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Power quality improvement in grid connected PV system by using UPQC with Fuzzy Logic Controller

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Abstract
Electrical energy is one of the most useful sources of energy, which is used to light up and run the world. The major source of electrical energy is from non-renewable energy sources like coal, natural gas, petroleum and other fossil fuels. Now-a-days, the world is moving towards renewable energy sources like solar, wind, hydro...etc. Among all these renewable energy sources, solar has become the widely used energy source because of its easy availability and installation. Solar power generated in PV system is connected to the grid and its power quality is affected due to the presence of voltage disturbances and harmonics. To resolve such an issue, this paper aims in improving power quality by using UPQC with the aid of fuzzy logic controller. UPQC consists of a series inverter for voltage related power quality issues and a shunt inverter to address the current harmonics caused by nonlinear loads. In addition to the power quality improvement. The proposed system will be implemented and the analysis will be carried out using MATLAB.
Keywords: *Photo Voltaic solar cell, solar radiation, Maximum Power Point, fuzzy logic controller, UPQC.*

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I. INTRODUCTION

This paper presents a photovoltaic system connected to the grid through UPQC. The main purpose of this paper is to eliminate the voltage and current related power quality issues due to source as well as nonlinear load. The interfacing medium between the grid and the PV system is UPQC which consists of two voltage source inverters (VSI) connected by a common dc link. One voltage source inverter is connected in series to the grid and another is connected in shunt to the nonlinear load. This also provides a solution for power quality issues like current and voltage harmonics as well as various issues related to reactive power and voltage source magnitude. A bidirectional DC-DC converter is used to boost the PV voltage in order to fulfill the DC bus voltage requirement of the voltage source inverter.

Flexible AC Transmission System (FACTS) devices like static VAr compensators are used to meet the load reactive power in a transmission system or near a designated load. Power electronic devices like active power filters are evolved to dynamically compensate the disturbances due to the source voltage as well as due to the connected non-resistive and non-linear loads. Active power filters are classified as series and shunt connected power filters depending on their implementation and mode of integration into power system. The shunt connected power filters consists of shunt active power filters (SAPF), parallel active filters (PAF), DSTATCOM and STATCOM. The main objectives of these filters are load reactive power compensation, load harmonic power compensation and to protect the grid from unbalanced loads and industrial disturbances. The series connected active filters consists of Series Active Filters (SAF) and Dynamic Voltage Regulator (DVR). The main objective of these devices is to protect the connected load from voltage sag, swell and distorted main voltage.

To provide an active & flexible solution for power quality problems, various efforts have done from time to time. Among these power quality solution lossless passive filters consists of L-C tuned component have been widely used to suppress harmonic. Passive filters are advantageous as its initial cost is low and high efficiency. On the other hand, it has various drawbacks of instability, fixed compensation, resonance with supply as well as loads and utility impedance. To overcome these limitations active power filters have been used. Active power filter has various configurations: shunt, series and hybrid. Hybrid is the combination of series and shunt types. Shunt APF is used for compensating current based distortions while series APF compensates voltage-based distortions. Hybrid APF is applied for filtering high order harmonics. However, they have a problem that their rating is sometimes very close to load (up to load 80 %) in typical applications. Due to this reason, power quality level is not obtained. This causes power disturbances and customer dissatisfaction. To increase the reliability of the distribution system and face the power disturbance problems, an advanced power electronics controller devices have launched over last decades. The evolution of power electronics controller devices has given to the birth of custom power devices. UPQC is one the custom power devices. UPQC utilizes the advantages of both series and shunt active filters. UPQC is also the combination of two different inverters, so it is also called a hybrid active power filter.

II. METHODOLOGY

In this grid connected PV system UPQC is interfaced between photovoltaic system and grid. UPQC consists of two voltage source inverters (VSI) one connected in series with the grid and another connected in shunt to the load. The series voltage source inverter eliminates voltage related power quality issues and shunt voltage source inverter eliminates the current harmonics and reactive power burden caused by connecting non-resistive and nonlinear loads.

The series inverter is placed on the left-hand side where as the shunt inverter on the right side. The aim of the entire configuration to eliminate voltage and current related power quality issues related to source as well as the connected load simultaneously. The voltage magnitude across the load is always kept constant and free of any distortion irrespective of nature of source voltage. Once the constant voltage is available across the load, the operation of the rest of the system compensates for the load reactive power and the harmonics due to the connected load.

