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Comparative Analysis of Conventional PI and Fast Fuzzy Logic Controllers for Unbalanced Load Recovery using a Unified Power Quality Condition UPQC

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ABSTRACT

This paper proposes a novel control strategy for a Unified Power Quality Conditioner (UPQC) to effectively mitigate voltage and current disturbances in three-phase four-wire (3P-4W) systems. Existing UPQC control approaches often struggle to address unbalanced load conditions, resulting in significant power quality degradation. This research addresses this gap by introducing a fast fuzzy logic (FFZ) controller, which, in comparison to traditional PI controllers, offers enhanced performance in managing DC voltage fluctuations and generating accurate reference currents for the shunt active filter. The proposed FFZ controller effectively minimizes the impact of unbalanced loads on DC voltage, reducing error and improving overall system performance. Simulation results using MATLAB validate the effectiveness of the FFZ controller in reducing total harmonic distortion (THD) and improving transient response, demonstrating its superiority over traditional PI control for unbalanced load scenarios.

Keywords: FFZ, Unbalanced load, Three phase four wire.

1. INTRODUCTION

The increasing use of nonlinear loads and renewable energy sources in distributed power generation has significantly raised pollution levels within distribution systems **(Dash and Ray, 2018; Goud and Rao, 2021; Dheeban et al., 2021)**. Maintaining high power quality (PQ) is crucial for ensuring reliable and efficient electrical power systems. However, the proliferation of nonlinear and unbalanced loads on distribution grids presents a considerable challenge to achieving this goal. Various devices, including arc welding machinery, current regulators, switch-mode power supplies, low-wattage lights, as well as faults and switching activities, contribute to poor PQ **(Hossain et al., 2018)**. These kinds of loads introduce various disturbances, such as voltage sags, swells, harmonics, and unbalance, which can negatively impact the performance and longevity of sensitive equipment **(Aredes et al., 1998; Ghosh and Ledwich, 2001)**. One of the most influential settlements to PQ problems in the distribution quarter is the installation of UPQC, the

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function of UPQC is to mitigate the trouble that affects the performance of the critical load **(Han et al., 2005; Basu et al., 2007; Khadkikar and Chandra, 2009; Fatiha et al., 2011; Muneer et al., 2017)**. Nonlinear loads act as both causes and consequences of PQ concerns. The widespread use of power electronics in modern appliances and industrial equipment generates harmonics that can lead to increased heating in electrical systems and reduced efficiency **(Mohammed et al., 2012; Dass and Fathima, 2021)**. The effectiveness of UPQC relies on the rapid and precise compensation of the derived signals. PI control techniques are straightforward and efficient, Fuzzy controllers offer advantages in managing dynamic interactions between active and reactive power, both PI and fuzzy controllers have been widely investigated in the literature.**(Kesler and Özdemir, 2009)** employed UPQC to eliminate harmonics in both current and voltage, thereby enhancing power quality through experimental methods and PSIM software. **(Suja and Raglend, 2013)** conducted simulations using Matlab Simulink to validate their controller's effectiveness in addressing these PQ issues. This research contributes to better management of electrical systems, ensuring stability and efficiency. **(Ghanizadeh and Ebadian, 2015)** developed a novel control approach for a three-phase four-wire UPQC to address PQ challenges under distorted and unbalanced load conditions, with results optioned via Matlab Simulink. **(Bhavani et al., 2015)** focused on mitigating voltage dips and harmonics, which are common power quality issues that can disrupt electrical systems and affect equipment performance. The effectiveness of this method was assessed through simulations, comparing its performance a giant a traditional PI controller.

(Reddy and Kumar, 2017) aimed to enhance power quality in three-phase network dealing with nonlinear loads. Used UPQC to address matters like harmonic distortion, voltage fluctuations and dips, and load imbalances utilizing Matlab Simulink. **(Vanapalli et al., 2017)** proposed an enhanced UPQC control using fuzzy logic and an artificial neural network controller to improve power quality by eliminating current harmonic and compensating for voltage by using Matlab Simulink. (Kumar and Ramachandran, 2018) They analyzed a digital Kalman filter to control a UPQC, resolving its execution through simulation and experiments. The Kalman filter precisely controls the voltage and current at the load aspect. The control strategy is designed to work in a system with PQ problem. **(Krishna et al., 2019)** introduced a new control strategy aimed at addressing PQ issues like current disfiguration, voltage sags, swells, and THD in nonlinear loads. Utilizing a UPQC setup with partial order fuzzy logic, with the implementation carried out using MATLAB. **(Das and Adhikari, 2020)** presented enhanced control strategies employing fuzzy logic to detect the faults in a UPQC constructed for a three delivery lines, which is designed to lessen various PQ troubles like voltage sags and harmonics. The proposed method was tested by using Matlab Simulink, with faults examined at different locations along the line, demonstrating its effectiveness in improving power quality and system reliability. **(Sai Sarita et al., 2023)** presented a new control UPQC pattern to measure up both voltage and current disturbances, it controls unbalanced and distorted weak grid cases. As a result, the suggested dynamic control approach provides a good stable state and dynamic reaction; the proposed approach was tested using Matlab Simulink. **(Belahcene et al., 2024)** implemented a hybrid control strategy, integrating a FLC with a PI controller to enhance the overall performance of the UPQC. This access impacts the strengths of both control techniques, enabling adaptive and robust control of the system. This paper proposes a fast fuzzy logic controller FFZ as a solution to address unbalanced loads in case of different faults in power systems. The proposed FFZ replaces traditional PI controllers and isolates unbalanced signals from the sources, aiming to demonstrate the potential for improved system stability and power quality PQ. The paper emphasizes the benefits of the FFZ, highlighting its ability to effectively manage uncertainty and nonlinearity. This way results in reducing total harmonic distortion (THD) and overshoot, ultimately leading to a more potent and functional power system operation.

