where the UPQC operates between 0.25 s and 0.32 s to address errors or overloads. When faults occur, such as three-phase, line-to-line, single-line-to-ground, or double-line-to-ground faults, the UPQC with PI and PR controllers compensates for the disturbances, reducing Total Harmonic Distortion (THD) by injecting voltage through a transformer.

Case 1: Three-phase fault compensation

Figure 4 illustrates the three-phase voltage during a fault occurring at 0.35 sec. Specifically, Figure 4(a) shows the grid voltage experiencing sag from 0.35 sec to 0.42 sec, while Figure 4(b) displays the load voltage during the fault period from 0.4 sec to 0.42 sec. Figure 4(c) presents the injected voltage, which shows a swell from 0.35 sec to 0.42 sec..

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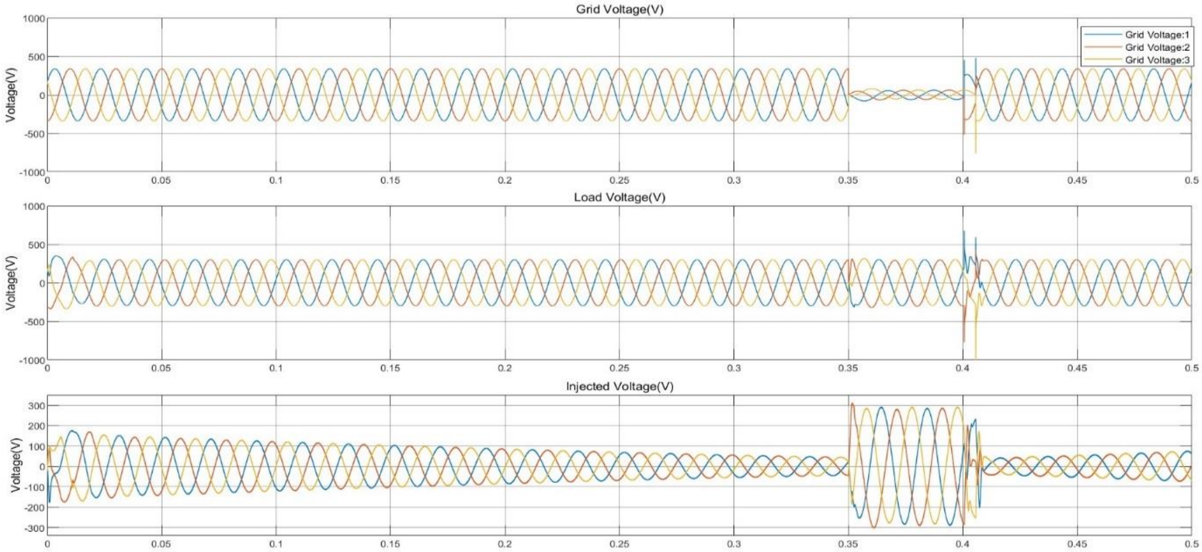

Figure 4: Three phase fault voltage sag compensation of Grid voltage, Load voltage and Injected Voltage

For three-phase fault compensation, the Total Harmonic Distortion (THD) without UPQC was 25.02% for grid voltage, 15.62% for load voltage, and 20.95% for injected voltage. With UPQC compensation using a PI controller, THD reduced to 3.82% for grid voltage, 3.79% for load voltage, and 3.45% for injected voltage. Using a PR controller, THD further decreased to 2.33% for grid voltage, 2.65% for load voltage, and 2.67% for injected voltage.

Case 2: Three-phase to Ground fault compensation

Figure 5 illustrates a three-phase-to-ground fault occurring at 0.35 sec, with grid voltage sagging from 0.35 sec to 0.42 sec (Figure 5(a)) and load voltage affected from 0.4 sec to 0.43 sec (Figure 5(b)). The injected voltage shows a swell from 0.35 sec to 0.43 sec (Figure 5(c)). Without UPQC, THD values were 4.38% for grid voltage, 4.43% for load voltage, and 4.74% for injected voltage. With UPQC compensation, PI control reduced THD to 3.89%, 4.12%, and 3.5%, respectively, while PR control further reduced THD to 2.98%, 3.05%, and 2.90%.

