Three-Phase Solar PV Integrated UPQC Design and Performance Analysis

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Abstract**--** The purpose of this research is to discuss the design and performance of a three-phase single stage solar photovoltaic integrated unified power quality conditioner (PV-UPQC). The PV-UPQC is made up of a shunt and series coupled voltage compensators that are linked together with a shared DC-link. In addition to adjusting for load current harmonics, the shunt compensator extracts electricity from the PV array. For better PV- UPQC performance, an improved synchronous reference frame control based on a moving average filter is employed to extract the load active current component. The series compensator corrects grid-side power quality issues such as voltage sags/swells. During sag and swell circumstances, the compensator injects voltage in-phase/out-of-phase with the point of common coupling (PCC) voltage. The suggested technology combines the advantages of sustainable energy production and improved power quality. The system's steady-state and dynamic performance are assessed by modelling it in MATLAB-Simulink under a nonlinear load. The system's performance is then validated using a scaled-down laboratory prototype subjected to a variety of perturbations such as load unbalancing, PCC voltage sags/swells, and irradiation fluctuation.

Index Terms *— Power Quality, shunt compensator, series compensator, UPQC, Solar PV, MPPT.*

I. INTRODUCTION

The prevalence of power electronic loads is increasing as semiconductor technology advances. These loads, such as computer power supplies, variable speed drives, switched mode power supplies, and so on, have extremely high efficiency yet demand nonlinear currents. These nonlinear cur- rents create voltage distortion at the point of common coupling, which is most noticeable in distribution systems. There is also a growing focus on sustainable energy production via rooftop PV system installation in small apartments as well as commercial buildings [1], [2]. However, owing to the intermittent nature of PV energy sources, greater penetration of such systems, especially in underserved distribution networks, causes voltage quality issues such as voltage sags and swells, which ultimately leads to grid instability. [3]–[7]. These voltage quality issues also cause frequent false tripping of power electronic systems, electronic system malfunctioning and erroneous triggering, and increased heating of capacitor banks, among other things. [8]–[10]. Power quality concerns on both the load and grid sides are key challenges for contemporary distribution systems. Because of the need for clean energy as well as the rigorous power quality requirements of complex electronic loads, multifunctional systems that can incorporate clean energy production as well as power quality enhancement are required. [11], [12] present a three-phase multi-functional solar energy conversion system that accounts for load side power quality concerns. [13, 14] present a single phase solar PV converter with active power filtering capabilities. Significant study has been conducted in the integration of sustainable energy production with shunt active filtering. Though shunt active filtering is capable of both load voltage management and reactive power injection, it does so at the expense of injecting reactive power. As a result, shunt active filtering cannot simultaneously manage PCC voltage and preserve grid current unity power factor. Due to the demanding voltage quality requirements for advanced electronics loads, the use of series active filters in small residences and commercial buildings has recently been advocated [15], [16]. In [17], a solar photovoltaic system with a dynamic voltage restorer is presented. In comparison to shunt and series active power filters, a unified power quality conditioner (UPQC) with both series and shunt compensators may conduct load voltage management while also maintaining grid current sinusoidal at unity power factor. Integrating a PV array with a UPQC provides the added advantage of clean energy production as well as universal active. [18–20] describe the integration of a PV array with UPQC. When compared to typical grid-connected inverters, the solar PV integrated UPQC offers various advantages, including improved grid power quality, protection of key loads from grid side disturbances, and increased fault ride through capabilities of the converter during transients. There is increasing interest in UPQC systems with the rising focus on distributed generation and microgrids [21], [22].

The creation of reference signals is a significant job in the management of PV- UPQC. Strategies for generating reference signals may be roughly separated into time-domain and frequency-domain techniques [8]. Because of the decreased processing needs in real-time implementation, time domain methods are widely employed. Instantaneous reactive power theory (p-q theory), synchronous reference frame theory (d-q theory), and instantaneous symmetrical component theory [23] are some of the regularly employed methodologies. The fundamental difficulty with using synchronous reference frame theory-based methods is that a double harmonic component is present in the d-axis current when the load is imbalanced. As a result, low pass filters with very low cut off frequencies are utilised to filter out the double harmonic component. As a consequence, dynamic performance suffers [24]. A moving average filter (MAF) is utilised in this study to filter the d-axis current in order to derive the fundamental load active current. This provides appropriate attenuation while without lowering the controller's bandwidth [25]. MAF has recently been used to improve the performance of DC-link controllers as well as for grid synchronisation employing phase locked loops (PLL). [26], [27].