2. THE CONTROLLER OF UPQC

The UPQC controller is a specialized power instrument created to reduce PQ disturbances on both the supply and load sides. The schematic diagram of UPQC in a three-phase four-wire configuration, illustrated in **Fig. 1** consists of combined active power filters APF, which include both series and shunt components joined to a mutually connected DC link capacitor. The capacitor decisive role in the system operation by maintaining voltage levels and improving PQ. Also act as energy storage elements, providing reactive power support when needed and enhancing the dynamic response of the method to alter in load or disturbances. **(Axente et al., 2011; Karelia et al., 2019; Amini and Jalilian, 2020)**. The shunt inverter belonging to the UPQC operates in the current control scheme. In addition, maintaining the shunt converter is controlled in the current control scheme. Regulating the shunt converter ensures that the current delivered matches the set reference value as dictated by the UPQC control algorithm, also ensuring the DC bus voltage is at a specified set point **(Hossam-Eldin et al., 2018; Sarita et al., 2020)**.

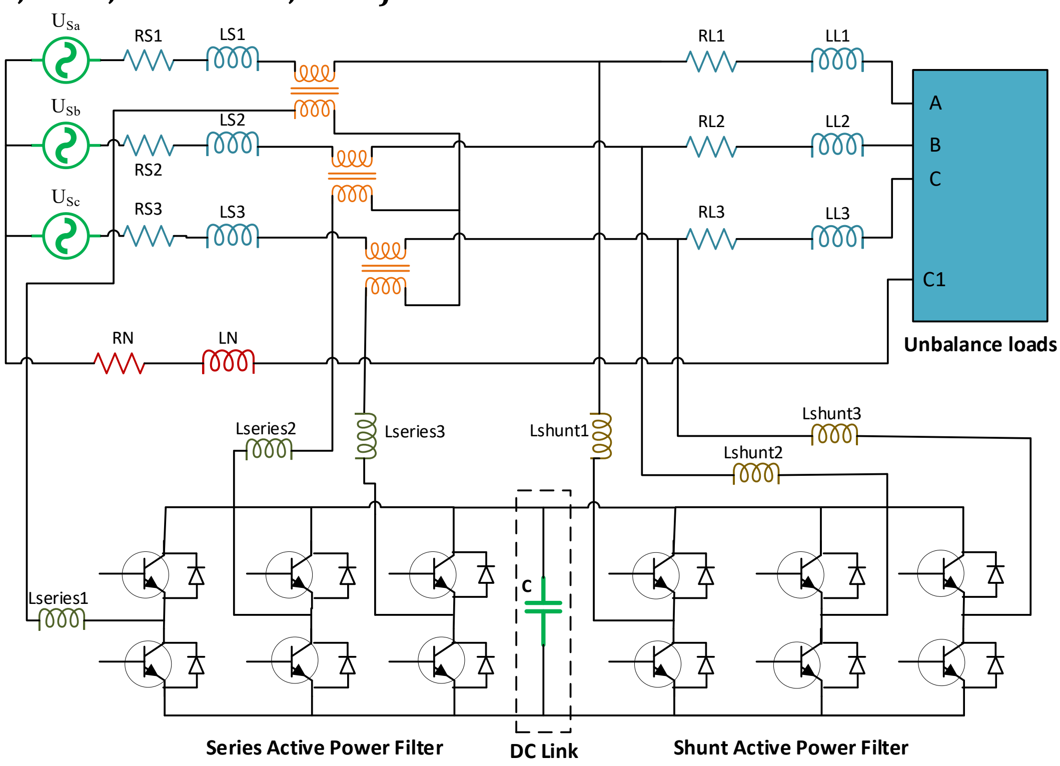

Figure 1. Proposed Model 3P- 4W using UPQC.

A series active filter is installed in line with a load via an injection transformer, which has a specific turn ratio. The transformer's primary side is wired in a star pattern, and the secondary windings are joined in series with a three-phase power source. The UPQC is designed to effectively manages the load ,which comprises both unbalanced elements, and nonlinear components **(Mohammed et al., 2016)** .

3. MODELING AND CONTROL

3.1 Shunt Active Filter Control

The shunt active filter primarily deals with PQ issues on the consumer's portion. Shunt active filters are essential for improving power quality by addressing both harmonic and reactive current issues. Effectively eliminate harmonic currents produced by the load, ensuring a cleaner power supply. The DC link capacitor voltage enhancing system efficiency. By recompensing for reactive currents, shunt active filters contribute to better power factor, optimizing power utilization. **Fig. 2** depicts the arrangement of the shunt compensation for disturbances. A PLL circuit is employed to drive the phase shift and oscillation frequency information from the source voltage. This data facilitates the conversion of the load currents between the a-b-c and d-q-0 domains. **(Patel et al., 2018; Yadav et al., 2020; Anitha and Jeyadevi, 2020)**, and an essential indication for the modification is produced using a three-phase PLL. The system contains harmonic components resulting from nonlinear loads, and when the load is unbalanced, there will be a neutral current $I_{neutral}$ along the neutral line. To reduce this current, it is necessary to calculate zero power. All zero-sequence power needs to be provided by the shunt active power filter.