CONTROL ALGORITHMS FOR UPQC

The UPQC is a combination of series and shunt inverter with a common dc link capacitor. A good control structure is needed to integrate the PV system into the grid through UPQC. The control approaches for series and shunt inverter of UPQC are discussed below.

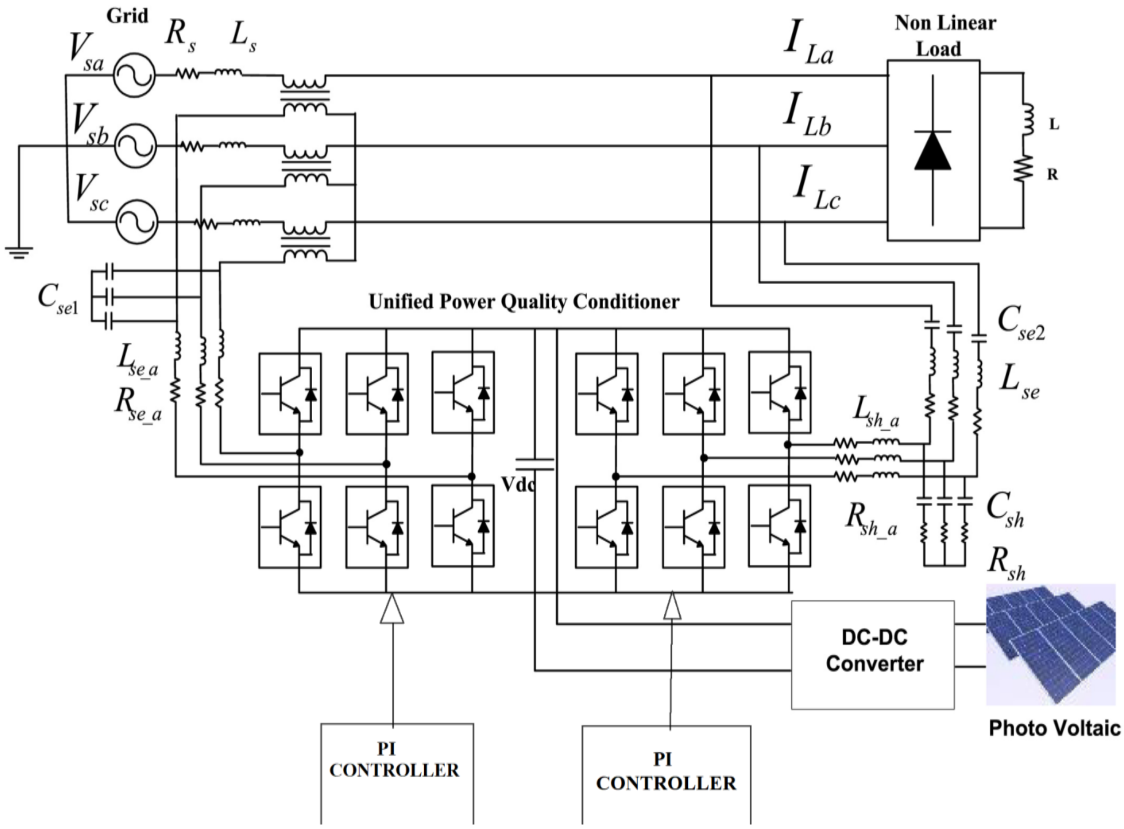


Figure 1: Traditional control method for UPQC.

CONTROL APPROACH FOR SERIES INVERTER OF UPQC

One of the frequently used control algorithms is the unit vector template generation (UVTG) control scheme, where the RMS value of voltage is multiplied with the unity sinusoidal signal extracted by using a phase locked loop (PLL) circuit is called as the reference source voltage. The reference source voltage obtained is compared with the load voltage and passed through a PI controller for generating required switching signal for the series inverter.

PI controller is used to control the series inverter. It continuously monitors the square of the RMS value of the measured source voltage and the RMS value of the compensated load voltage. The measured load voltage (V^2_{rms}) is considered as the reference voltage which is continuously compared with the source voltage (grid voltage). Any variation in the magnitude of grid voltage like voltage swell and sag can be corrected with this arrangement.

