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Mitigation of Voltage and Current Harmonics on Solar PV Integrated Power System by Using Unified Power Quality Conditioner (UPQC)

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ABSTRACT

Meeting the energy demands during peak hours is proving to be a significant challenge. With the limited availability of renewable energy sources, power generation largely relies on non-renewable sources. To address this issue, researchers and industry professionals have concentrated on developing solar energy systems to lower the dependency on non-renewable energy sources. Integrating photovoltaic (PV) panels with the grid may lead to issues with power quality (PQ), such as voltage and current harmonics. However, connecting PV panels to the grid may result in PQ problems, such as voltage harmonics and distortion. The UPQC (Unified Power Quality Conditioner) is an advanced device designed to address a range of power quality issues. This work focuses on a Unified Power Quality Conditioner (UPQC) for integrating solar PV systems into the grid. Series Compensator have series active filter that compensates for voltage harmonics and sags by injecting a compensating voltage. Shunt Compensators typically a shunt active filter that addresses current harmonics by injecting or absorbing current to correct the harmonic distortion. When photovoltaic (PV) panels are connected to the grid, they can cause PQ concerns including voltage harmonics and distortion. UPQC implementation improves overall power quality by stabilizing voltage and current waveforms, reducing the impact of harmonic distortions on sensitive equipment. The shunt compensator within the UPQC addresses current harmonics by injecting or absorbing current. The UPQC integrates both series and shunt compensation within a single device, enabling it to simultaneously address both voltage and current harmonics. This is in contrast to traditional methods, which typically require separate devices or solutions for each type of harmonic problem.

Key words: Solar PV, Power System, Power quality, THD, UPQC

INTRODUCTION

By the importance of renewable sources in the present world energy sector is growing steadily. This happens due to the constraints of limited resources and the adverse environmental effects associated with conventional energy sources. Among the various renewable energy options, solar energy stands out as a strong contender because it is naturally abundant and its conversion to electricity via the photovoltaic (PV) process is free from pollution. The enhanced power demand scenario made the step into the application of eco-friendly power generated from renewable energy sources [1] to the existing power system. Hence, the renewable energy integrated based power system operation aids to meet the enhanced power demand. In addition to this, the renewable energy integration-based power system operation [2,3] supports the socio-economical operation. Therefore, the choice of solar renewable energy-based integrated power system supports the socio-economical operation. As the integration of photovoltaic (PV) systems into existing power grids grows, these challenges are anticipated to become increasingly significant, potentially affecting the system's overall effectiveness. With the rising prevalence of renewable energy on the grid, the power quality (PQ) of medium and low voltage transmission systems has become a key focus. Typically, integrating renewable energy into the grid involves the use of inverters and electronic power converters. The major problem associated with the dealing power system operation is its power quality complications due to enhancement of voltage and current harmonics in the system. These power quality complications [4] are intensified for renewable energy integrated-based power system operation. In order to mitigate these power quality complications various suitable power quality controllers and control schemes are needed to achieve superior power quality operation. This in turns the cost of expensive power system operation and any obstacles in the operation [5,6] results in further cost expensive power system operation. Therefore, comprehensive research is essential on various cost-effective controllers or control strategies [7] for renewable energy integrated power system operations at enhanced power quality operation.

There are various controllers FACTS controllers etc. are developed and implemented to maintain the tenacity of the power system for various power quality issues [8]. However, the performance analysis of these controllers was not analysed completely for renewable energy-based integrated power system circuits. Hence, it is essential to modify the existing controllers to address the power quality issues at solar renewable energy integrated power system operations. It efficiently tackles problems such as voltage sags and surges, harmonics in voltage and current, imbalances in voltage and current, and issues with reactive power [9]. The proposed solar renewable energy integrated power system with UPQC is developed [1, 8].

