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Control strategies for power quality enrichment in Distribution network using UPQC

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ABSTRACT

Unified Power Quality Conditioner (UPQC) is a cutting-edge Custom Power Device (CPD) that is being used to improve power quality in the distribution network. UPQC contributes to the distribution network by compensating for both voltage and current-related power quality disturbances. Its control strategy in unbalanced and distorted weak grid conditions is of particular interest for research. In addition, the performance of UPQC in the presence of unbalanced and non-linear harmonic loads is critical for maintaining desirable power quality. This paper investigates the implementation of UPQC control strategies and algorithms for improving power quality (PQ) and proposes a versatile control strategy to improve UPQC performance. When tested on a critical distribution network, the proposed dynamic control strategy provides better steady-state and dynamic response. Models developed in MATLAB/SIMULINK are used to validate the proposed control scheme.

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1. Introduction

The proliferation of power electronics-based equipment has caused a slew of serious issues with the quality of electric power supply. Conventional power quality mitigation equipment is proving insufficient for an increasing number of applications, prompting researchers to focus on developing dynamic and adjustable solutions to power quality issues. This has resulted in the development of CPD. Voltage distortions and fluctuations are common in the weak grid network systems. The distorted load currents cause non-sinusoidal voltage drops, which distort the network voltages. Voltage sag and swell problems, on the other hand, are defined as a sudden decrease or increase in grid voltages from their nominal value and are typically caused by short-circuit current flowing into a fault. To address such power quality issues, UPQC is one of the most advanced custom power devices [1,2]. UPQC is a combination of series and shunt active power filters connected back-to-back by a common DC link capacitor. The UPQC's series section is in charge of managing network-side voltage disturbances such as voltage unbalance, sags/swells, voltage flicker, and harmonics. It inserts compensation voltages in order to keep the load voltages balanced and distortion-free. The shunt section is in charge of dealing with current quality issues raised by the consumer, such as low power factor, load harmonic currents, load unbalance, and so on.

Nowadays, electrical energy is of infinite importance because it is the most well-known of all energies and they rely on it to a large extent. Life would be impossible to imagine without electricity. At the same time, the quality and consistency of the electricity supplied are critical for the efficient operation of the end user's equipment. Many commercial and industrial loads necessitate high quality with no interruptions and consistent quality. As a result, the most important thing in the world today is to maintain the power of quality. The electronic power devices have a significant impact on the quality and stability of the power supply. There is a continuity unit, flicker, harmonics, voltage fluctuations, and other effects caused by electronic power devices. PQ issues include voltage sag/swell caused by network failures, lightning strikes, and switching capacitor banks. There are reactive and harmonic power disturbances in the energy distribution system when non-linear loads (computers, lasers, printers, rectifiers) are used excessively. It is critical to overcome this type of problem because its impact

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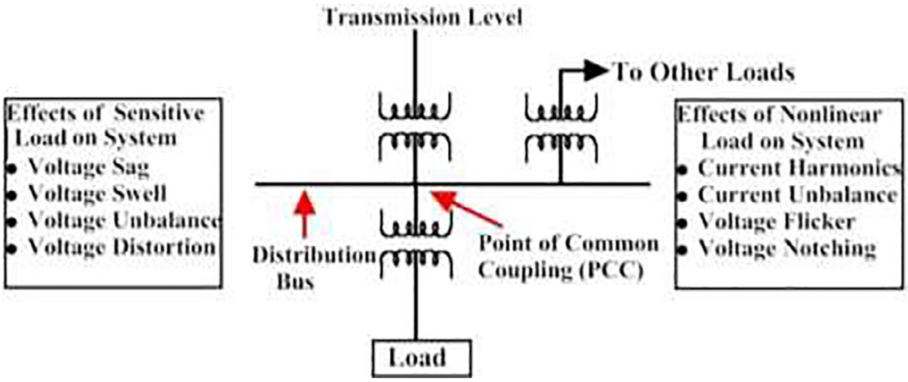


Fig. 1. Typical PQ issues in electrical distribution network.

can worsen in the future and have a negative impact. Passive filters have traditionally been used for reactive power disturbances and harmonic generation, but they have a number of drawbacks, including large size, resonance issues, and the effect of the source of impedance on performance.

Active Power Filters are used to improve power quality. Active power filters are classified based on their system configuration. Active power filters are classified into two types: series and shunt. When we combine series APF and shunt APF, we get the UPQC device. UPQC eliminates both voltage and current-based distortions at the same time. A Shunt APF eliminates all current issues such as current harmonic compensation, reactive power compensation, and power factor enhancement. A Series APF compensates for voltage dips and rises, ensuring that the voltage at the load side is perfectly regulated. Shunt APFs are connected in parallel to the grid, while series APFs are connected in series to the grid. On the DC side, UPQC is formed by combining both series APF and shunt APF connected back to back. In this paper, the controlling technique used for UPQC is hysteresis band controller with “p-q theory” for shunt APF and hysteresis band controller with Park’s transformation or dq0 transformation for series APF. The power quality of the distribution system was improved in this paper by applying the proposed controlling technique to UPQC (Figs. 1 and 2).

2. Power quality issues

Power quality is defined as the ability of line voltages and currents to retain their sinusoidal shape at the rated magnitude and frequency. As a result, PQ issues are frequently used to express voltage and current quality.

Furthermore, these PQ problems are divided into two categories: steady-state problems such as current and voltage harmonics, and transient problems such as load dynamic condition, voltage sag/swell, voltage unbalance, and interrupts. In general, voltage and current harmonics are regarded as the most serious issues as a result of the advancement of nonlinear load in distribution networks, such as rectifiers, switching power supplies, and variable speed motor drives. Nonlinear loads introduce current harmonics into distribution systems, lowering the quality of the network’s voltage. Voltage quality, on the other hand, refers to