The design and performance study of a three-phase PV-UPQC are discussed in this research. To boost dynamic performance during load active current extraction, a MAF-based d-q theory-based control is applied. The following are the primary benefits of the suggested system,

- Integration of clean energy generation and power quality improvement.
- Simultaneous voltage and current quality improvement.
- Improved load current compensation due to use of MAF in d-q control of PV-UPQC.
- Stable under various dynamic conditions of voltage sags/swells, load unbalance and irradiation variation.

The suggested system's performance is thoroughly examined under both dynamic and steady-state settings using the MATLAB-Simulink programme. The performance is then experimentally validated using a scaled-down laboratory prototype under different distribution system circumstances like as voltage sags/swells, load imbalance, and irradiation fluctuation.

II. UNIFIED POWER QUALITY CONDITIONER (UPQC)

The Unified Power Quality Conditioner (UPQC) is a versatile power conditioner that may be used to compensate for a variety of power source voltage disturbances and voltage changes, as well as to prevent harmonic load current from entering the power system. It is a specialised power device designed to mitigate the impact of disturbances on sensitive load performance. UPQC consists of two voltage-source inverters connected by a common dc connection that may be single-phase, three-phase three-wire, or three-phase four-wire [2]. One inverter is controlled as a variable voltage source in the series active power filter (APF), while another inverter is controlled as a variable current source in the shunt active power filter (APF). In series, the Active Filter compensates for voltage supply anomalies (e.g., including harmonics, imbalances, sag, swell, flickers, negative and zero sequence components). The shunt filter compensates for load current distortions (due to harmonics or imbalances), reactive power, and dc link voltage management.

III. SYSTEM CONFIGURATION AND DESIGN OF UPQC

Figure 3.1 depicts the PV-UPQC design. The topology is specifically developed for a 3ph system. The system layout included series converters and shunt converters connected back to back with a DC-bus in between. The shunt converters are generally linked at the load end. To prevent electricity from flowing in the other direction, the solar photovoltaic array will be directly linked to the UPQC's common DC-link capacitor through a diode with reverse blocking capabilities. The series converter is generally controlled by voltage and will correct for grid voltage sags/swells. A shunt converter and a series converter are linked to a network or an electrical grid through interface inductors. A series connected injection transformer may be used to inject voltage signals produced by a series connected compensator into a power grid system. The harmonics generated by the frequent switching of the converters will be filtered out by ripple filters. In this case, a nonlinear load with a bridge rectifier linked to a voltage-fed load is employed.

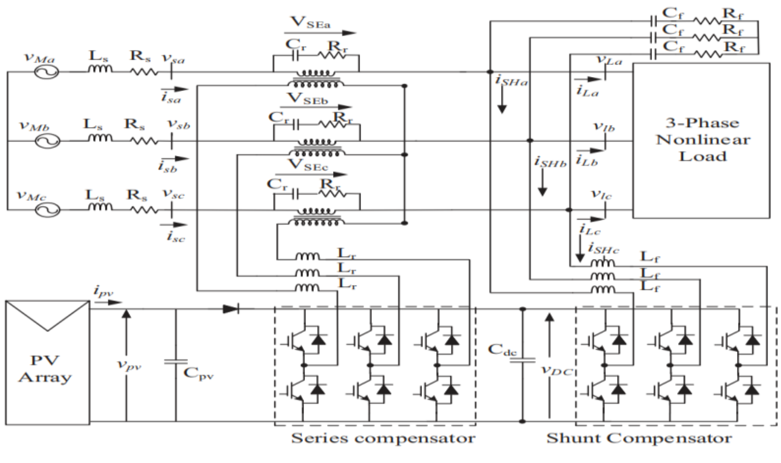

Figure 1: System Configuration of PV-UPQC

A. Basics of design configuration of PV-UPQC

The processes in developing the PV-UPQC begin with the right size of the solar photovoltaic array, DC-Link voltage level, and DC-link capacitor. Shunt converter size should be carefully chosen since it must resolve the highest amount of power output accessible from the solar Photovoltaic array as well as compensate for reactive power and current harmonics. Because the photovoltaic solar array is precisely integrated with the system through a shared DC connection of the UPQC, while choosing the size of the PV array, it should be ensured that the MPP voltage equals the needed voltage at the DC link. When determining the power rating, it is critical to remember that, under typical circumstances, a solar array should give active power to the load as well as feed power back into the power grid. Other components include series-connected interfacing inductors, shunt compensators, and a series injecting transformer coupled to a series-connected compensator.