METHODOLOGY

To meet the present enhanced power demand scenario, the eco-friendly renewable energy power generation-based power system operation conquers the enhanced power demand problem. The application of this solar renewable energy [10,11, 12] integrated system at an appropriate location nullifies the maximum power demand problem. It is a well-known fact that the power demand initiates at the load point only, therefore, the solar-based integrated system is applicable at the load side nullifying the power demand problem directly. If photovoltaic (PV) systems are widely deployed, they can impose several negative effects on the grid. These include: i) reverse power flow, ii) overvoltage along distribution lines, iii) challenges in voltage regulation, iv) phase imbalance, v) power quality issues, and vi) increased reactive power. Power quality problems, particularly harmonics, are a concern. The inverter, which is central to the PV system's connection to the grid, is essential in influencing the quality of the energy supplied. During the DC to AC conversion, inverters can introduce harmonics into the system, especially with non-linear loads. Such harmonic currents can lead to voltage drops and distort the supply voltage. Additionally, harmonics may lead to resonance in the power system, which can result in equipment malfunctions, reduced lifespan, or even permanent damage to electrical components.

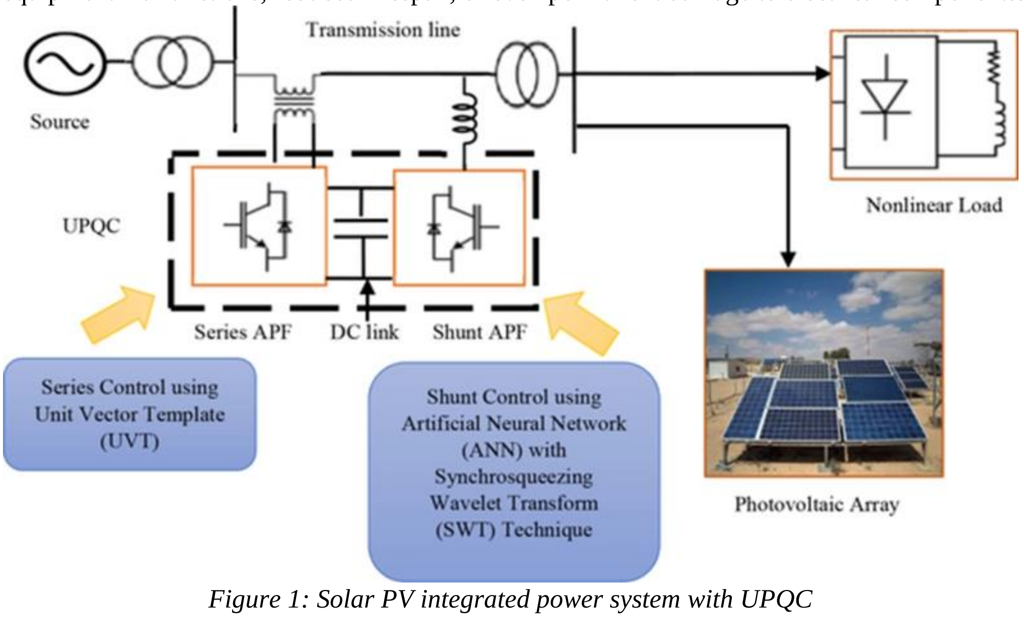


Figure 1: Solar PV integrated power system with UPQC

The prevalence of non-linear loads in contemporary power distribution systems is rising, which contributes to various PQ issues, including voltage drops, surges, harmonics, brief and extended outages, noise, and voltage imbalances. To address these current and voltage distortions, various custom power devices can be employed. Devices such as Dynamic Voltage Restorers (DVRs), Static Synchronous Compensators (STATCOMs), and Unified Power Quality Conditioners (UPQCs) are reported to effectively mitigate voltage sags and surges, with UPQCs offering superior compensation capabilities [14].