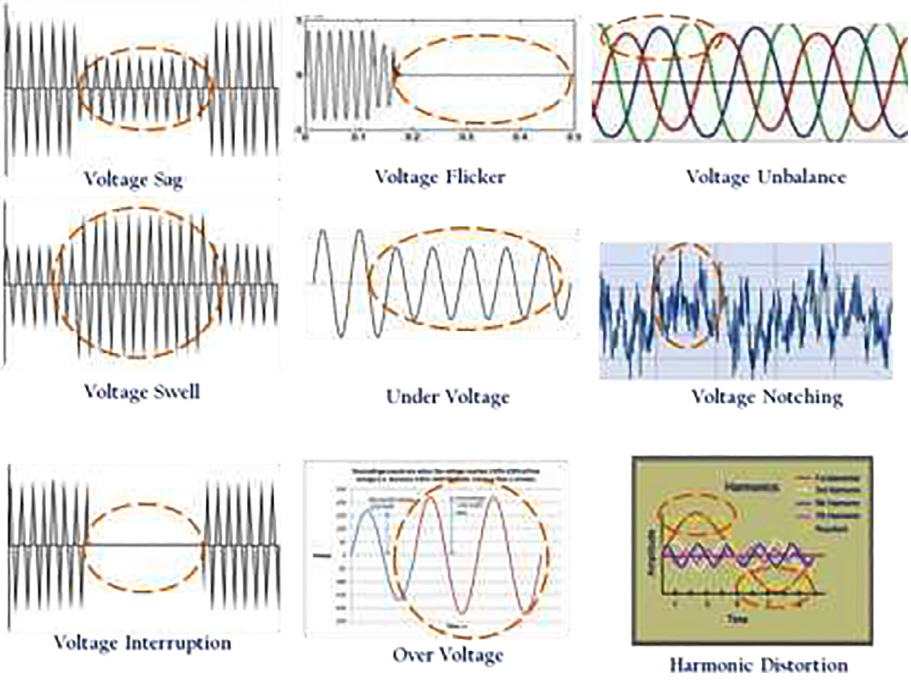


Fig. 2. Visual representations of PQ issues.

Table 1
PQ issues solved by CPDs.

Custom power device Topologies	Power Quality Issues	
	Caused by Load	Caused by Power supply
Shunt Compensator	Harmonic filtering Reactive power compensation Load balancing Flicker reduction	–
Series Compensator	–	Voltage sag/swell compensation Voltage distortion compensation Supply voltage unbalance compensation
UPQC	Harmonic filtering Reactive power compensation Load balancing Flicker reduction	Voltage sag/swell compensation Voltage distortion compensation Supply voltage unbalance compensation

Table 2
Capability of controllers on various PQ issues.

Common PQ problems	Capability of compensator on PQ issue		
	Shunt APF (SAPF)	Series APF (DVR)	UPQC
Current harmonics	YES	NO	YES
Voltage harmonics	NO	YES	YES
Voltage sag/swell	NO	YES	YES
Voltage unbalance	NO	YES	YES

voltage disturbances such as voltage sag/swell, voltage unbalance, and voltage distortion caused by grid faults, which cause line voltage to deviate from its nominal value [3–5].

3. Solution to the PQ issues

Several PQ issues were discussed in the previous section. It can be assured that if no action is taken to compensate for the aforementioned PQ issues, they will have a significant impact and effect on electrical distribution systems. PQ issues, on the other hand, can be improved by using active power filters (APFs) and custom power devices (CPDs). Shunt compensators or shunt active power filters (SAPF) [6–8], series compensators or dynamic voltage restorers (DVR) [9–10], and combinations of these two (i.e., unified power quality conditioners (UPQC)) [11–15] are the most common CPDs. These CPDs are a viable option for PQ enrichment because they eliminate all of the drawbacks of passive power filters while also providing adequate PQ solutions. Table 1 depicts common power quality issues and their solutions using CPDs. Table 2.

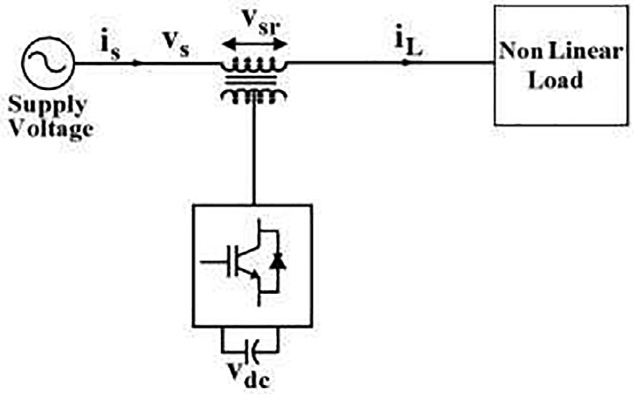


Fig. 4. Series-connected power quality compensator.

A. Shunt compensator

Shunt compensators, also known as SAPFs, are commonly used across the load to compensate for all current-related issues such as current harmonics, reactive power compensation, load balancing, and flicker reduction. It functions as a current source, injecting compensating current at the PCC to eliminate all current harmonics and make the source current sinusoidal and in phase with the source voltage.

When creating a shunt compensator, two types of converters can be used: voltage source inverter (VSI) and current source inverter (CSI) (CSI). Fig. 3 (a) shows a VSI-based shunt compensator. It is equipped with a self-supporting dc bus capacitor. It has grown in popularity because it is less expensive, lighter, and expandable to multilevel and multistep versions, which improve performance with lower switching frequencies. It is more popular in UPS-based applications because, when mains are present, the same inverter bridge can be used as a shunt compensator to eliminate harmonics of critical non-linear loads.

Current Source Inverter

B. Series compensator

The PWM converter is shown in Fig. 4 connected in series with the power line via series injection transformers. The series compensator, also known as the DVR, functions as a component of a controllable voltage source. This structure is best suited for safeguarding loads that are susceptible to supply voltage sag, swell, voltage distortion, and voltage unbalance [16–18].

The power rating of the series compensator is a fraction of that of the load, and the control response is in the millisecond range,

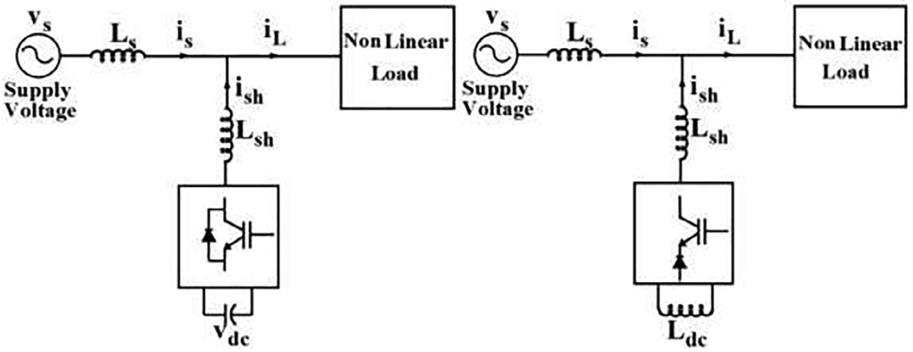


Fig. 3. Shunt-connected power quality compensator (a) Voltage Source Inverter (b).