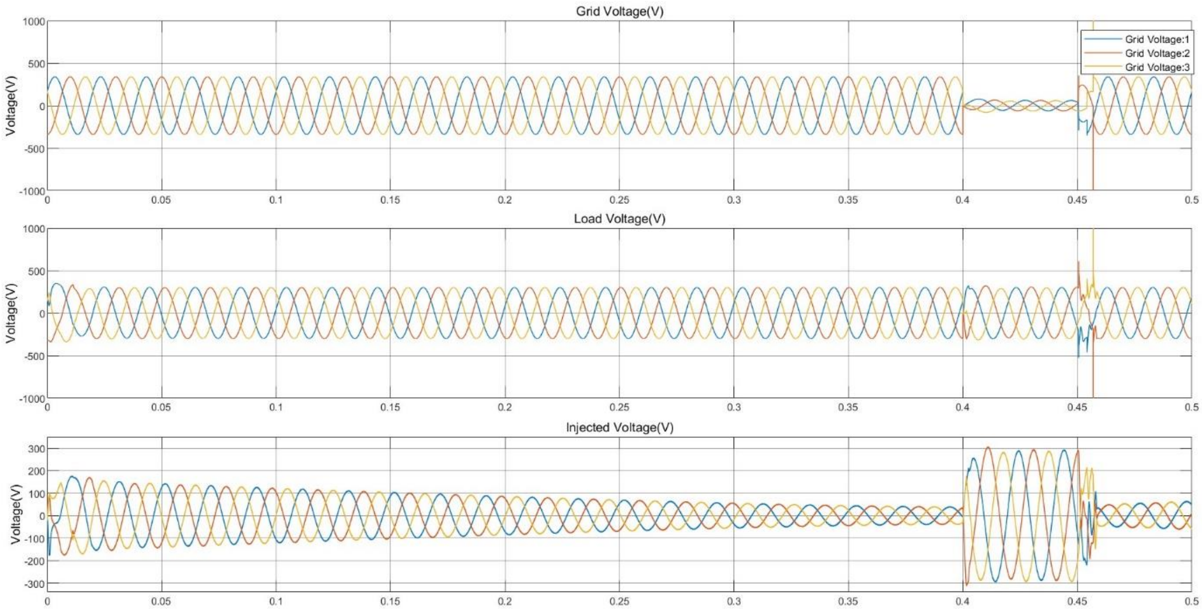

Figure 5: Three phase to ground fault voltage compensation of Grid voltage, Load voltage and Injected Voltage

Case 3: Double line fault compensation

Figure 6 depicts a double-line fault occurring at 0.35 sec. The grid voltage experiences sag from 0.25 sec to 0.32 sec (Figure 6(a)), while the load voltage is affected from 0.32 sec to 0.33 sec (Figure 6(b)). The injected voltage shows a swell from 0.25 sec to 0.32 sec (Figure 6(c)). For this fault, THD without UPQC was 18.67% for grid voltage, 20.05% for load voltage, and 4.89% for injected voltage. With UPQC compensation, PI control reduced THD to 3.9%, 3.12%, and 4.05%, respectively, while PR control reduced THD to 3.10%, 2.56%, and 2.87%.