Upqc Control Strategy

It is observed from the above model in Figure 1 that the proposed solar renewable energy integrated power system with UPQC. The increasing use of non-linear loads in modern power distribution systems results in several power quality issues, including voltage drops, surges, harmonics, brief and extended interruptions, noise, and voltage imbalances. To address these distortions in current and voltage, various Custom Power Devices (CPDs) can be utilized. Among these, devices such as DVRs, STATCOMs, and UPQCs are noted for their effectiveness in mitigating voltage dips and peaks, with UPQCs providing superior compensation. A UPQC combines active series and shunt filters connected in cascade through a common DC capacitor, primarily aimed at compensating for supply voltage issues. The integrated power system is a type of interconnected power system network only. The major problems associated with an interconnected system are a higher amount of system potential interruption complications and an unwanted higher amount of inrush currents and which leads the enormous potential and current harmonics. However, these power supply complication problems are severe in the context of integrated power system networks due to the addition of two or more power supplies are meets one point. The unified power quality control (UPQC) strategy [10,11,13] is best suitable for interconnected system operations compared to the other control strategies to minimize power quality issues. The basic UPQC control system is shown in figure 2 and comprises two fully controlled three-phase bridges connected in series with the transformer of the line to be protected.

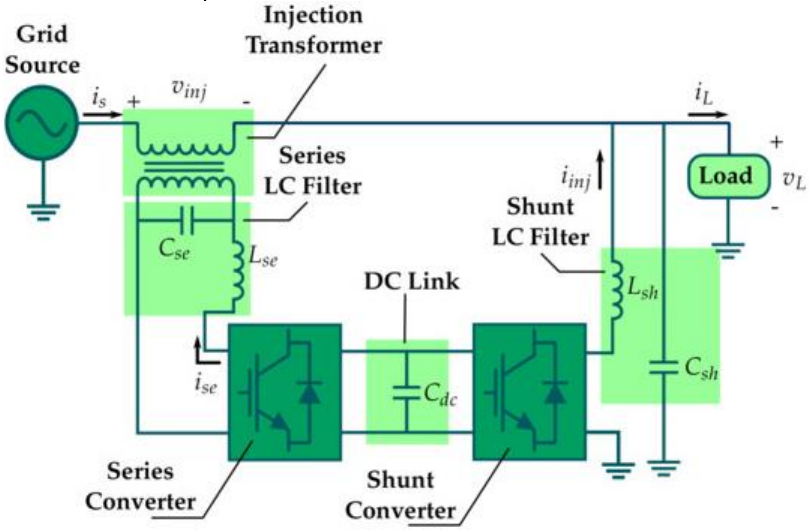


Figure 2: Schematic view of basic UPQC control scheme

UPQC addresses mains voltage disturbances to maintain a stable load voltage. It also compensates the load current to achieve the desired grid current. According to Kirchhoff's laws, as illustrated in Figure 1, the primary compensation equations involve the compensated load voltage VL(t), which is derived from the disturbed grid voltage Vs(t) and the voltage injected Vinj(t) by the UPQC. The grid current is(t) is influenced by the perturbed load current iL(t) and the current injected iinj(t) by the shunt converter. Additionally, the UPQC includes a series current converter ise(t).

The two three phase bridges are activating with the line voltage and line current input in feedback path to compensate the main line voltage and current complications i.e., harmonics in the system. The proposed UPQC control scheme is designed for nonlinear loads where these active and reactive power complications are higher.

RESULTS AND DISCUSSION

The proposed UPQC-based solar integrated power system was designed and analysed using MATLAB / Simulink software. The simulation results are checked without and with UPQC to examine the accuracy of the proposed work. The various parameter ratings assigned to study the proposed work are as follows below:

Table 1: System Parameters

Parameters	Values
Grid voltage and frequency	440 V, 50 Hz
Line resistance and inductance	0.2 ohm and 0.5 mH
PV generation system Open Circuit Voltage Short Circuit Current MPP voltage MPP Current Parallel Strings Series connected modules per string	 64.2 V 5.96 A 54.7 V 5.58 A 66 5
Series Transformer	630 KVA 440/440 V
Series converter Filter	2mH, 20 μF
Shunt Converter Filter	1.35 mH, 215 μF