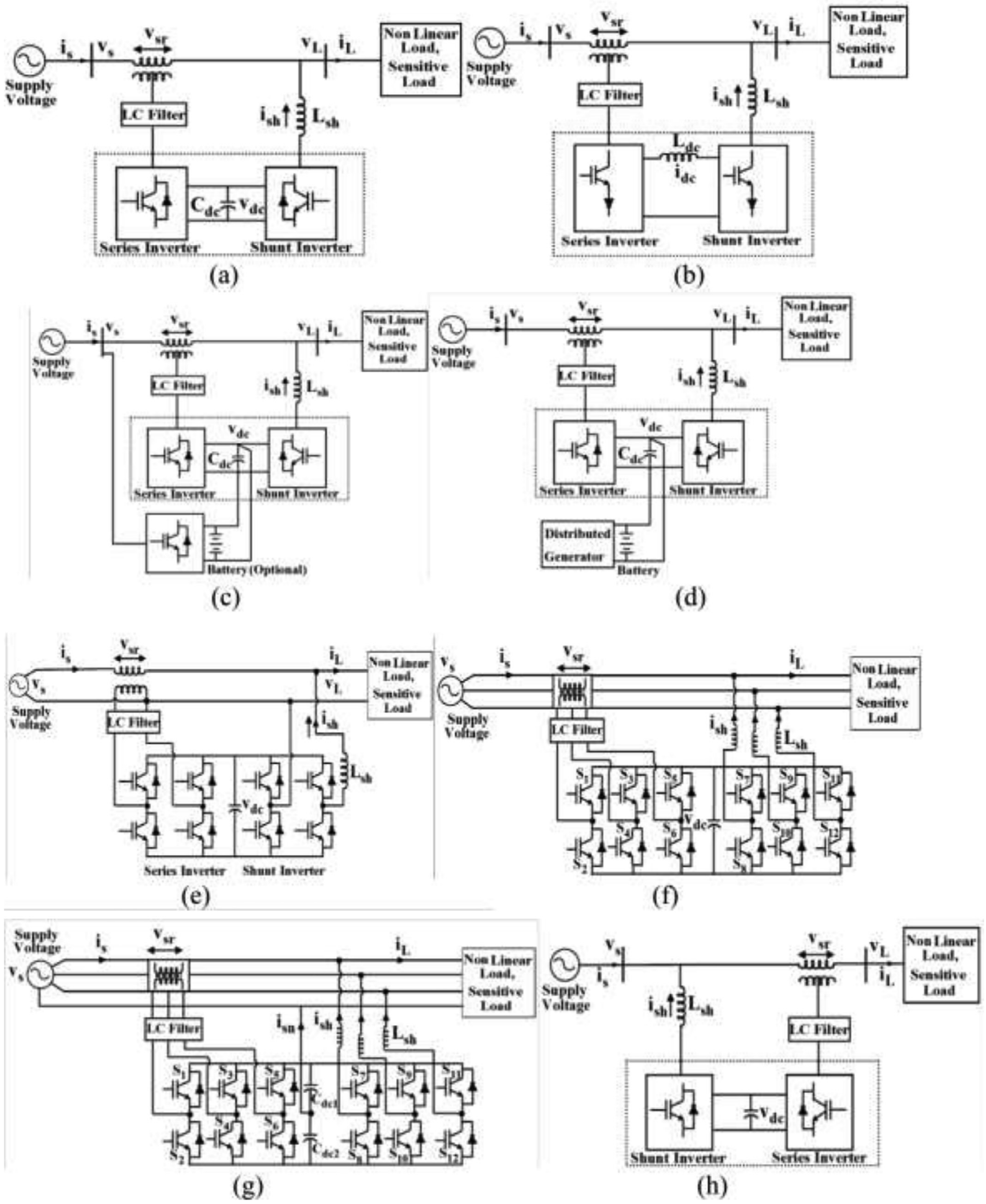


Fig. 5. UPQC topologies (a) Typical block diagram of UPQC (b) CSI-based UPQC topology (c) UPQC-MC system topology (d) UPQC-DG system topology (e) Single Phase Two wire UPQC system topology (f) Three phase Three Wire UPQC system topology (g) Three phase Four Wire UPQC system topology (h) UPQC-L system topology.

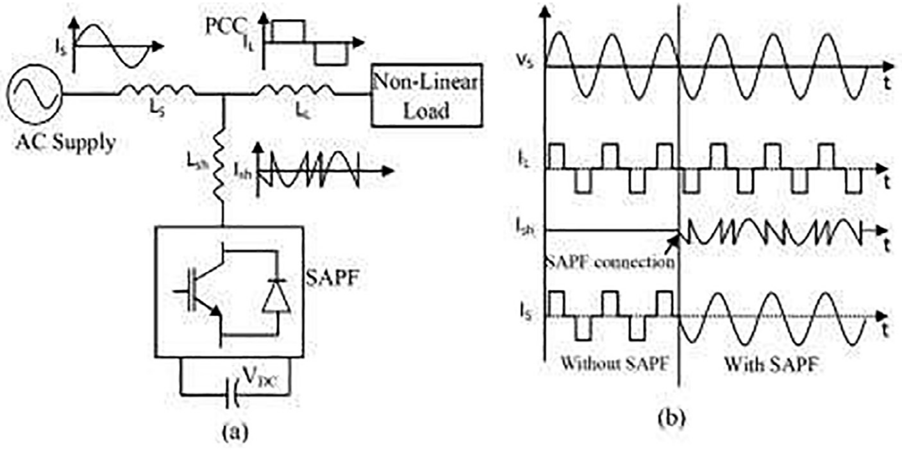


Fig. 6. (a) Block diagram of Shunt APF with Non linear load (b) Capability of Shunt APF on PQ issues.