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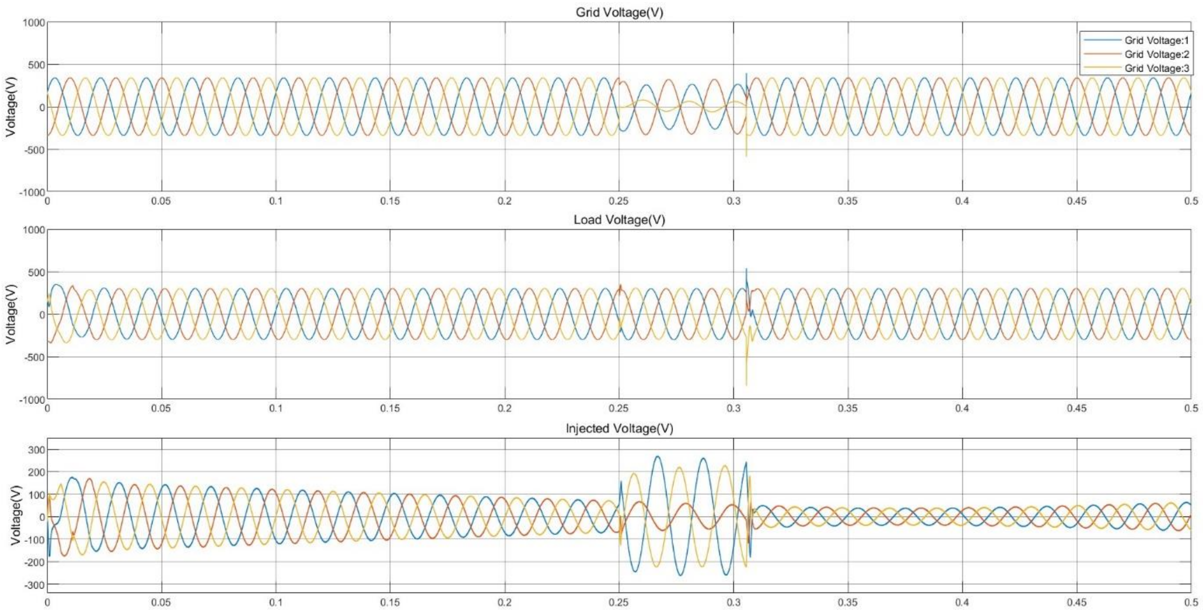

Figure 6: Double line fault voltage compensation of Grid voltage, Load voltage and Injected Voltage

Case 4: Double line to ground fault compensation

Figure 7 illustrates a double-line-to-ground fault occurring at 0.0025 sec. The grid voltage sags from 0.0025 sec to 0.13 sec (Figure 7(a)), while the load voltage is affected from 0.12 sec to 0.13 sec (Figure 7(b)). The injected voltage shows a swell from 0.005 sec to 0.12 sec (Figure 7(c)). Without UPQC, THD values were 4.38% for grid voltage, 21.4% for load voltage, and 15.66% for injected voltage. With UPQC compensation, PI control reduced THD to 3.9%, 4.12%, and 4.2%, respectively, while PR control further reduced THD to 3.05%, 2.67%, and 2.87%.