The designed simulation model of the proposed UPQC based solar integrated power system is shown in figure 3

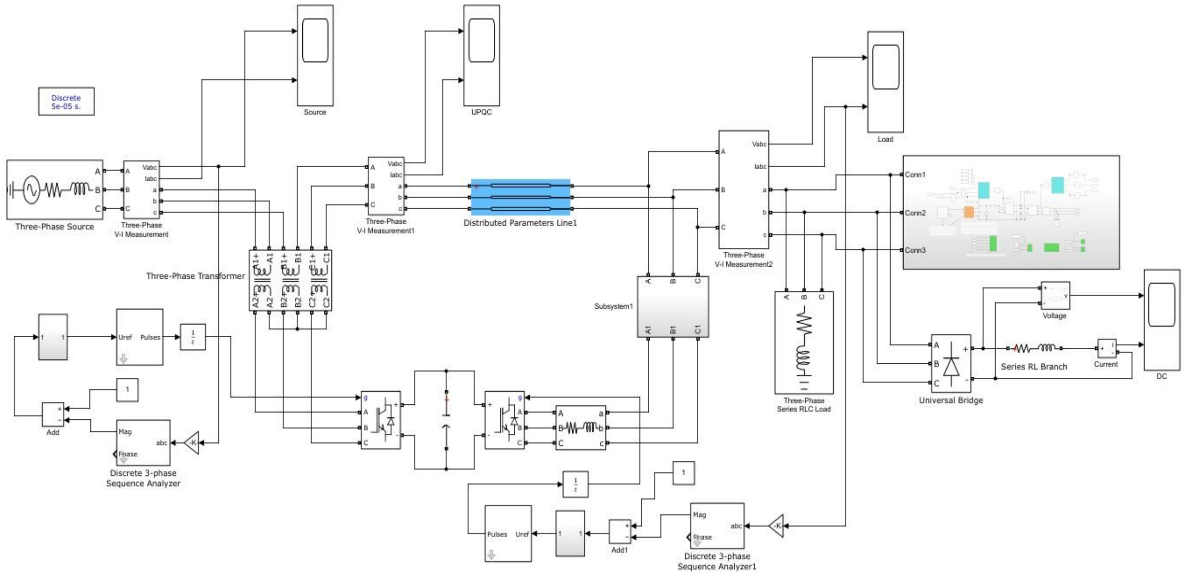
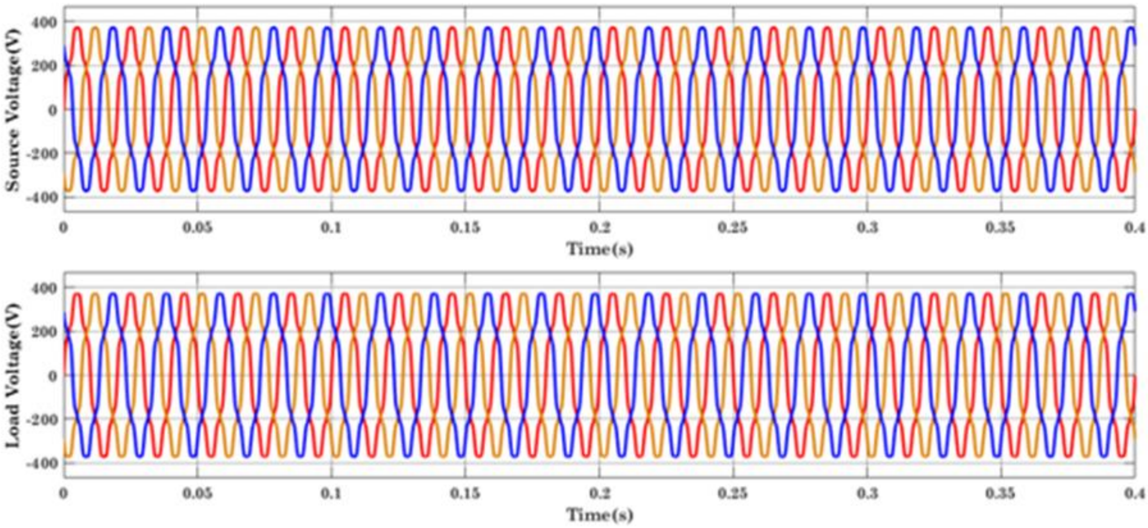