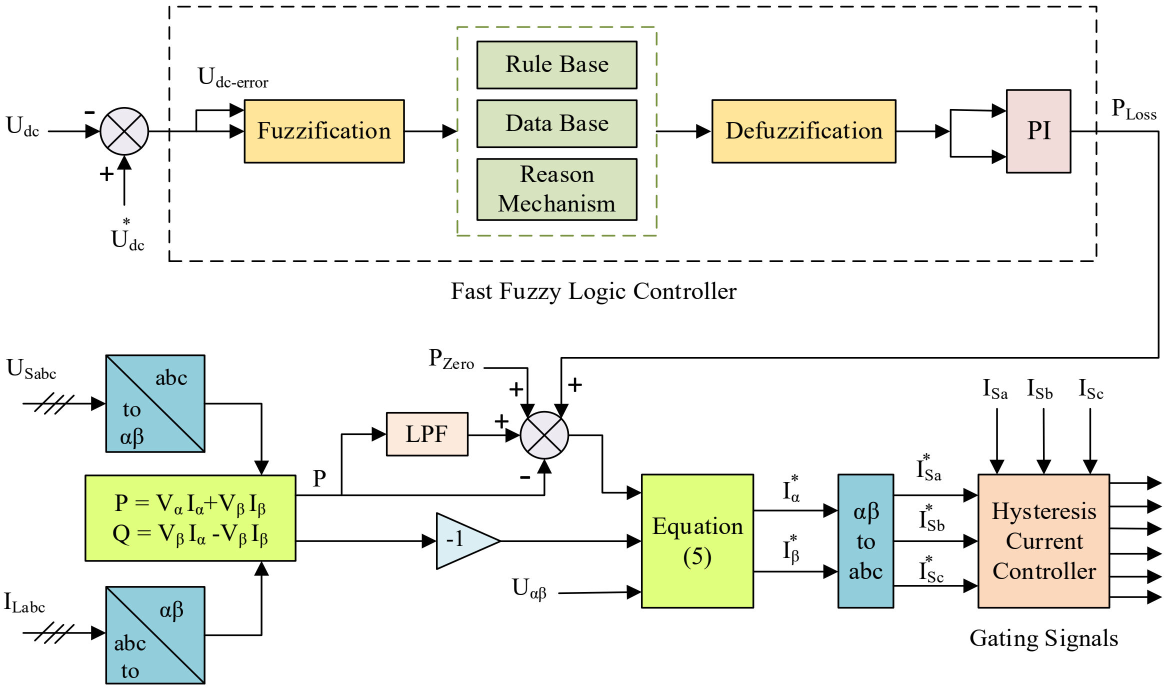

Figure 2. Schematic representation of shunt active power filter utilizing the proposed controller

This is accomplished by employing the DC and AC parts of both real and imaginary power, as indicated in the equations below **(Amirullah et al., 2020):**

$$P_{zero} = V_{zero} \times I_{zero} \quad (1)$$

$$P = P_{DC}^{-} + P_{AC}^{\sim} \; ; \; Q = Q_{DC}^{-} + Q_{AC}^{\sim} \quad (2)$$

$$P = U_{S\alpha} \times I_{L\alpha} + U_{S\beta} \times I_{L\beta} \quad (3)$$

$$Q = U_{S\beta} \times I_{L\alpha} - U_{S\alpha} \times I_{L\beta} \quad (4)$$

$$\begin{bmatrix} I_{\alpha}^{*} \\ I_{\beta}^{*} \end{bmatrix} = \frac{1}{U_{\alpha}^{2}+U_{\beta}^{2}} \begin{bmatrix} U_{\alpha} & U_{\beta} \\ U_{\beta} & -U_{\alpha} \end{bmatrix} \begin{bmatrix} -P^{\sim} + P_{Zero} + P_{Loss} \\ -Q \end{bmatrix} \quad (5)$$

Eq. (3) and Eq. (4) detail the calculations for actual power (P) and imaginary power (Q), which are determined in instantaneous power within the $\alpha - \beta$ axes. Where P_{DC}^{-} represents the average portion of actual power, while $P_{AC}^{\sim}$ representes the oscillating portion of actual power. Similarly, Q_{DC}^{-} is the average section of imginary power, and $Q_{AC}^{\sim}$ is the unsteady section of reactive power. The total imaginary power and oscillating portion of true power are chosen as the power and current references, excuted through utilized through Eq. (2) The DC elements of P_{DC}^{-} and Q_{DC}^{-} are based on the positive sequence part of load current. The AC elements of $P_{AC}^{\sim}$ and $Q_{AC}^{\sim}$ incorporate harmonics and negative sequence of load current. In the shunt APF, the reference currents for the three-phase system are determined to offset the neutral current, harmonic load current, and reactive current in the load. The switching instructions for controlling the shunt active power filter are produced by evaluating the guiding current and the real line currents.

3.2 FFZ Control

The fuzzy regulator's control algorithm is realized by replacing the standard, PI controller via a fuzzy controller. In this setup, the optimal fuzzy gain value is determined through a fuzzy inference system that considers the incline of the DC average bus voltage and the DC voltage error as its input to the controller. The DC voltage error, denoted as P_{error}^{-} is used as an input variable to generate a reference source current, as illustrated in **Fig. 2**. The fuzzy logic components include fuzzification, decision making which encompasses rule base, database, and reasoning approach and de-fuzzification, as shown in **Fig. 2**. The fuzzy rules process gathers a set for fuzzy control rules arranged in a specific sequence. These rules are essential for controlling the system to achieve the desired performance objectives and are developed based on knowledge from various smart control systems. The fuzzy logic controller employs the Mamdani method, utilizing a max-min composition relationship **(Benachaiba et al., 2011; Amirullah and Kiswantono, 2016)**. To define this fuzzy controller, five sets (big positive, small positive, zero, small negative ,and big negative) are selected for both the error and slope inputs, while the output is also characterized by five distinct sets. The presented technique in this paper utilized a Fast Fuzzy FFZ controller, which merges the simplicity of a PI controller with the intelligence and adaptability of a fuzzy logic-based control system. The information fed into the fuzzy PI controller is characterized as different linguistic several with their respective membership amounts as detailed in **Table 1**. Based on the range (big, small and zero) for the positive or negative indication of the difference signals $U_{DC\,error}$ and $\Delta_{UDC_{error}}$, the FFZ relatives the matching output based on the linguistic codes presented in **Table.1**. This occurs during the fuzzification process, which involves five fuzzy linguistic categories and fuzzy functioning system modules,

$U_{DC\,error}$ and $\Delta_{UDC_{error}}$, alongside the fuzzy rule bases. Ultimately, this process helps determine P_{error}^{-} during defuzzification. The value of P_{error}^{-} serves as an essential input factor needed to obtain the compensation currents ($I_{L\alpha}^{*}$ and $I_{L\beta}^{*}$) in **Fig. 2.** During the fuzzification operation, various input variables are computed and transformed into linguistic variables according to defined subset known as the membership function. The $U_{DC\,error}$ and $\Delta_{UDC_{error}}$ are suggested as input variables alongside P_{error}^{-} for the system output variables.