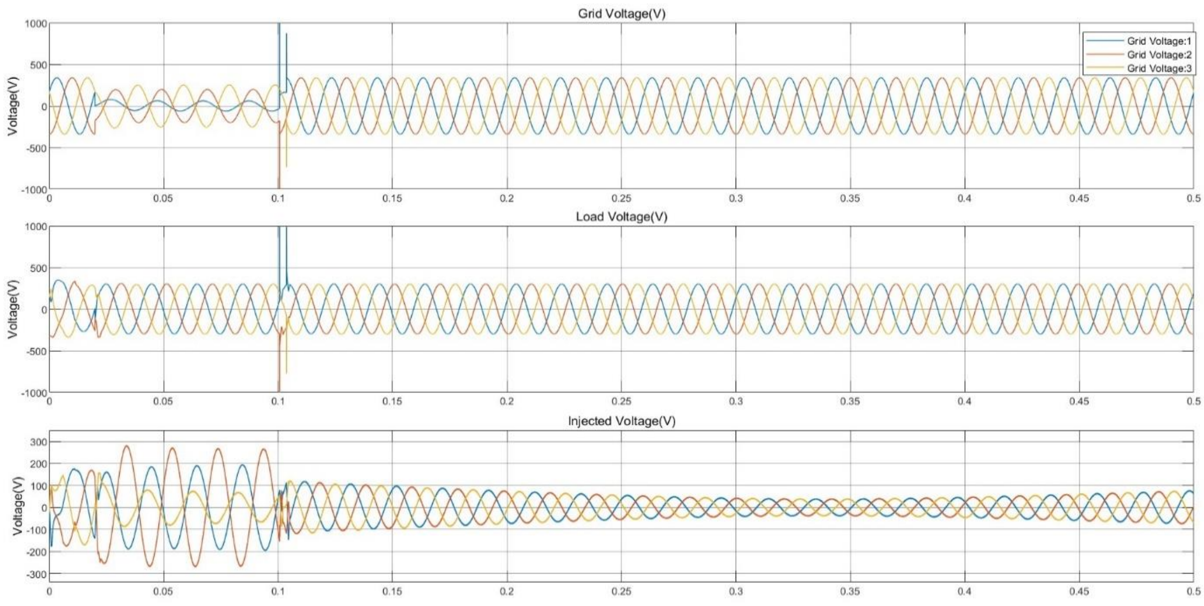

Figure 7: Double line to ground fault voltage compensation of Grid voltage, Load voltage and Injected Voltage

Case 5: Single line to ground fault compensation

Figure 8 depicts a single-phase-to-ground fault occurring at 0.35 sec. The grid voltage experiences sag from 0.14 sec to 0.21 sec (Figure 8(a)), while the load voltage is affected from 0.21 sec to 0.23 sec (Figure 8(b)). The injected voltage shows a swell from 0.14 sec to 0.22 sec (Figure 8(c)).

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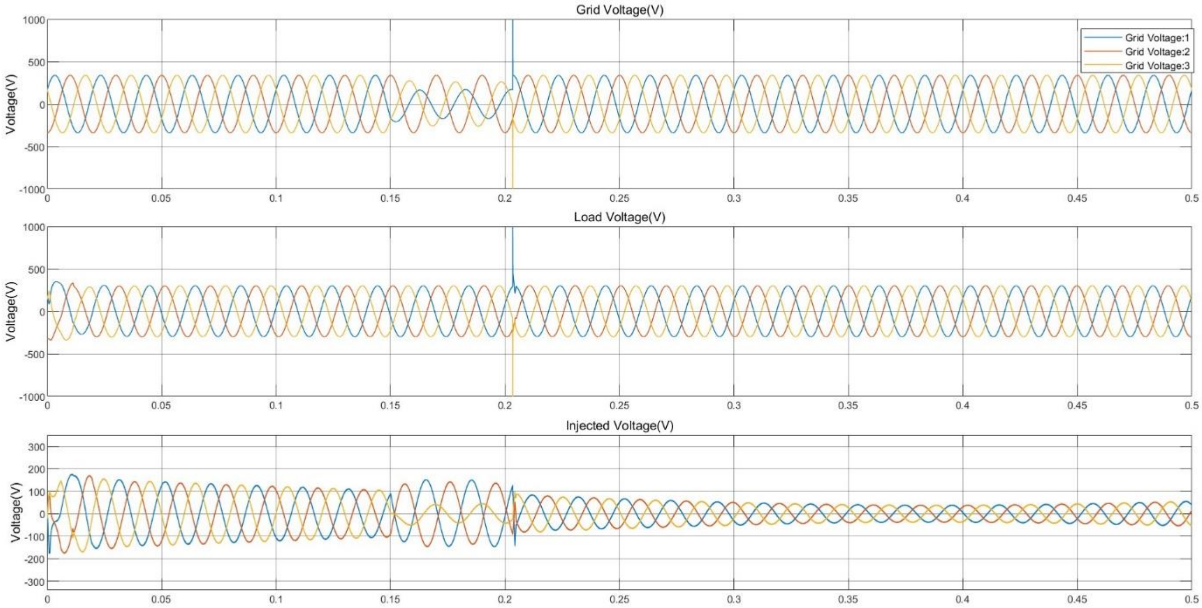

Figure 8: Single phase to ground fault voltage compensation of Grid voltage, Load voltage and Injected Voltage

For single-phase-to-ground fault compensation, the THD without UPQC was 25.02% for grid voltage, 20.61% for load voltage, and 14.62% for injected voltage. With UPQC compensation, PI control reduced THD to 3.99%, 4.12%, and 4.02%, respectively, while PR control reduced THD to 3.35%, 2.94%, and 2.99%.