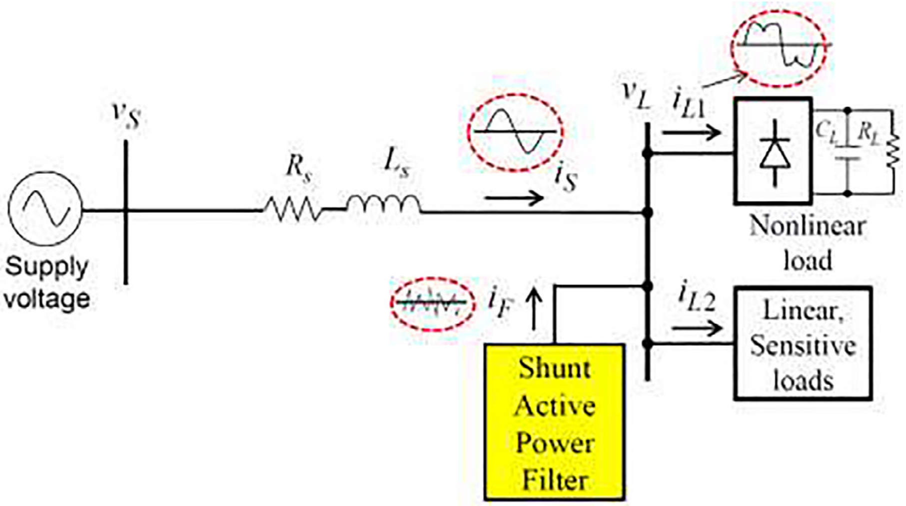


Fig. 7. Capability of Shunt APF with Non linear and Sensitive loads.

ensuring a safe voltage supply under transient power network conditions. It was used to reduce the negative-sequence voltage and voltage distortion on the three-phase power line. In the event of a supply voltage fault, the series compensator can feed a certain amount of active power to the power line by extracting active power from the dc-link capacitor, while the shunt compensator takes active power from the power line to regulate the dc-link voltage.

C. Unified power quality conditioner (UPQC)

Fig. 5 (a) depicts the UPQC block diagram, which consists of two voltage source compensators (series and shunt compensators) connected back to back via a common DC-link capacitor (CDC). Between the input supply voltage and the PCC, a series compensator is connected via transformers. An interfacing inductor connects the shunt compensator in parallel with the common

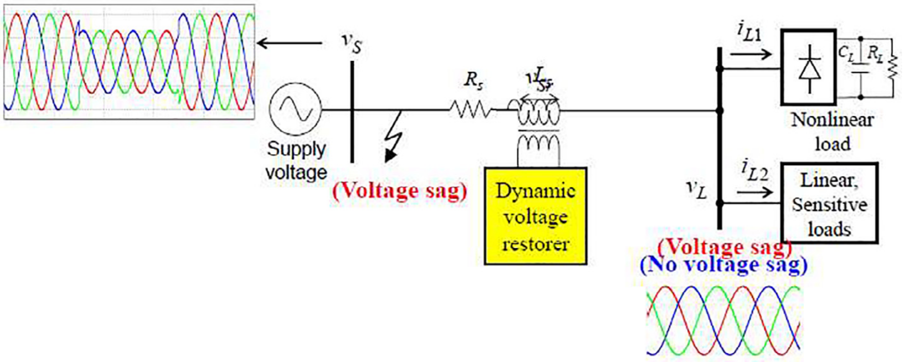


Fig. 8. Capability of DVR with Non linear and Sensitive loads.

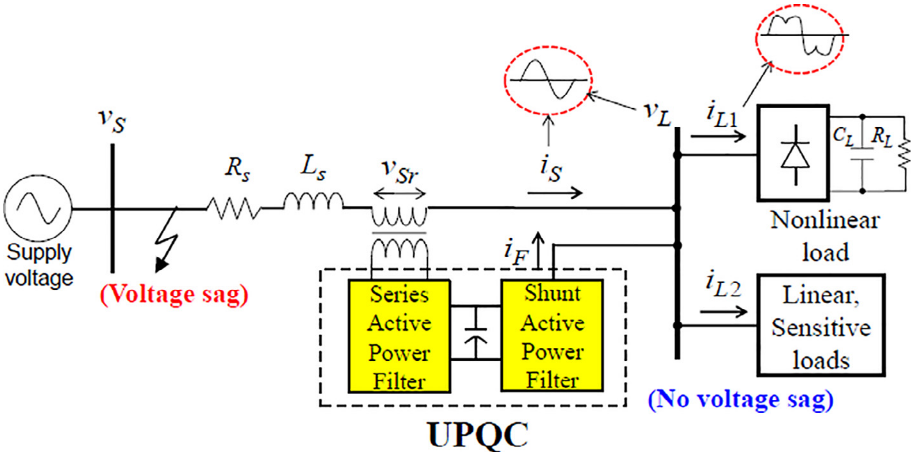


Fig. 9. Capability of UPQC with Nonlinear and sensitive loads.

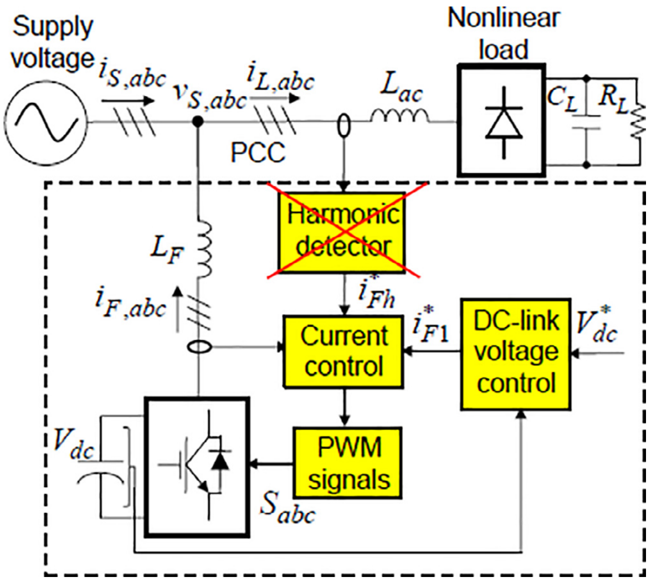


Fig. 10. Traditional Control topology of SAPF.

connection point. The series compensator is a voltage source, whereas the shunt compensator is a current source.