Figure 3: UPQC based solar integrated power system

Case 1: Without UPQC

In Case 1 of the study, the focus lies on investigating voltages and currents without integrating UPQC to proposed system. Figure 4, 5 displays the results without UPQC the load voltage and source current had a THD of 11.64% and 30.90%. These values underscore the significant presence of harmonic components in the system currents, indicating potential power quality issues. The suggested UPQC was integrated through filtration facilitated by the series and shunt converters, the UPQC mitigated the distorted load voltage and source current. By means of the implementation of the UPQC, the study aimed to effectively mitigate the adverse effects of harmonic distortions and enhance the PQ of the grid-connected PV system. These remedial measures are crucial for ensuring the consistency and efficiency of the system.



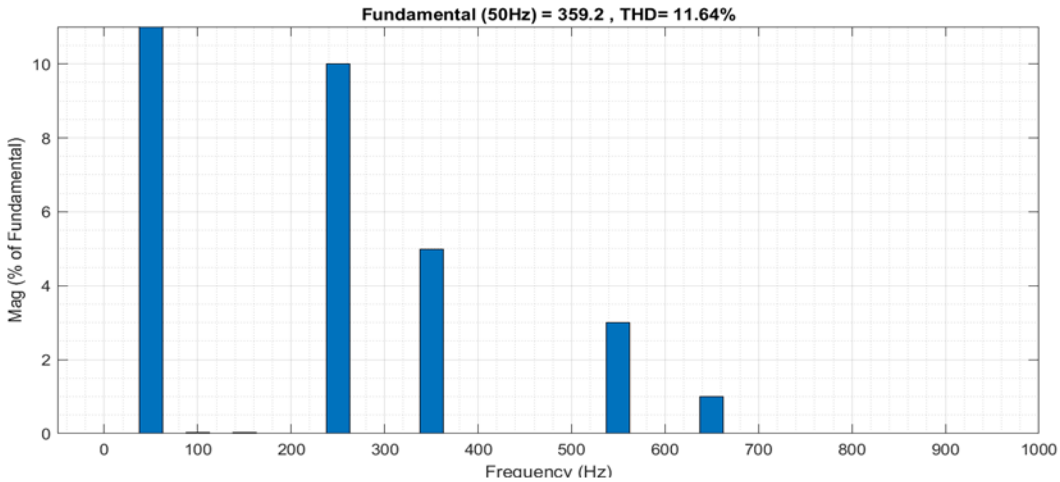


Figure 4: Source Voltage and Load Voltage without UPQC, %THD of Load Voltage without UPQC