CONTROL APPROACH FOR SHUNT INVERTER OF UPQC

The shunt inverter of UPQC is controlled by using fuzzy logic controller. Fuzzy logic control is well known artificial intelligent based control technique. It makes use of the prior experience of the functionary about the system to be controlled .The main objective of the functionary is to set up decision based rules by analyzing the system behavior and linguistic input variables within the framework of the system .The inputs provided to the FLC have to process through three basic stages of fuzzification, decision-making stage and defuzzification before generating the output .In the fuzzification stage , the input variable is transformed into linguistic variable with the help of predefined membership functions (MFs). The output of the fuzzification stage is then used to generate the fuzzified output according to the rules set defined. Finally, in the defuzzification stage the fuzzified output is transformed into the required output used for controlling the system.

Figure 4 Shows the block diagram representation of fuzzy logic controller, where the measured dc voltage (V_{dc}) is compared with the reference dc voltage (V^*_{dc}) to generate error signal e (error(e)=V^*_{dc}-V_{dc}). The error signal and (e) and the rate of change of error (de/dt) is passed through the fuzzy logic controller for further processing to generate the reference currents by maintaining the voltage across the capacitor at a constant level.

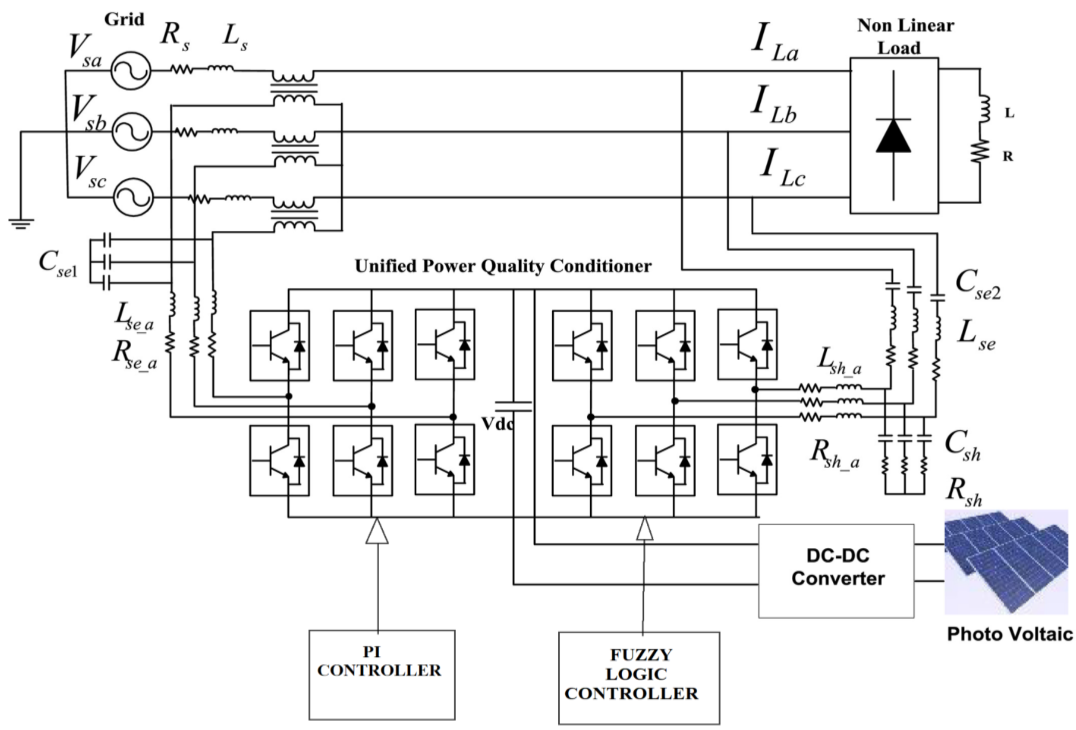


Figure 2: Proposed control method for UPQC.

The internal configuration is carried out through language-based rules. This implies e and de/dt are transferred to linguistic variables using seven numbers of fuzzy sets. The seven fuzzy sets are: (i) NL (Negatively Large), (ii) NM (Negatively Medium), (iii) SN (Negatively Small), (iv) Z (Zero), (v) LP (Positively Large), (vi) PM (Positively Medium), PS (Positively Small). With two numbers of inputs and seven set for each of the inputs, there can be forty-nine (49) numbers of input pairs as shown in the table. The fuzzy if-then rule is utilized to control the DC bus voltage. The min-max method has been implemented for the fuzzification of language-based inputs. Figure 5 shows the normalized triangular membership functions used in the fuzzification.