IV. RESULTS

A. Simulation results and discussion

The MATLAB model of the PV Integrated UPQC system is shown in Figure 4.1. A steady state as well as dynamic system behaviour of Solar PV-UPQC may be investigated using a simulation research in MATLAB programme. A nonlinear load is employed, consisting of a 3Ph diode bridge linked rectifier coupled to an R-L load. For simulation studies, a stepping size of 1e-6s is used. Different dynamic situations arise in the system, such as voltage sag and voltage swells at the PCC end and variations in photovoltaic irradiation.

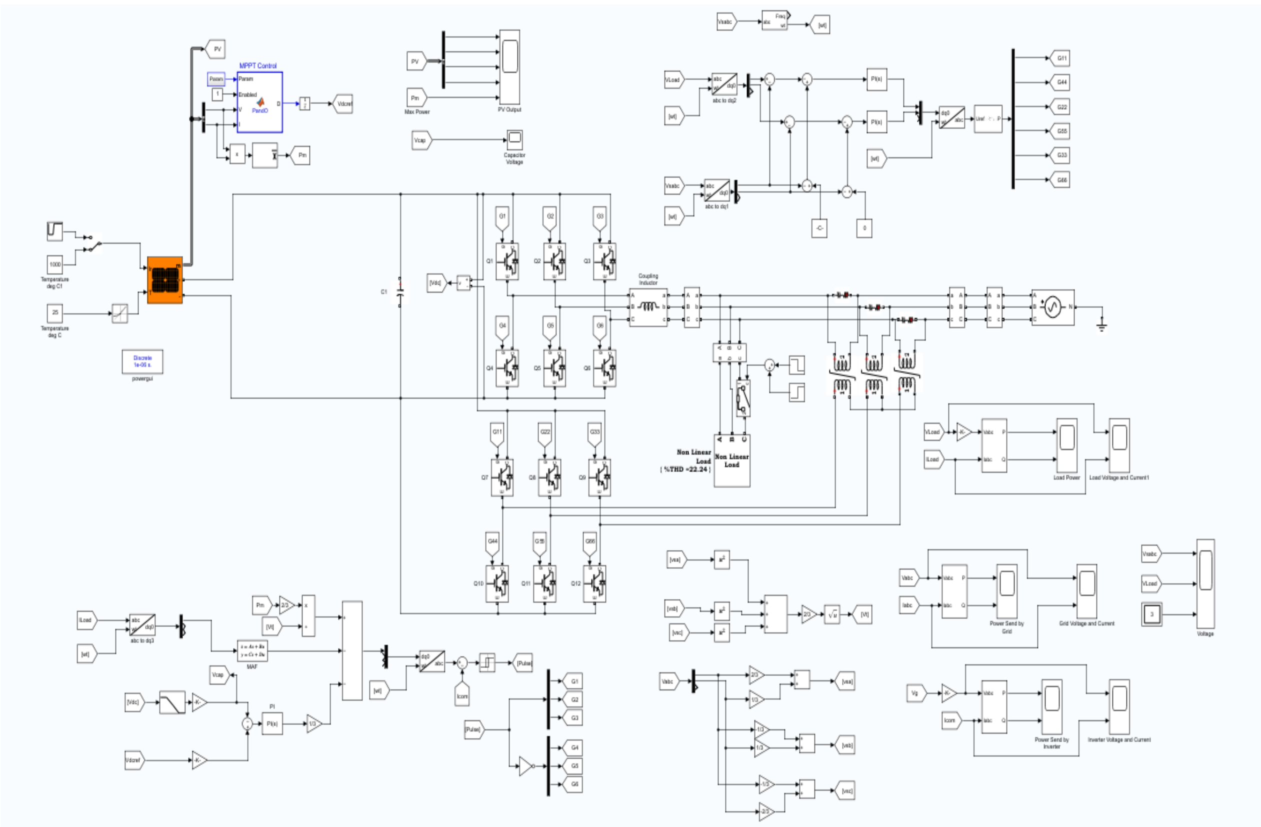

Figure 2: MATLAB Model of PV Integrated UPQC system

Table 1: Simulation Parameters

Simulation Parameters	Values
Maximum Power (W)	213.15
Cells per module (Ncell)	60
Open circuit voltage Voc (V)	36.3
Short-circuit current Isc (A)	7.84

Voltage at maximum power point Vmp (V)	29
Current at maximum power point Imp (A)	7.35
Parallel Strings	18
Series-connected modules per string	25