4.2 Total Harmonic Distortion

The THD values calculated from the grid-side voltage graphs are listed in Table 1, comparing results without UPQC and with UPQC using PI and PR controllers. The results show that the PR controller achieves better THD performance than the PI controller.

Table 1: Before and After UPQC compensation

TYPE OF FAULT	Before UPQC THD(%)	After Compensation THD (%)	
		PI	PR
L-G FAULT	25.02	3.99	3.35
	20.61	4.12	2.94
	14.62	4.02	2.99
LL-G FAULT	4.38	3.9	3.05
	21.4	4.12	2.67
	15.66	4.2	2.87
LLL-G FAULT	4.38	3.89	2.98
	4.43	4.12	3.05
	4.74	3.5	2.90
LL FAULT	18.67	3.9	3.10
	20.05	3.12	2.56
	4.89	4.05	2.87
LLL FAULT	25.02	3.82	2.33
	15.62	3.79	2.65
	20.95	3.45	2.67

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Table 1 presents THD values for grid voltage, load voltage, and injected voltage without UPQC. Figure 9 displays the load voltage THD using an FFT analyzer. With UPQC installation, THD values using PI and PR controllers are also shown in Table 1. Additionally, Figures 10 and 11 illustrate three-phase-to-ground fault and three-phase fault scenarios, respectively.