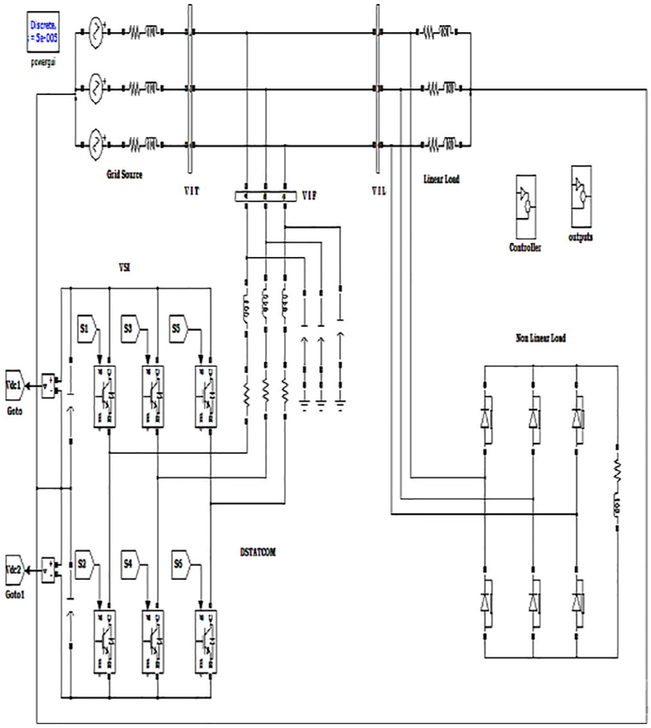


Fig. 12. Simulink model of Proposed control topology for SAPF.

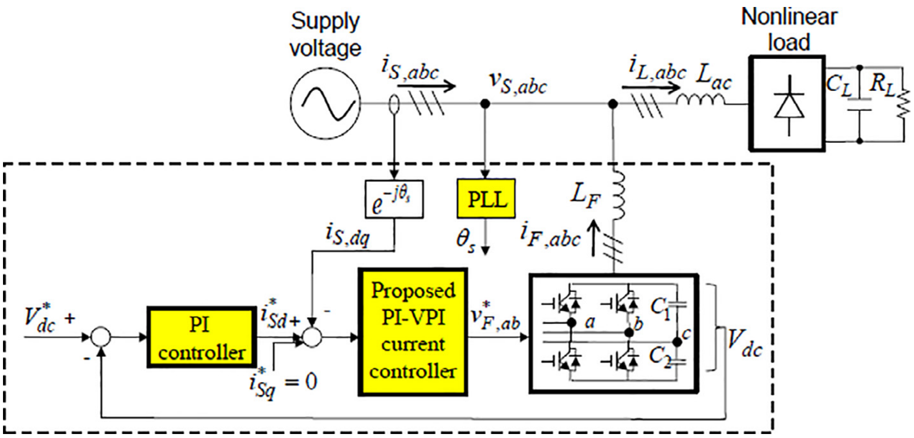


Fig. 11. Proposed control topology for SAPF.

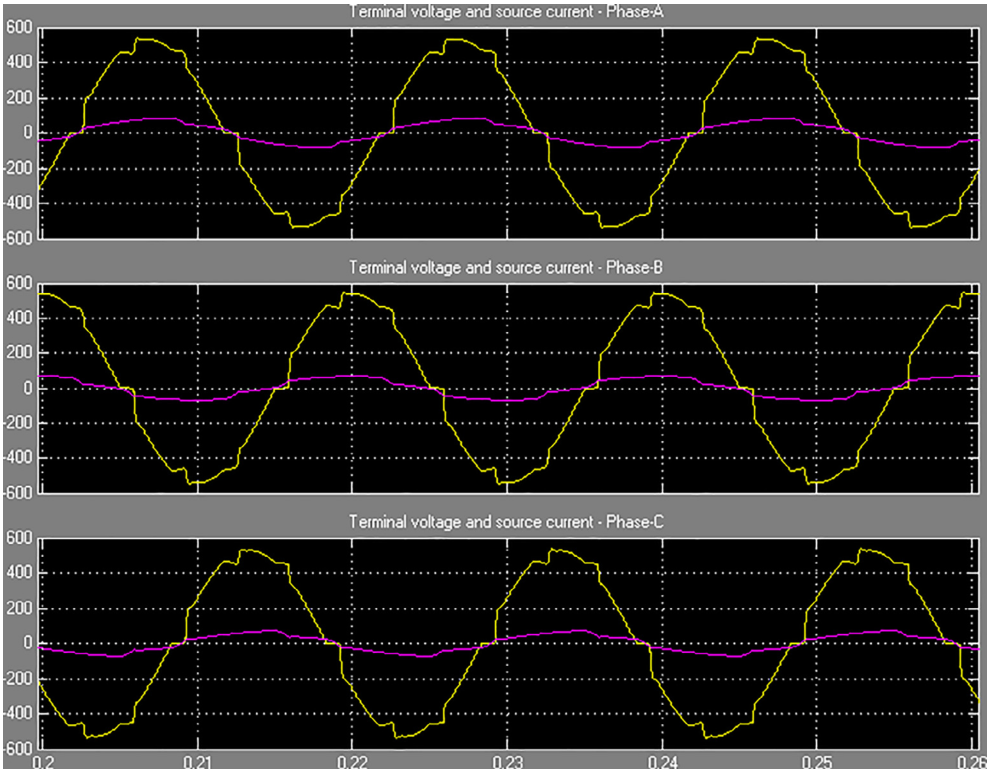


Fig. 13. Simulated waveforms of terminal voltage and source currents without SAPF.

The shunt compensator's power circuit consists of a three phase voltage source PWM converter powered by Cdc. The shunt compensator is connected directly to the power line via a coupling inductor Lsh, which provides isolation between the shunt converter and the power line. The shunt compensator's goals are to regulate the DC link voltage of both compensators and to suppress