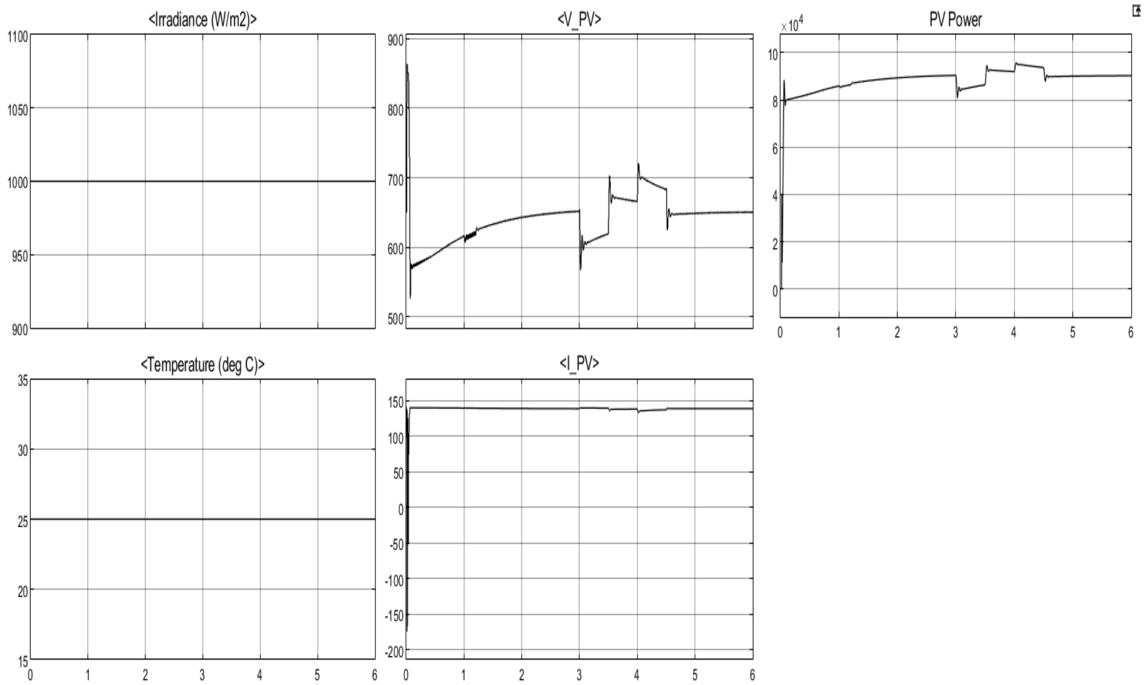

Figure 3: Irradiance, Temperature, Voltage-PV, Current-PV & Power-PV V/s Time in (S)