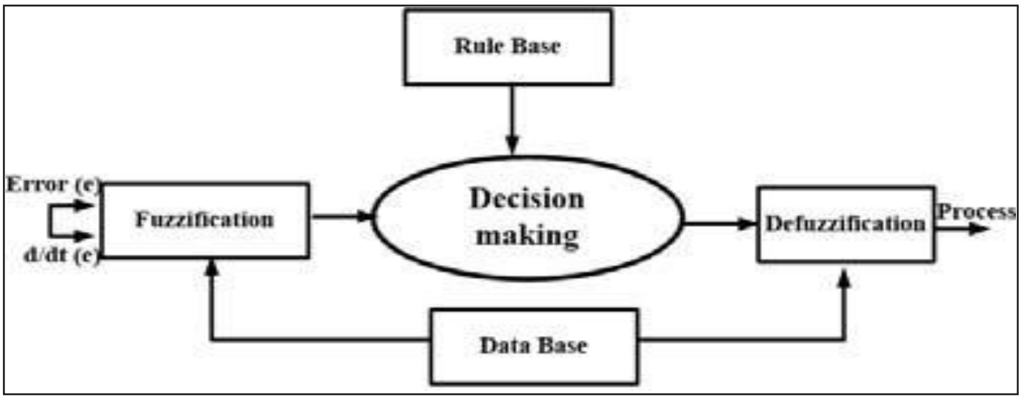


Figure 3: Block diagram of a Fuzzy Logic Controller.

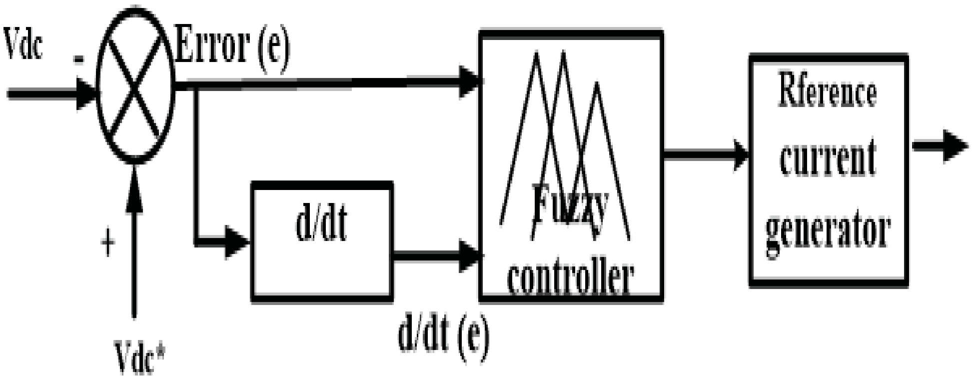


Figure 4: Block diagram representation of FLC.

Similarly, for the de-fuzzification of the crisp variables centroid method is preferred. Hysteresis band current control technique (HBCCT) is used for controlling the inverter output current. For keeping the inverter's output current within a specific zone, the error signal of reference current and inverter current signal is fed to the relay switch. This zone is created around the reference current, where the single-phase control algorithm is applied in each phase independently. Even though incorporating three individual control circuits for a three-phase system seems to be a difficult task. Under unbalanced load currents, unbalanced source voltages, and distorted source voltage the single-phase p-q control algorithm is more suitable. As each phase is independently controlled using a single three-leg inverter. The advantage of using single-phase control in the three-phase systems is a) it compensates for load reactive power b) it generates sinusoidal current waveforms in the utility side for following cases b.1.) unbalanced utility voltages b.2.) Unbalanced load side currents.