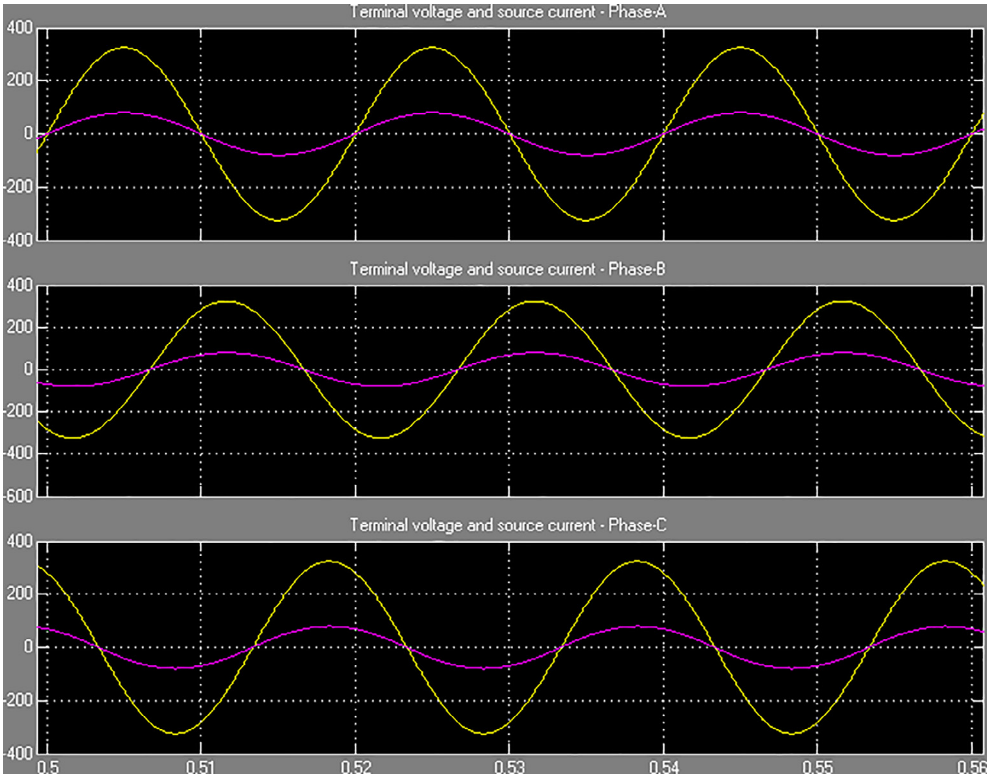
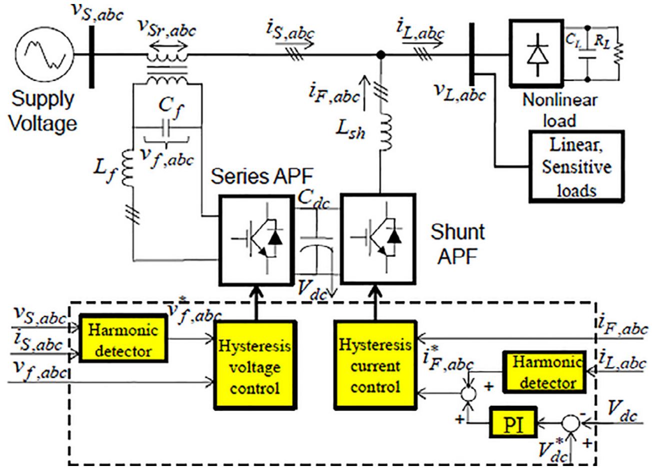


Fig. 14. Simulated waveforms of terminal voltage and source currents with SAPF.



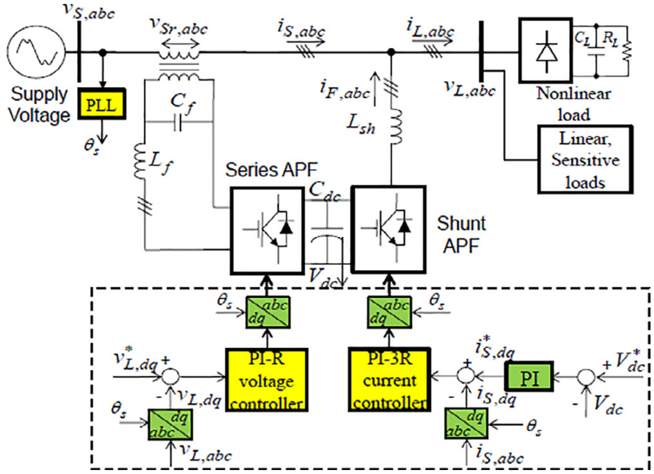


Fig. 16. Proposed control strategy of UPQC without Fuzzy logic controller.

load current harmonics. The common DC-link voltage of the series and shunt compensators is provided by the dc-link capacitor (Cdc). Once charged, the DC-link voltage dc V should not fall off its charge, but due to the inverter-inductor and capacitor's finite switching losses, some power is consumed, and the charge of the DC-link voltage must be maintained in a closed-loop control, via the shunt compensator [19–26]. IGBTs with anti-parallel diodes are used as switching devices in both the series and shunt compensators. Because UPQC is used to handle both current and voltage problems, it is classified into the following categories based on physical structure and voltage compensation approach.

- Type of energy storage device used.
- Number of phases used.
- Physical location of shunt and series inverter.
- According to the energy storage device, the UPQC is classified as
- C SI-UPQC (Current Source Inverter based).
- MC-UPQC (Multi converter based).
- DG-UPQC (Distributed generator based).
- According to the Number of phases used, the UPQC is classified as
- UPQC-L (Single Phase UPQC topology).
- 1P2W UPQC (Single Phase Two wire UPQC topology).
- 3P3W UPQC (Three phase Three Wire UPQC topology).
- 3P4W UPQC (Three phase Four Wire UPQC topology).
- According to the Physical location of shunt and series inverter, the UPQC is classified as
- Left Shunt Inverter UPQC topology.
- Right Shunt Inverter UPQC topology.

4. Working of various compensators on PQ issues

A. Operation of Shunt APF (SAPF) on PQ issues

Shunt APF is utilized for current harmonics compensation by injecting equal-but-opposite harmonic compensating currents at the point of common coupling (PCC). For this situation, the Shunt APF works as a current source injection, and it injects the harmonic components produced by the load but phase shifted by 180° [27–36].

This principle is appropriate for any kind of load considered as a harmonic source. Additionally, with a suitable control technique, the Shunt APF would be able to compensate load power factor. Therefore, the source current remains sinusoidal and in phase with

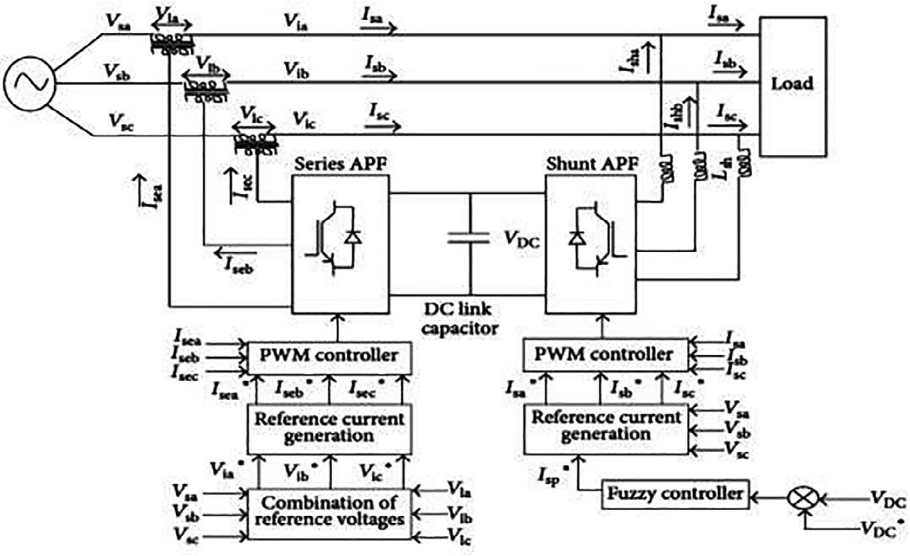


Fig. 17. Detailed proposed control strategy of UPQC with Fuzzy logic controller.