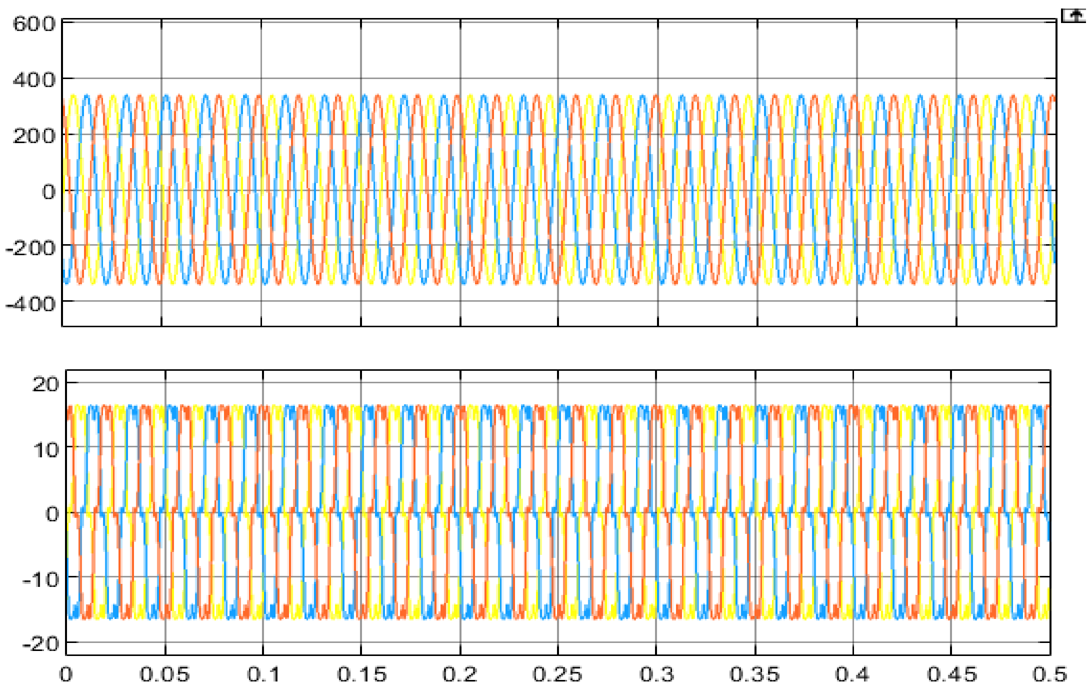

Figure 4: Load Voltage and Current V/s Time in (S)

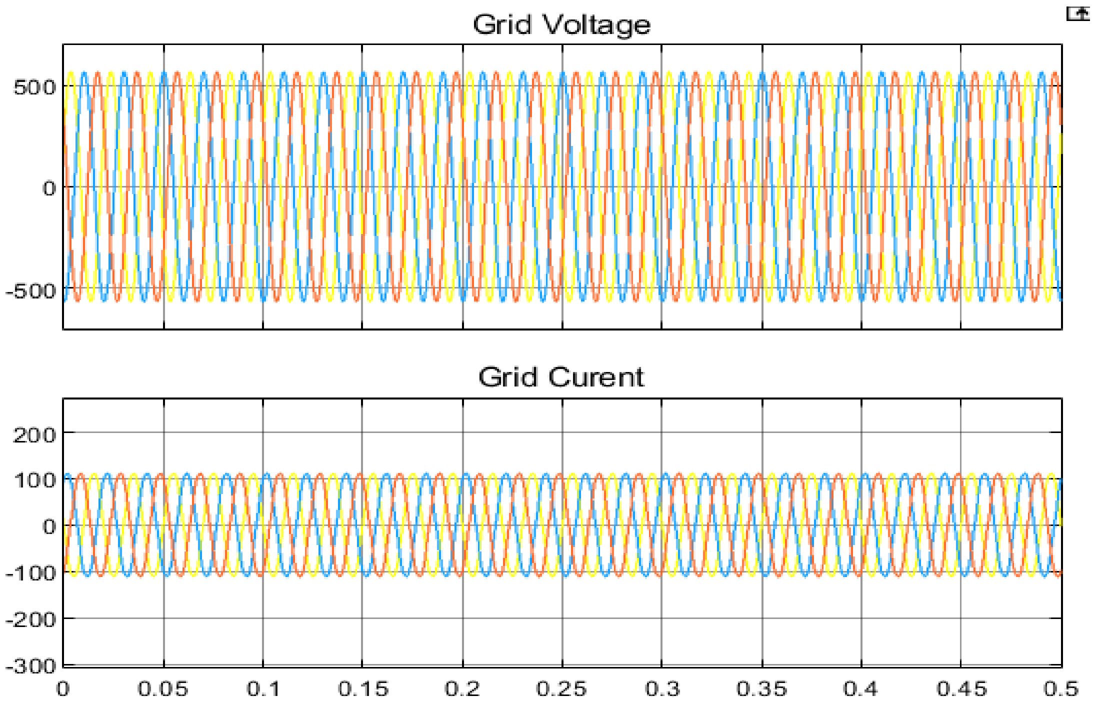

Figure 5: Grid Voltage and Grid Current V/s Time in (S)