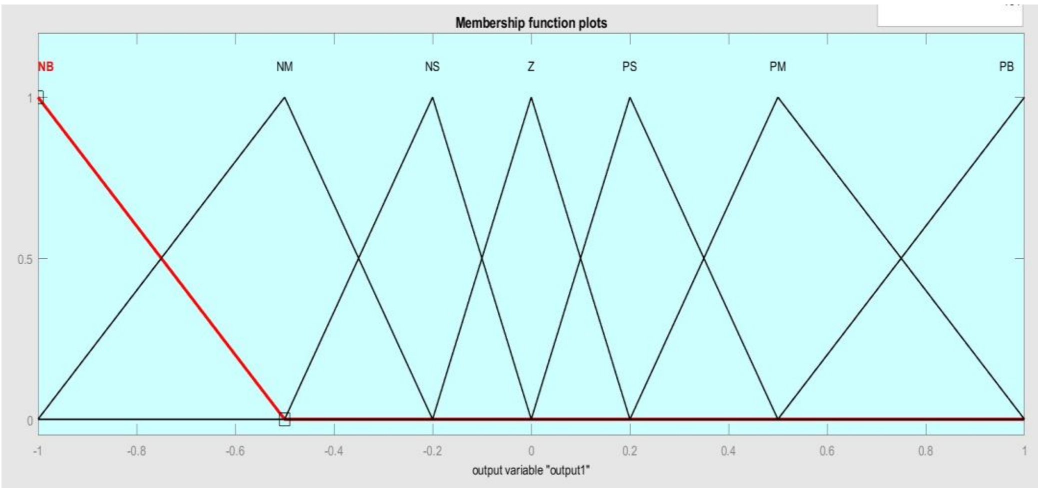


Figure 5: Membership Functions.

Table 1: Simulation Parameters

Components	Values	
PV module parameters	Open Circuit Voltage	37.2 V
	Short Circuit Current	8.48A
	Maximum Power	235 W
Inductive Coupling	3.6mH	
DC capacitor	9.3mF	
Load	R	5
	L	15 mH
Grid	Voltage	230V
	Frequency(f)	50Hz

The analysis of three phase grid connected PV system with two voltage source inverters is done. Power quality issues have been identified and resolved by the use of UPQC. Modification in the control algorithm is needed to address the voltage magnitude deviation. A detailed dynamic case study has been carried out in the next analysis to find out the effect of PV-UPQC performances under various voltage related distortion and deviation in magnitude. The Simulink blocks and simulation results are given below.

III. SIMULATION RESULTS

The trials were carried out in a grid-connected photovoltaic system with a non-linear load for source voltage sag/swell and swelling with distortion. The series inverter's ideal voltage can be filtered out and applied across the shunt connected inverter and the non-linear load. This shows that the source voltage across the load is always of the same magnitude and phase as the source current and ideal.

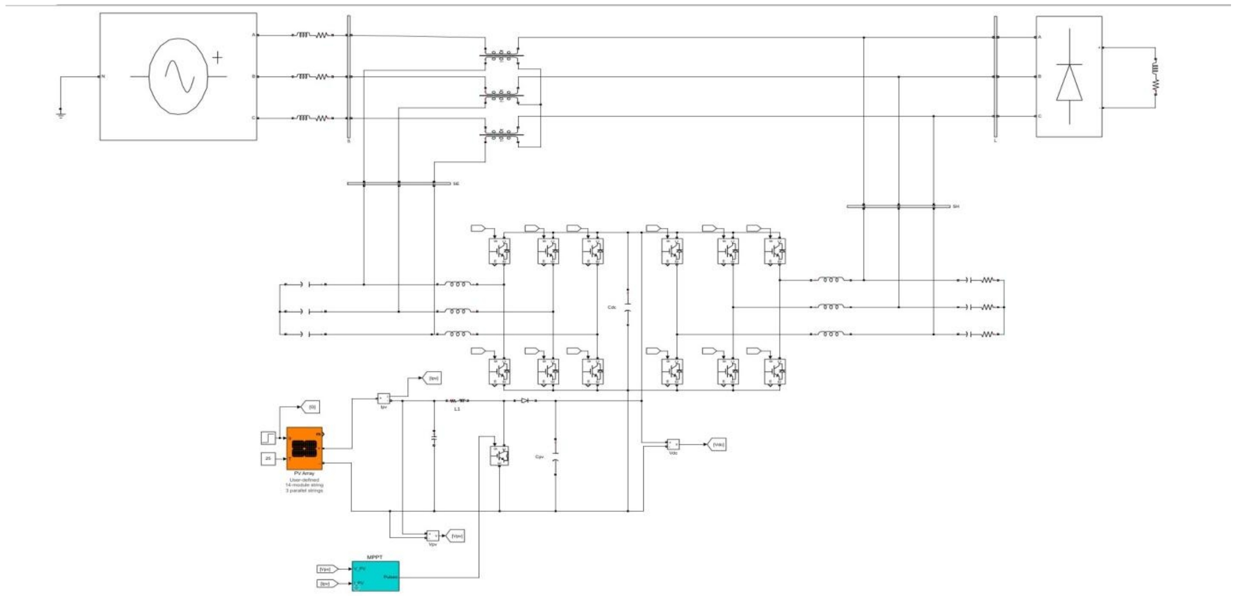
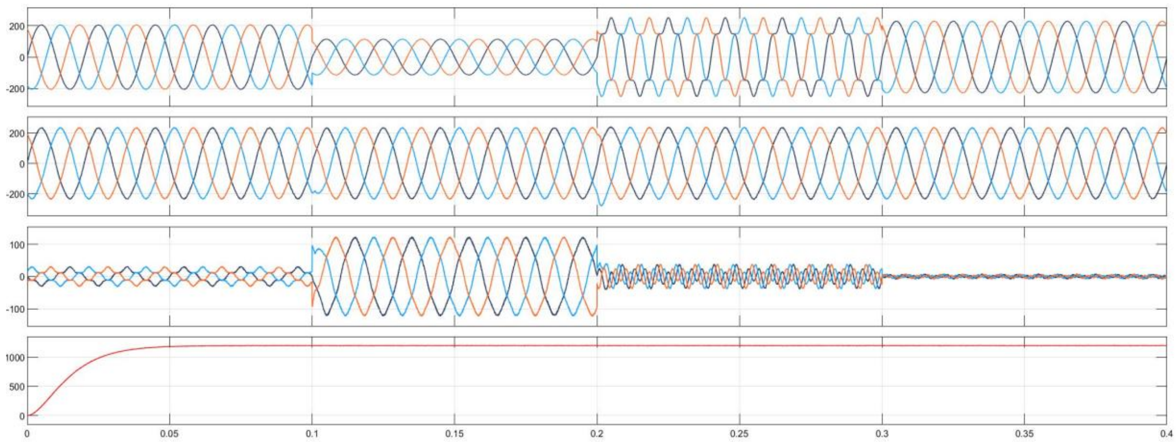