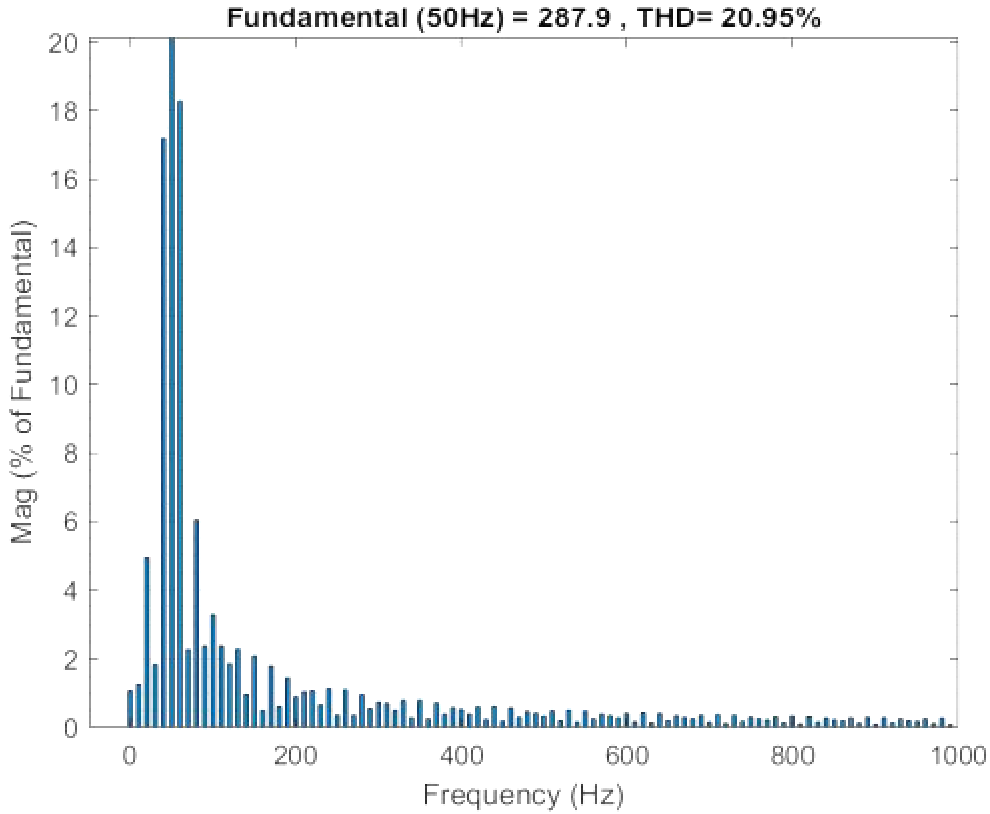

Figure 9: Without UPQC compensation –THD measurement using FFT analyser

After UPQC – LLL-G fault

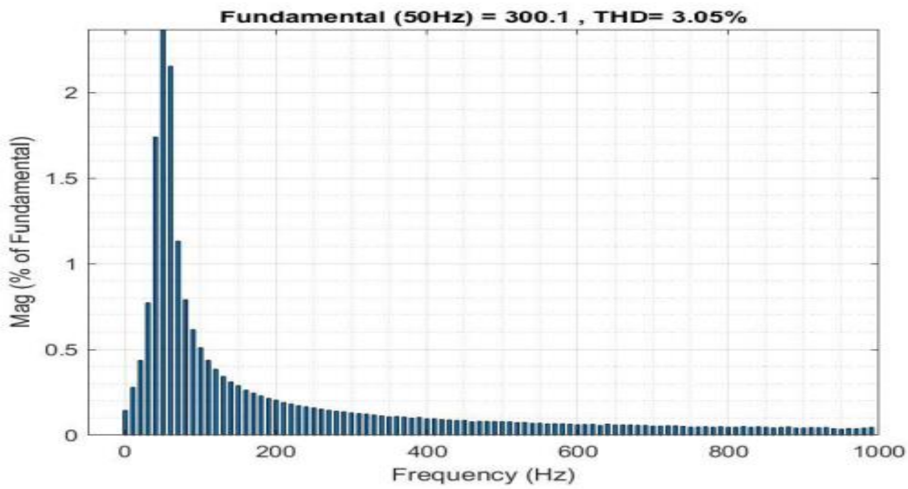

Figure 10: With UPQC compensation –Three phase to Ground fault THD measurement using FFT analyser

After UPQC – LLL fault

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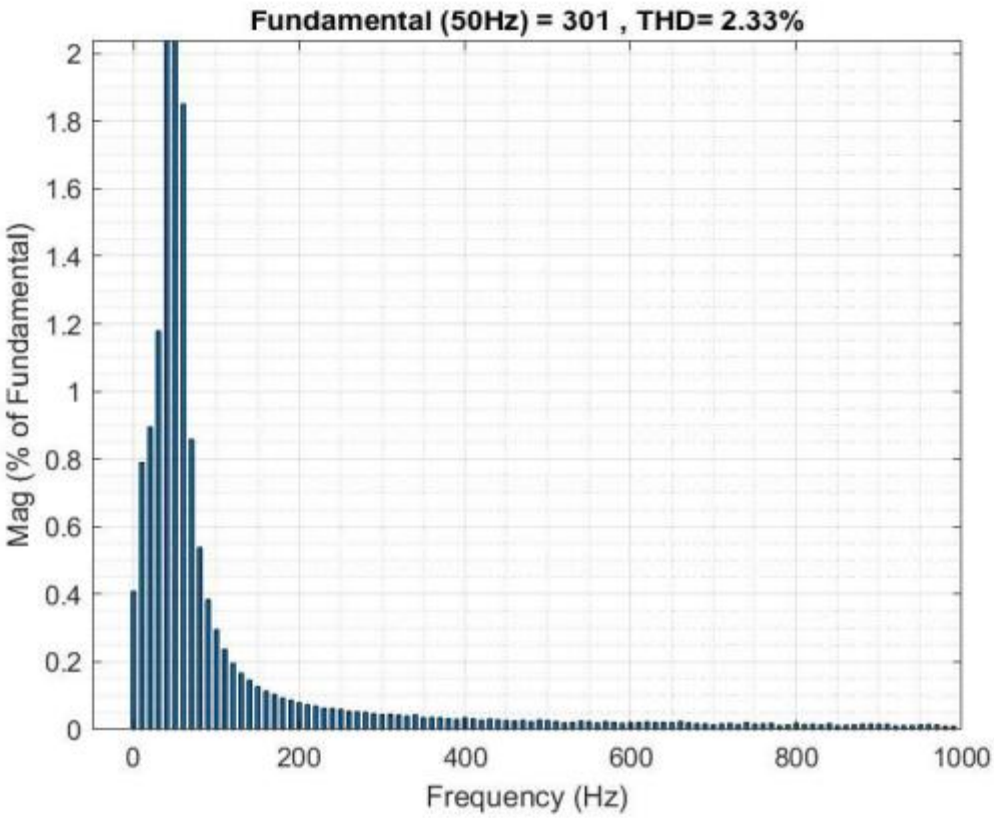