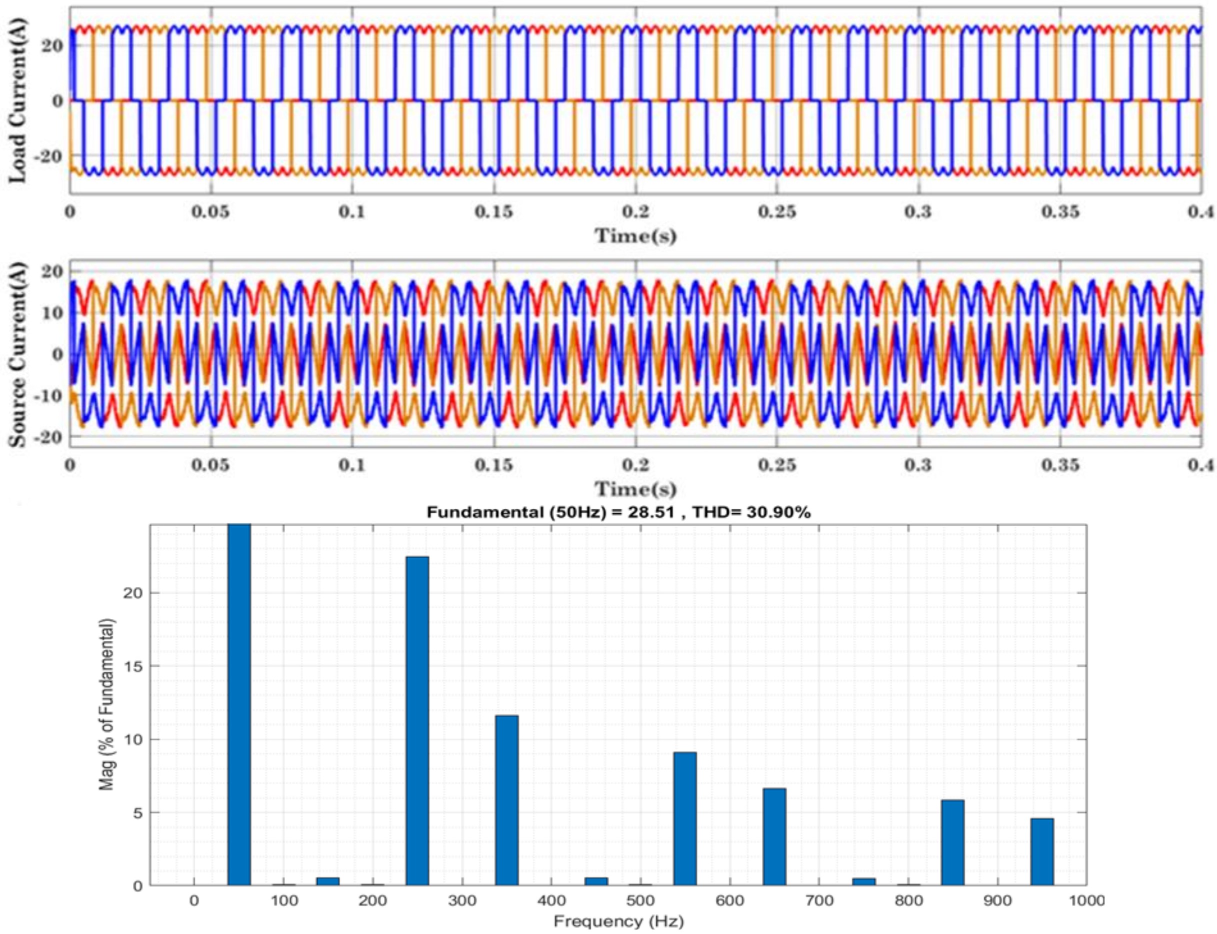


Figure 5: Load Current and Source Current without UPQC, %THD of source current without UPQC

Case 2: With UPQC

Upon implementation of the proposed UPQC, it was observed that the added voltage by the series converter reduced the THD of the load voltage to a 8.35% and THD of the source current to a 8.71%, indicating successful harmonic mitigation. Figure 6, 7 depicts the graphs of the voltage, current at Load and source with UPQC. With the added current from the shunt converter, the THD of the source current experienced a significant reduction from 30.90% to 8.71%, underscoring the effectiveness of the shunt converter in mitigating harmonic distortions.