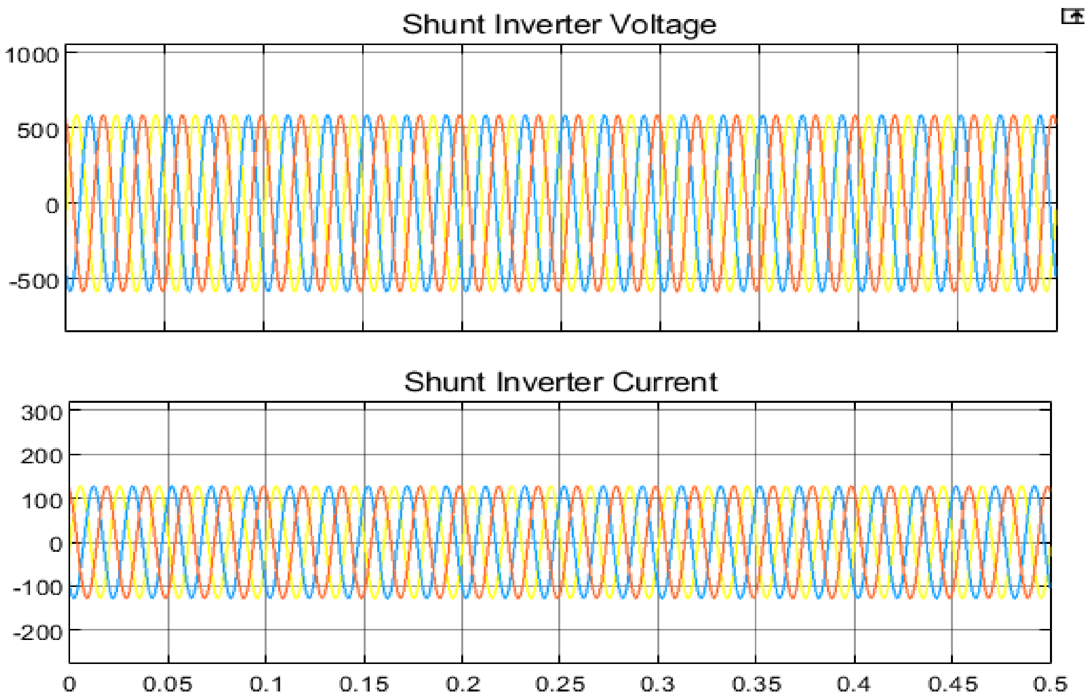

Figure 6: Shunt Inverter Voltage and Shunt Inverter Current V/s Time in (S)

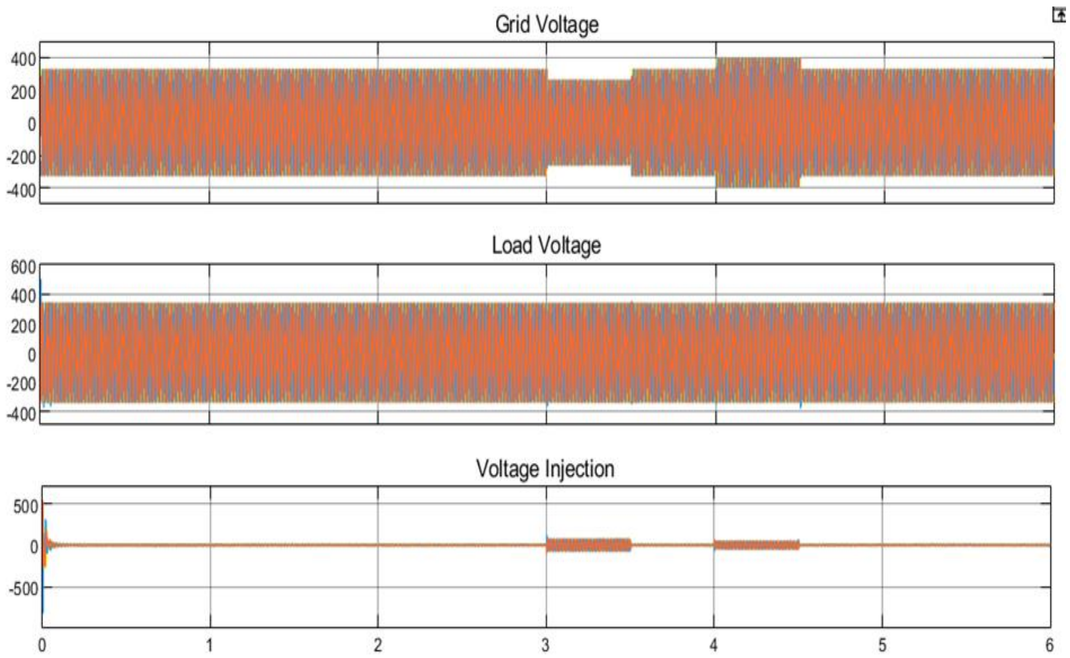

Figure 7: Grid Voltage, Load Voltage and Voltage Injection V/s Time in (S)

CONCLUSION

The design and dynamic performance of a three-phase PV-UPQC system were studied under varying irradiance and grid voltage sags/swells. The system's performance has been proven via testing on a scaled-down laboratory version. It has been discovered that PV- UPQC reduces harmonics induced by nonlinear loads and keeps grid current THD within IEEE-519 limits. The system is found to be stable during irradiation, voltage sags/swell, and load imbalance variations. The introduction of a moving average filter increased the performance of d-q control, especially under load imbalanced conditions. PV-UPQC is an excellent option for current distribution systems since it integrates dispersed generation with power quality enhancement.

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