Table 1. Fuzzy rule representation

$U_{DC\,error}$ / $\Delta_{UDC_{error}}$	N_{big}	N_{small}	Zero	P_{small}	P_{big}
N_{big}	N_{big}	N_{small}	N_{small}	N_{small}	Zero
N_{small}	N_{small}	N_{small}	N_{small}	Zero	P_{small}
Zero	N_{small}	N_{small}	Zero	P_{small}	P_{small}
P_{small}	N_{small}	Zero	P_{small}	P_{small}	P_{small}
P_{big}	Zero	P_{small}	P_{small}	P_{small}	P_{big}

3.3 Series Active Filter Control

The series active power filter plays a crucial role in voltage compensation by generating a compensation voltage **(Torabi Jafrodi et al., 2020)**. This voltage, synthesized by the SVPWM converter, is inserted in series with the supply voltage and must be injected at a particular angle relative to the supply current. This injection leads to a phase the variation between the consumer's voltage and supply voltage, a critical factor in effective power quality administration **(Axente et al., 2011)**. The series APF effectively addresses the issues caused by unbalanced loads that can lead to fluctuation in $V_{D.C}$ by separating the unbalanced voltage from the supply and injecting into the series APF, the three load voltages (U_{La}, U_{Lb}, U_{Lc}) are subtracted from the corresponding supply voltages (U_{Sa}, U_{Sb}, U_{Sc}) along with the unbalance supply voltage, this results in three phase reference voltage ($U_{La}^{*}, U_{Lb}^{*}, U_{Lc}^{*}$) that are injected in series with the load. Through an appropriate transformation, the three reference currents ($I_{series.a}^{*}, I_{series.b}^{*}, I_{series.c}^{*}$) of the series APF are derived from these phase reference voltages. These reference currents ($I_{series.a}^{*}, I_{series.b}^{*}, I_{series.c}^{*}$) are fed into the current controller alongside their sensed counterparts($I_{series.a}, I_{series.b}, I_{series.c}$). By detecting input voltage, imbalances allows for the effective computation of voltage and the load voltage. The three -phase reference values of the injected voltage are defined as:

$$U_{inject} = U_{S(abc)} - U_{L(abc)} \tag{6}$$

$$U_{La}^{*} = \sqrt{2}\, U_{inject} \sin(\theta t + \theta_{inject}) \tag{7}$$

$$U_{Lb}^{*} = \sqrt{2}\, U_{inject} \sin(\theta t + \frac{2\pi}{3} + \theta_{inject}) \tag{8}$$

$$U_{Lc}^{*} = \sqrt{2}\, U_{inject} \sin(\theta t - \frac{2\pi}{3} + \theta_{inject}) \tag{9}$$

Where: θ_{inject} represents the phase angle of the injected voltage. The currents ($I_{series.a}^{*}, I_{series.b}^{*}, I_{series.c}^{*}$) represent the ideal currents that must be preserved through the secondary winding of the transformer to inject the voltages ($U_{La}^{*}, U_{Lb}^{*}, U_{Lc}^{*}$), which is crucial for effectively compensating for the unbalanced load. These currents ($I^*_{series.a}$, $I^*_{series.b}$, $I^*_{series.c}$) are then compared to series compensating currents in the SVPWM current controller to create signals for the switches as depicted in **Fig. 3.**

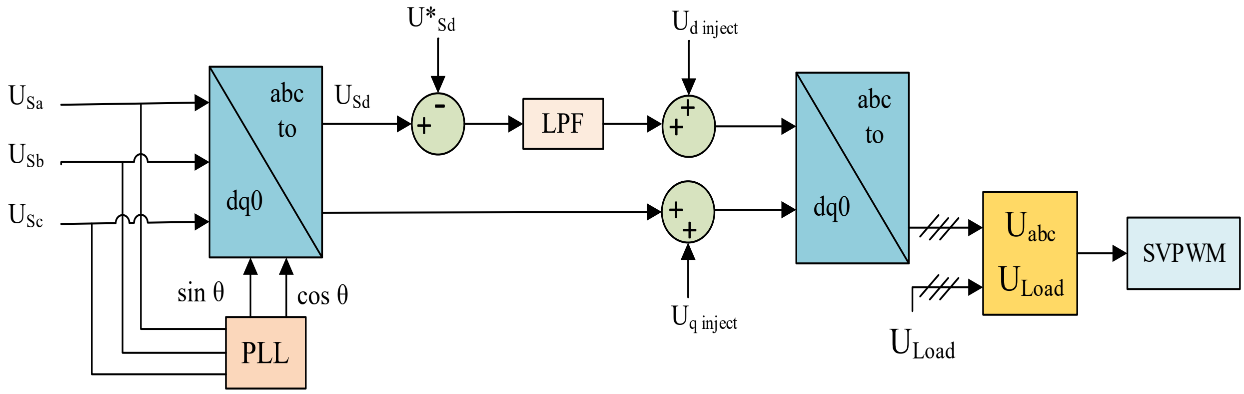

Figure 3. The series active filter control

4. SIMULATION RESULTS AND EVALUATIONS

A proposed control strategy for a UPQC was tested to validate its effectiveness. The results in different scenarios are simulated in Matlab. The system consists of a three phase source with a 380 volte at a frequency 50 Hz. It includes line impedance characterized by a resistance 0.1 Ω and inductance of 0.001 mH. The series active filter inductance of 4.2 mH and shunt inductance of 3.25 mH. The injection transformers operate at 50 Hz, and turn ratio of 1:1. The non-linear load with three phase diode rectifier followed by R–L load including Rdc = 24 Ω, L = 20 mH and the three phase load is presented with three phase resistance of 8.1 Ω and inductance of 30 mH with a different situation will impact the load characteristics. The DC-link operates at a voltage of 650 volts and has a capacitance of 6370 µF. The PI controller parameters are Kp= 6.202 and Ki = 7.56. The fast fuzzy logic controller model utilizes the Mamdani method with max-min composition, and the input membership functions include trapezoidal and triangular shapes for UDC error and delta UDC-error. The system with UPQC controller first Scn from 0-0.1 second the system worked with PI controller and from 0.1-0.2 seconds the same system with proposed controller the system with two fault cases first one at 0.02-0.08 and the second case at 0.12 to 0.16 seconds.