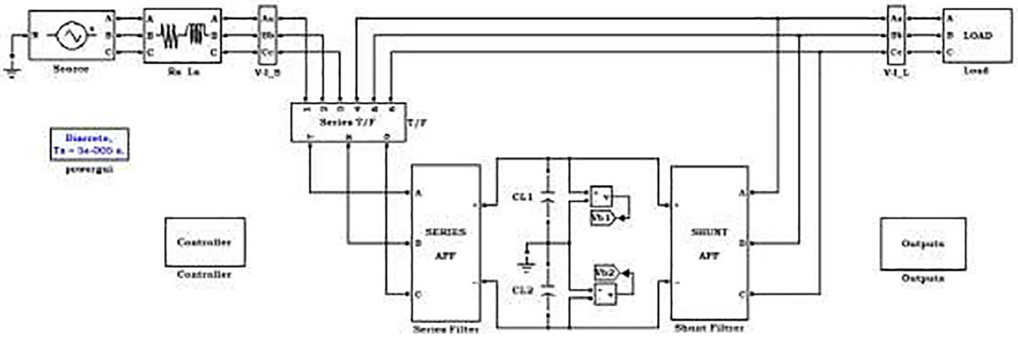


Fig. 18. Simulink model of Proposed UPQC.

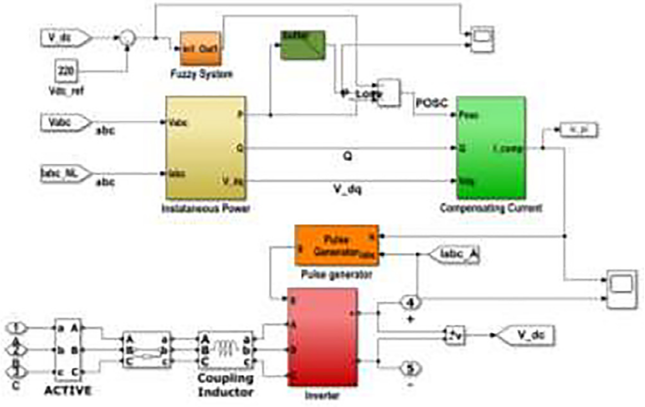


Fig. 19. Control structure of UPQC with proposed Fuzzy control.

the supply voltage. The current compensation capability of the Shunt APF is shown in Fig. 6.

Shunt APF is a voltage source inverter (VSI), which is installed in power system to compensate harmonic current caused by nonlinear loads.

B. Operation of Series APF (DVR) on PQ issues

Dynamic voltage restorer (DVR) is a voltage source inverter (VSI), which is installed in power system to protect load from voltage sag at supply side.

C. Operation of UPQC on PQ issues

Unified power quality conditioner (UPQC) is the combination of series and shunt APF, which can deal with most of common power quality problems such as current and voltage harmonic, voltage sag, voltage unbalance, etc (Figs. 7-11).

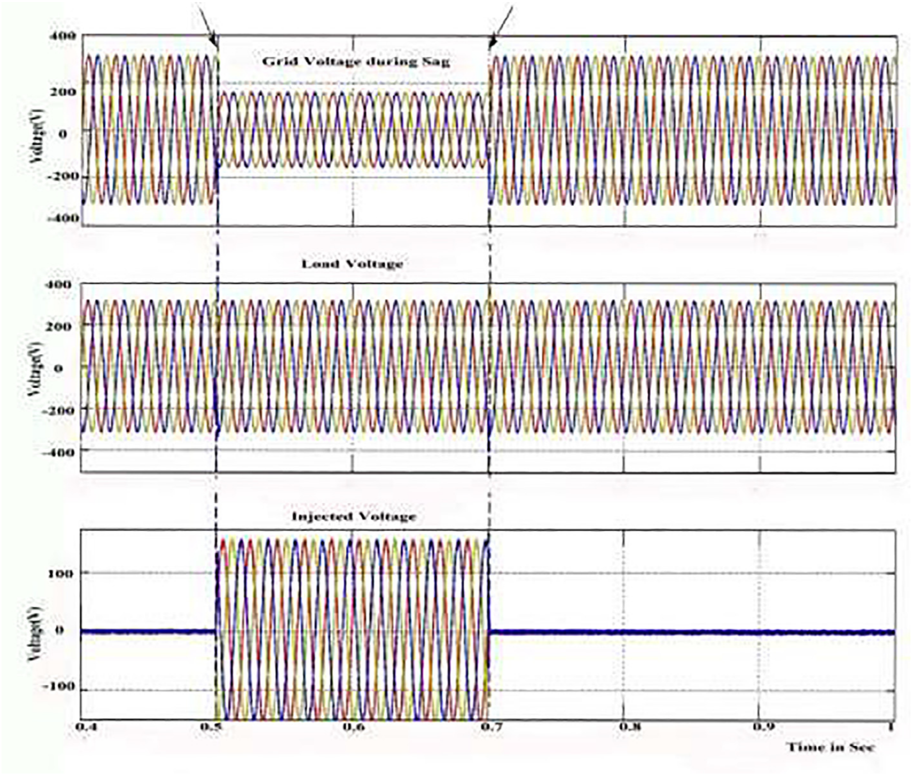


Fig. 20. Capability of UPQC under Voltage Sag- Waveforms of Grid Voltage, Load Voltage and Injected Voltage during sag condition.