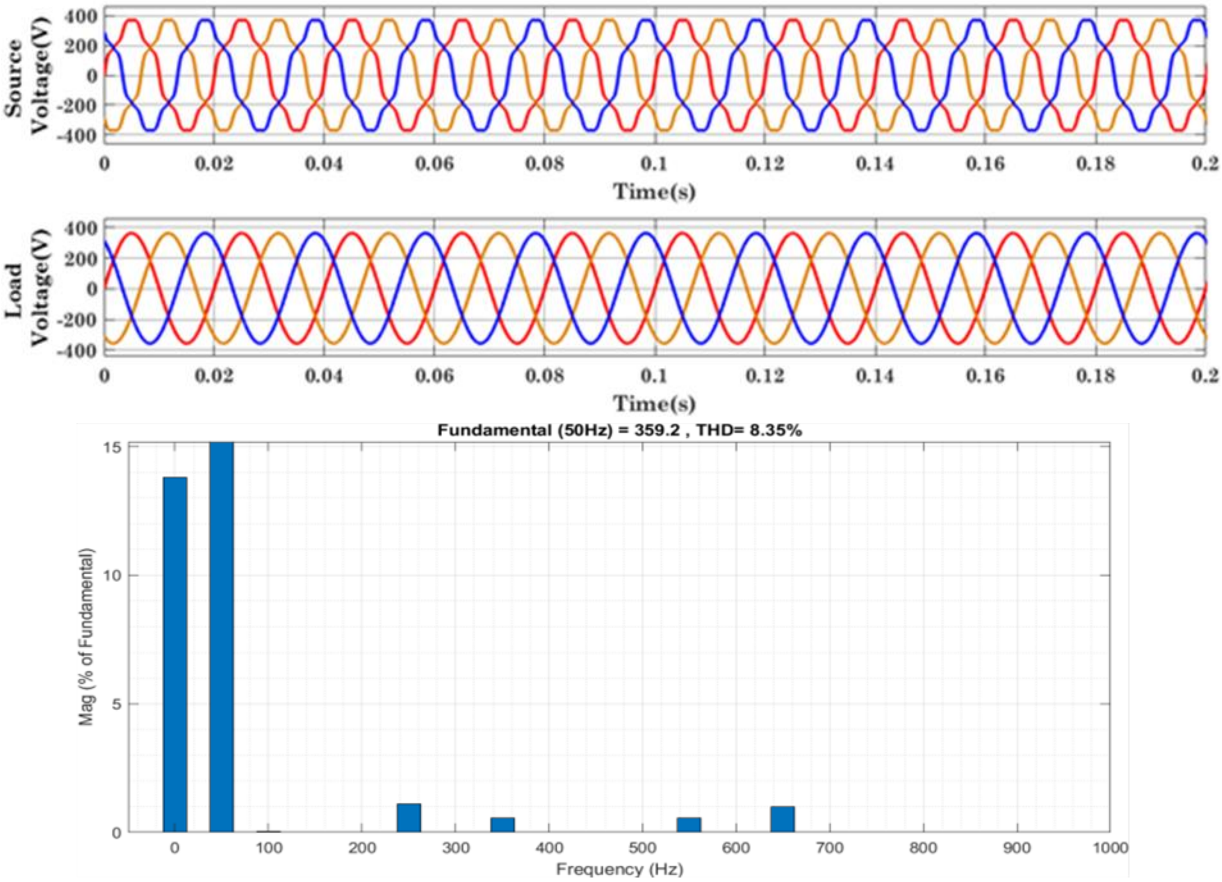


Figure 6: Source Voltage and Load Voltage with UPQC, %THD analysis of Load Voltage with UPQC