4.1 Unbalance Compensation Results

Line to ground faults disrupt the balanced current flow in a power system. Unbalance compensation aims to restore balance by injecting a corrective current, minimizing the impact on system performance. The first case demonstrates the effects of a line-to-ground fault on current and voltage balance in a power system. The fault, occurring on the load side, causes current imbalance during specific time intervals (0.02-0.08 seconds and 0.12-0.16 seconds) as seen in **Fig. 4.** This current imbalance then creates a voltage imbalance at the point where the system connects to the grid (PCC) as shown in **Fig. 5.** For the same case the source current and voltage are given in **Figs. 6** and **7** respectively.
There are minimal fluctuation in the voltage across the capacitor when it supplied the shunt inverter, as this inverter only transmits reactive power to adjust the load current. From **Fig. 8**, it can be observed that there is a distinction between the two controllers during the

transient phase for recharging the capacitor. The PI controller results in a prolonged rise time and an overshoot percentage is 4.55% reaching a peak 677.7 V. In contrast, on the other hand, the FFZ controller demonstrates a quicker rise time with an overshoot percentage only 0.815%, peaking at 655V.

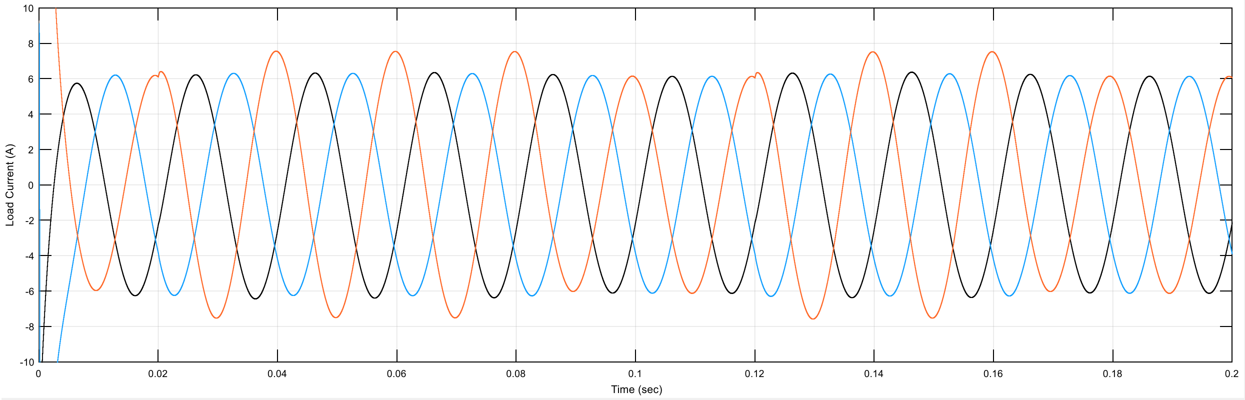

Figure 4. Current unbalance due to line to ground fault

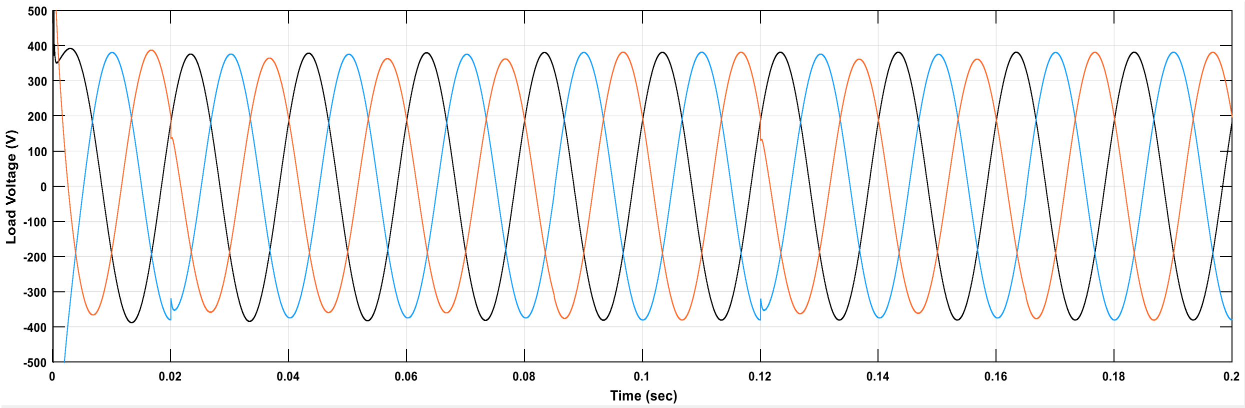

Figure 5. Voltage unbalance due to current unbalance

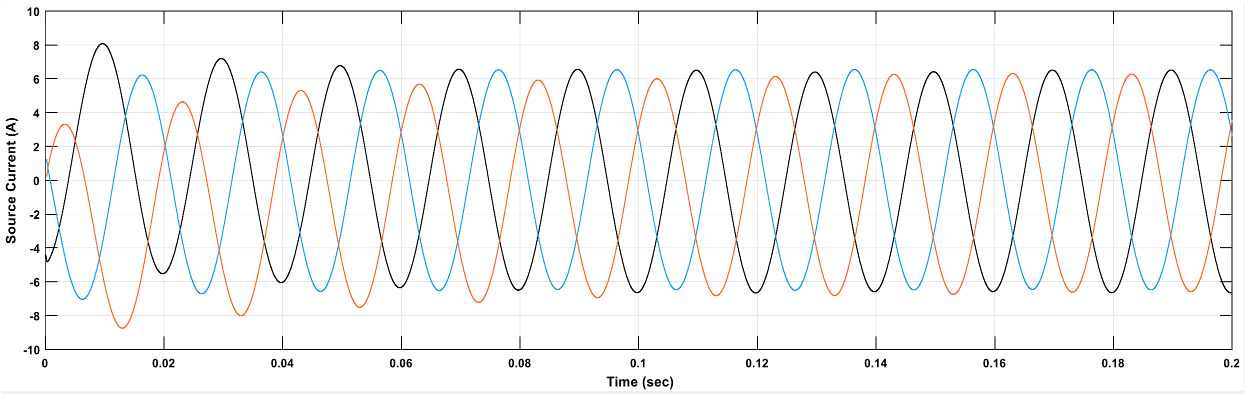

Figure 6. The source current UPQC utilizing PI and FFZ

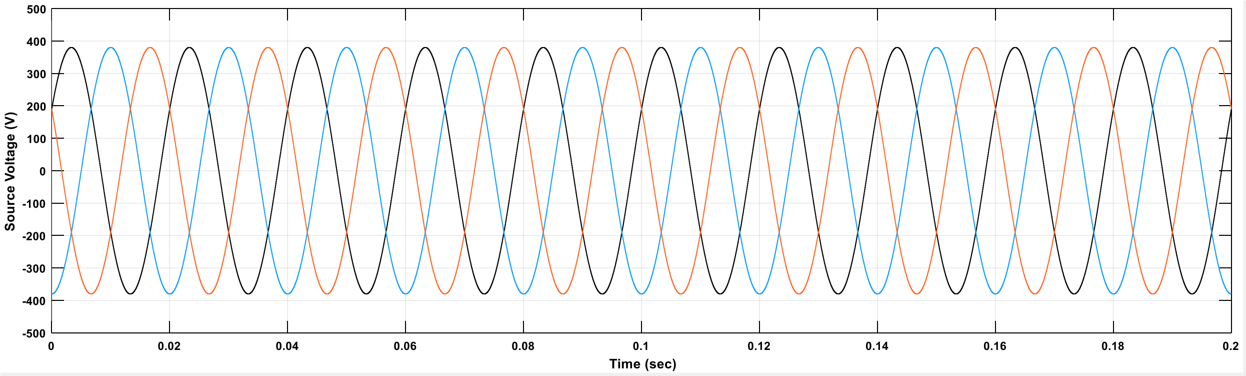

Figure 7. The source voltage UPQC utilizing PI and FFZ

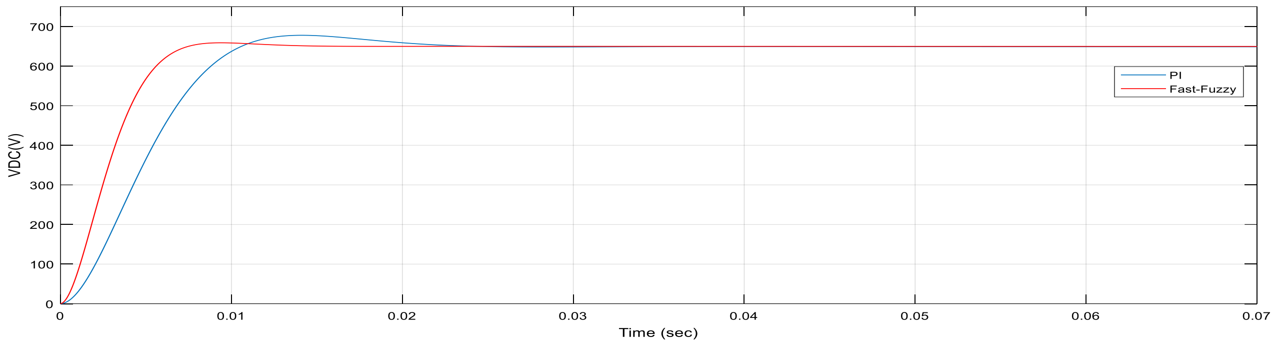

Figure 8. The DC link voltage using PI and FFZ

4.2 Comparative Analysis of Conventional PI and FFZ control for UPQC under Various Fault Conditions

The UPQC combinations of sequences for each condition include five disturbance situations. Each scenario describes a different type of fault connected to load. In Scn1, the system is attached to a load that has a line-to-ground fault. In Scn2, the system is linked to a load experiencing a line-to-line fault. In Scn3, the system is connected to a load with a three-phase line fault. In Scn4, the system is connected to a load with a three-phase line to ground fault, and the last senior is Scn5, where the system is connected to a line to ground fault with nonlinear load. Each combination uses a UPQC controller with both conventional PI and FFZ methods, leading to a total of ten situations. Using Matlab Simulink to get the voltage and current for both the source and load side and then calculate the average values for each phase. The outcomes are summarized in **Tables 2 and 3**.