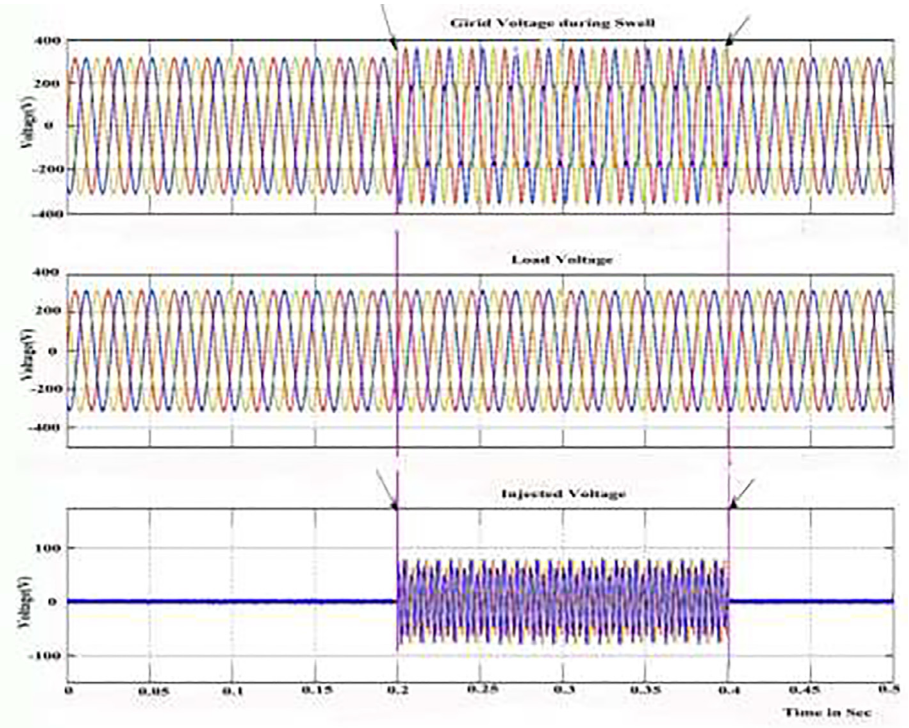


Fig. 21. Capability of UPQC under Voltage Swell- Waveforms of Grid Voltage, Load Voltage and Injected Voltage during swell condition.

5. MATLAB/SIMULINK results

A. Simulated results of SAPF

Traditional control method for SAPF consists of Load current measurement and Performance depends on Harmonic detector and current control provided in it.

Harmonic detector can be implemented by Instantaneous p-q power theory and HPF, LPF or BPF in synchronous (d-q) reference frame. Harmonic detector can make the whole control scheme more complex or even imprecise. Elimination of the harmonic detector can simplify the control system and improve the SAPF performance.

B. Simulated results of UPQC (Figs. 12-23)

6. Conclusion

This paper has presented new reference voltage and reference current generation schemes along with new current and voltage control approaches for performance enhancement of Unified Power Quality Conditioner (UPQC). Resonant controller is a suitable solution to deal with the current and voltage harmonics. The proposed control algorithm developed for SAPF and UPQC using resonant controller effectively compensates the load voltage and the supply current to be almost sinusoidal with a low THD.

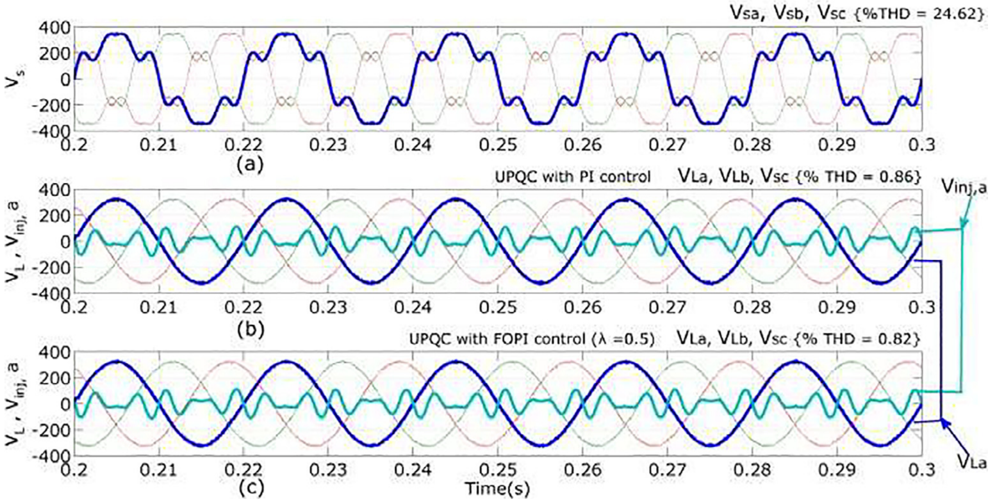


Fig. 22. Capability of UPQC on load Voltage harmonics- Waveforms of Load Voltage and Injected Voltage under without UPQC, UPQC with traditional control and UPQC with proposed control strategy.

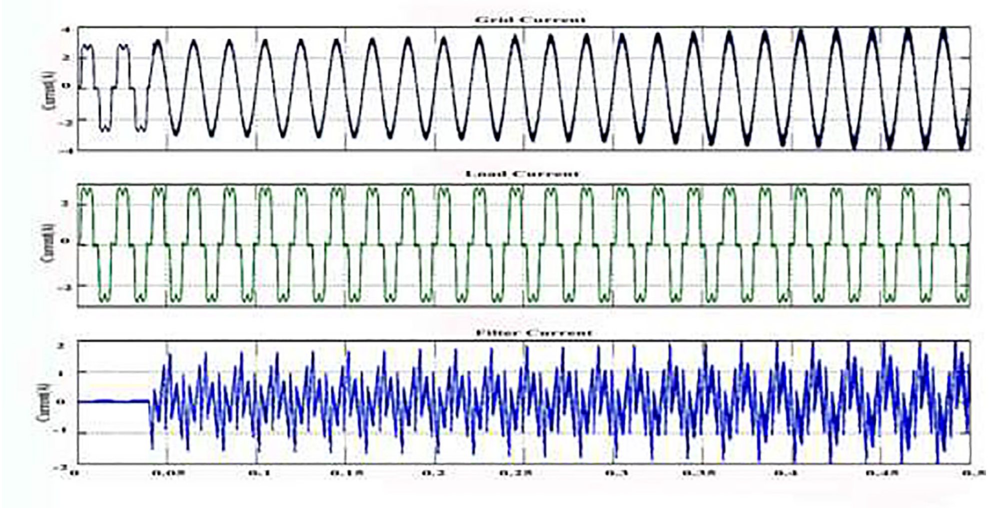


Fig. 23. Source current, Load current and Filter current Waveforms.

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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