Figure 11: With UPQC compensation –Three phase fault THD measurement using FFT analyser

The FFT analysis shows that UPQC effectively mitigates three-phase faults, with PI and PR controllers reducing harmonics. Comparing the two, the PR controller achieves lower THD values (2.33% for grid voltage, 2.65% for load voltage, and 2.67% for injected voltage) than the PI controller (3.82% for grid voltage, 3.79% for load voltage, and 3.45% for injected voltage), demonstrating better performance. Figure 12 illustrates the THD waveform comparison between PI and PR controllers.

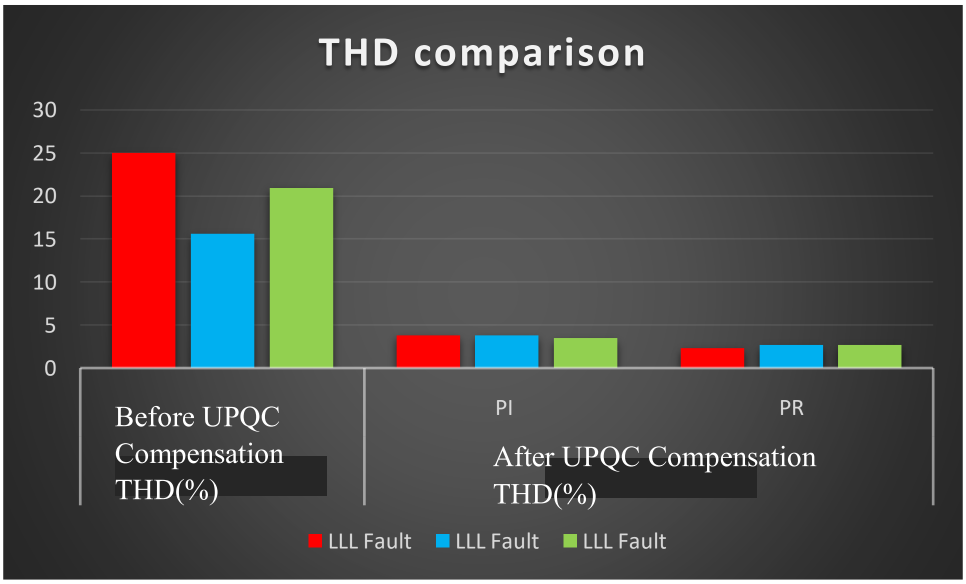

Figure 12: THD comparison

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Figure 12 compares THD values with and without UPQC compensation, showing that UPQC with a PR controller outperforms UPQC with a PI controller in reducing harmonics.

6. Conclusion

This paper presents a UPQC (Unified Power Flow Controller) with a Proportional Resonant (PR) controller to improve power quality and reduce Total Harmonic Distortion (THD). The UPQC enhances system performance during faults, and the PR controller outperforms the PI controller, achieving a lower THD of 2.65% compared to 3.79% for the PI controller.

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