Table 2 shows that a UPQC using the conventional PI controller with the five different scenarios in the 3P-4W system, the conventional controller is still able to maintain the average source voltage and a small maintain for source current during the different cases. In Scn1, the current from the load side increases and causes instability in the voltage, resulting in an average load voltage of 372.56V, which is reduced during the fault. However, the source voltage remains the same. During these cases, the current from load side increased to 7.51A while the average source current is 6.23A, but phase (S) not maintained. In Scn2, there is a voltage imbalance, and the source side experiences voltage spikes which increased the stress on the source equipment and causes variations in source current.

According to the test results in **Table 3.** The average load voltage increased to 380.2 V, while the average source voltage is 379.96V. However, the currents in two phases (R and T) increased to 8.7 A, while the source side current in those two phases reduced to 6.21A and 5.75A, respectively. In the third senior, there are significant voltage fluctuations, with the average load voltage dropping to 367.46V. The voltage across the three phases (R, S and T) fluctuated and also reduced, but the source average voltage remained at 380.05V. The load current increased to 8.97A minimized to 6.52A at the source side.

Table 2. The Voltage and current measurements for the 3P-4W system employing UPQC with conventional PI control

Scn	Source voltage U_s(V)				Source Current $I_{s\,(A)}$				Load voltage U_L(V)				Load Current I_L(A)			
	R	S	T	Avg	R	S	T	Avg	R	S	T	Avg	R	S	T	Avg
1	380.1	380.2	380	380.1	6.48	5.67	6.55	6.23	362.9	379.7	375.1	372.56	9.39	6.58	6.66	7.51
2	379.7	380.1	380.1	379.96	6.21	5.75	5.75	5.90	381.5	379.5	379.5	380.2	8.7	6.1	8.7	7.4
3	380.1	380	380.1	380.05	6.48	6.70	6.39	6.52	369	366.1	367.3	367.46	9.03	9.00	8.89	8.97
4	380.1	379.9	380	380	5.95	6.68	6.5	6.37	369	366.1	367	367.3	8.96	8.96	8.96	8.96
5	380.1	380.2	380.1	380.13	6.59	5.851	6.07	6.17	362.2	362.9	359.2	361.43	9.93	8.95	8.96	9.28

Table 3. The Voltage and current measurements for the 3P-4W system employing UPQC with the proposed method.