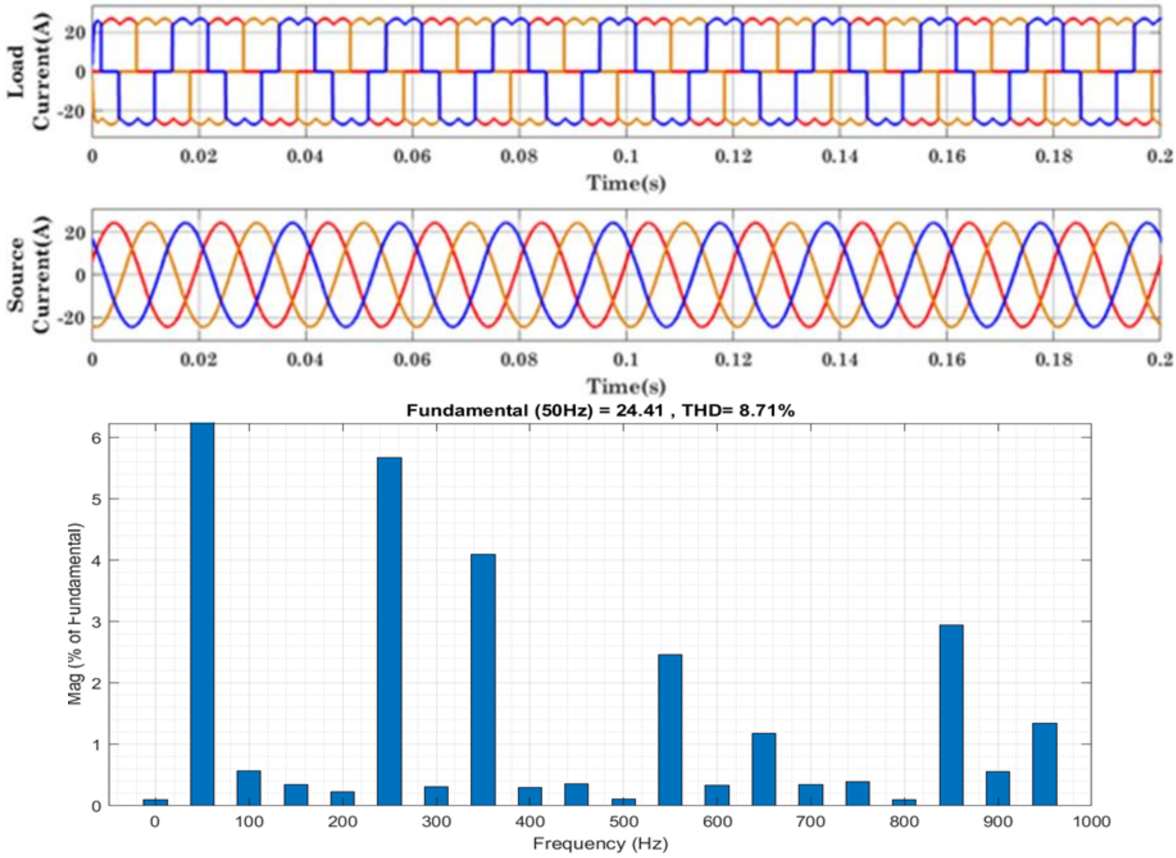


Figure 7: Load Current and Source Current and with UPQC, %THD analysis of Source Current With UPQC

In this study, the performance of UPQC was analyzed through simulation using MATLAB simulink software. The performance of the proposed UPQC is assessed in PV integrated 440V distribution network and the results are verified.

Table 2: % THD Comparison

	Without UPQC	**With UPQC**
%THD of Load Voltage	11.64%	8.35 %
%THD of Source Current	30.90%	8.71%

Conclusion

The proposed solar renewable energy integrated power system with UPQC offers low potential and current harmonics. The implementation of the UPQC has demonstrated significant improvement in power quality under harmonic distortions caused by nonlinear loads. Notably, UPQC decreasing the source current harmonics and the load voltage harmonics. These findings highlight the capability of UPQC in adapting to rapid changes in the reliability and efficiency of power delivery in renewable energy systems. The use of UPQC for harmonic mitigation in solar PV systems offers a robust and integrated solution that enhances power quality. Its ability to address multiple power quality issues with a single device represents a significant advancement in the management of renewable energy systems.

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