Sc	Source voltage U_s(V)				Source Current $I_{s\,(A)}$				Load voltage U_L(V)				Load Current I_L(A)			
	R	S	T	Avg	R	S	T	Avg	R	S	T	Avg	R	S	T	Avg
1	380	380	380	380	6.31	6.52	6.52	6.45	380.8	378.9	379.8	379.83	9.35	6.60	6.65	7.53
2	380.1	380	380	380.03	6.46	6.46	6.5	6.45	380.1	379.5	379.5	379.8	6.13	7.98	7.98	7.05
3	380	380	380	380	6.53	6.58	6.53	6.54	367.4	367.3	367.5	367.4	8.9	8.9	8.9	8.9
4	380	380	380	380	6.53	6.53	6.52	6.52	367	367	367.5	367.25	8.96	8.96	8.96	8.96
5	380	380	380	380	6.53	6.6	6.53	6.56	364	362.5	364.2	363.5	9.9	8.98	8.95	9.27

In Scn4, the effects from the faults lead to increased current flow and voltage instability on the source side. The average load current is measured at 8.96A, with the controller maintaining stability in just two phases, while the third phase is slightly less, showing an average of 5.95A, leading to an overall average of 6.37A.
In the last senior, when the fault occurs, the average load current increases to 9.28A, causing a reduction in the source current for phases (R and T), where the average source current is recorded at 6.17A, while the other phase shows 5.85A. During this case, the average load voltage minimized to 361.43V, sustained at 380.13V. In the same system and Scn1-5, using the proposed controller, the results are as indicated in **Table 3**. In the first senior, when the fault occurs on the consumer side, the average consumer voltage and current are 379.83V and 7.53A, respectively. The controller maintains stability at the source side, keeping the average voltage at 380V and the current at 6.45A. The load current from phase(R) is recorded at 9.35A, demonstrating that the controller is effective and reliable during this issue. In Scn2, the current in phases (S and T) rises to 7.98A during the fault, while the average load current is 7.05A. The average current stabilizes at 6.45A, which influences average load voltage to rise from 379.8V to 380.03V on the source side. In Scn3 and Scn4, the average consumer currents range from 8.9A to 8.96A, while the source side currents reduce to 6.54A-6.52A, respectively, for both scenarios. In the last scenarios, the average load voltage quickly drops to 363.5V during the issue, but with the proposed controller, the voltage remains stable at 380V. However, the load current rapidly increased to 9.27A, maintaining the source current at 6.56A.
Figs. 9 and **10** show the evaluation of results for source voltage and source current in sequence from the 3P-4W system using UPQC with PI and the proposed controller in five cases, as in **Table 2 and Table 3**. **Fig. 9** illustrates that in Scn1 to 5 for a 3P-4W system implementing UPQC alongside a PI controller, the voltage fluctuated between 379.96 V and 380.13 V, indicating instability. In contrast, the system with the newly proposed controller, despite experiencing different disturbances at the load side, managed to keep the source voltage constant throughout the disturbances. **Fig. 10** shows that in Scn1 to 5 of the 3P-4w system using a conventional controller with UPQC, the current with PI is not stable, with the average source current varying from 5.90A to 6.52A. However, with the proposed controller, the average source current changes only slightly, ranging from 6.45 A to 6.56 A.

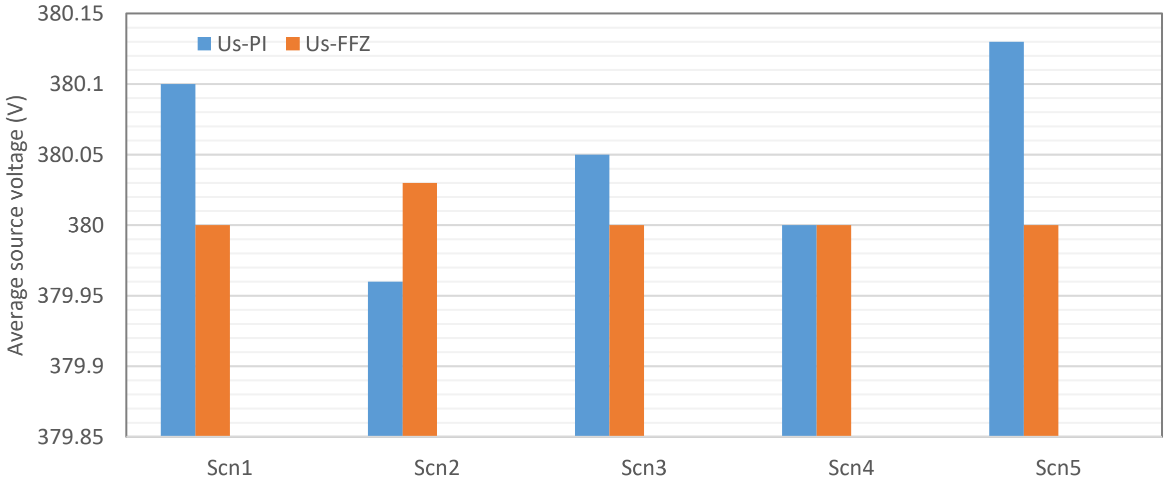

Figure 9. Comparison of source voltage in UPQC using PI and proposed method FFZ with a disturbance at load side

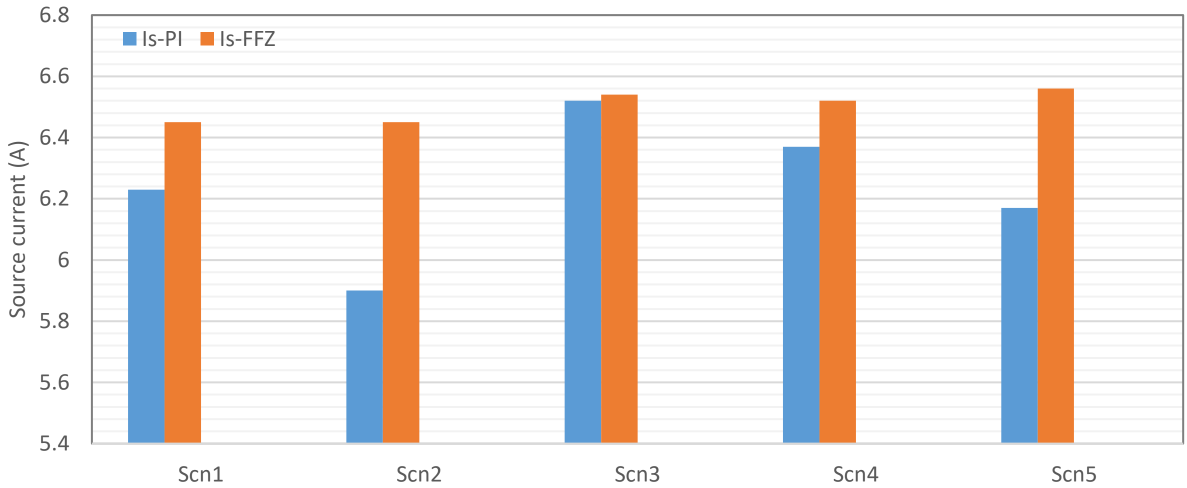

Figure 10. Comparison of source current in UPQC using PI and proposed method with a disturbance at the load side

Table4. Comparison of various controllers applied in UPQC

	Aspect	Conventional PI	FFZ
1	Time taken for capacitor voltage to reach first overshoot	0.0132 sec	0.0087 sec
2	Utility Load side current THD	4.29	3.78
3	Utility Source side current THD	0.17	0.05

From **Table 4** the proposed controller has a faster response time for the first overshoot than the PI controller. While the difference of 0.0045 seconds might look minor, in control systems, even small enhancements in response time can result in improved stability and performance. As in **Table 4,** the utility load side current total harmonic distortion THD, shows that the PI controller has a THD of 4.29, while the proposed controller improves this to 3.78. This reduction indicates that the proposed controller is more effective at minimizing harmonic distortion in the load current, which is beneficial for the system's overall effectiveness. On the source side, the THD for the PI controller is 0.17, whereas the proposed controller achieves a significantly lower value of 0.05. This substantial decrease in THD on the source side further emphasizes the proposed controller's effectiveness in improving power quality by reducing harmonic distortion.

5. CONCLUSIONS

The UPQC is a device made to tackle almost all power-related problems. It utilizes both series and shunt active power filters to mitigate disturbances caused by faults at the load, ensuring that voltage and current on the source side remain stable through the use of the new controller. In this paper, the fast fuzzy controller has been implemented to manage the DC bus voltage of the UPQC. The unique aspect of this paper is the comparison between the new controller and the traditional PI controller for regulating the DC bus voltage. The system performance situations, such as line-to-line fault, line-to-ground, three-phase line-to-line fault, three-phase-to-ground fault, and harmonics in the presence of nonlinear loads, have been thoroughly examined and analyzed, controlling and maintaining the voltage level across the capacitor within desired limits. The new controller provides better results than the PI controller. Also, the UPQC has been designed with DC bus controllers, comparing the PI controller and FFZ logic control. The simulation results demonstrate that the new controller exhibits a lower initial overshoot, achieves a steady state more quickly, has reduced error, and minimizes the THD.

NOMENCLATURE

Symbol	Description	Symbol	Description
U_{inject}	Injected Voltage	SVPWM	Space Vector Pulse Width Modulation
3P-4W	Three-phase four wire	PQ	Power quality
FFZ	Fast Fuzzy	THD	Total Harmonic Distortion
PI	Proportional Integral	UPQC	Unified Power Quality Conditional
PLL	Phase-locked loop	P and Q	Active and reactive power
Scn	Scenario	U_{sdq}	Source voltage in the direct and quadrature axes
UDC	DC voltage	PCC	Point of Common Coupling
R_N	Neutral Resistance	L_N	Neutral Inductance

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Credit Authorship Contribution Statement

Banaz S. Ibrahim: Writing – review & editing, Writing – original draft, Validation, Software, Methodology. Asmahan Y. Husen: Writing – review & editing, Methodology. Nihaya A. Othman: Writing – review & editing, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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التحليل المقارن بين المتحكم التقليدي PI والمتحكم السريع القائم على المنطق الضبابي لاستعادة الأحمال غير المتوازنة باستخدام مكيف جودة القدرة الكهربائية الموحد UPQC

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الخلاصة

تقترح هذه الورقة استراتيجية تحكم جديدة لمكيف جودة الطاقة الموحد ($UPQC$) لتخفيف اضطرابات الجهد والتيار بفعالية في أنظمة ثلاثية الطور رباعية الأسلاك (P-$4W3$). غالبًا ما تواجه مناهج التحكم الحالية بمكيف جودة الطاقة الموحد صعوبة في معالجة ظروف الحمل غير المتوازنة، مما يؤدي إلى تدهور كبير في جودة الطاقة. يعالج هذا البحث هذه الفجوة من خلال تقديم وحدة تحكم منطق ضبابي سريعة (FFZ)، والتي، مقارنةً بوحدات تحكم PI التقليدية، توفر أداءً مُحسّنًا في إدارة تقلبات جهد التيار المستمر وتوليد تيارات مرجعية دقيقة لمرشح النشاط التحويلي. تعمل وحدة تحكم FFZ المقترحة على تقليل تأثير الأحمال غير المتوازنة على جهد التيار المستمر بفعالية، مما يقلل من الأخطاء ويحسن الأداء العام للنظام. تُثبت نتائج المحاكاة باستخدام $MATLAB$ فعالية وحدة تحكم FFZ في تقليل التشوه التوافقي الكلي (THD) وتحسين الاستجابة العابرة، مما يُظهر تفوقها على وحدات تحكم PI التقليدية في سيناريوهات الحمل غير المتوازن.

الكلمات المفتاحية: FFZ، حمل غير متوازن، ثلاث اطوار بأربع اسلاك.