Figure 6: Simulink diagram of grid connected PV system through UPQC.



Time(s)

Figure 7: Simulation results under various voltage disturbances.

Figure illustrates the simulated mains voltage sag and swell processes in four sub-figures organized from top to bottom. The input (mains) voltage to the left-series (or UPQC) voltage source converter is shown at the top, followed by the compensated output voltage available across the loads (or across the right shunt VSC) connected to the grid, the compensating series inverter voltage output signal, and finally the DC bus capacitor voltage, which remains steady and constant throughout the observation. From t = 0.1 s to 0.2 s, sag is applied, and from t = 0.2 s to 0.3 s, voltage swell is applied with distortion, and the distortion is eliminated at t = 0.3 s.

The voltage and current output of the UPQC's series-connected inverter are shown in Fig. 10. Regardless of source voltage fluctuations, the voltage observed by the shunt converter or the voltage seen at the load is always sinusoidal and perfect.

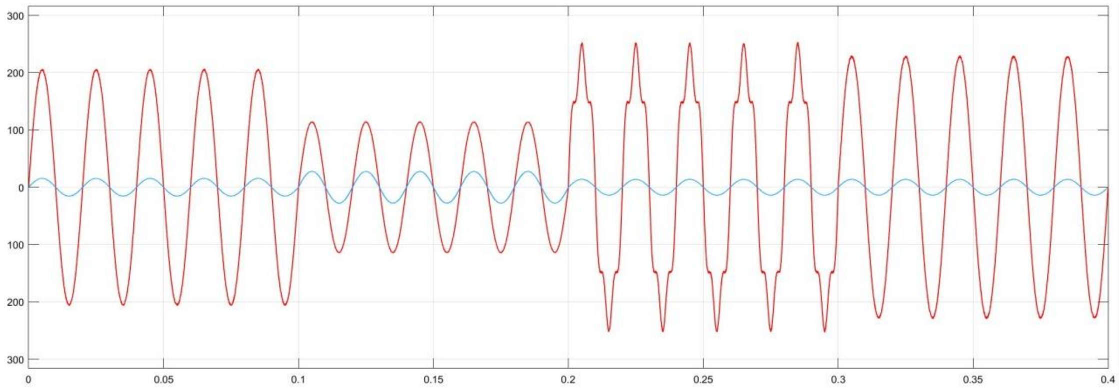


Figure 8: Phase relationship between voltage and current of phase 'b'.

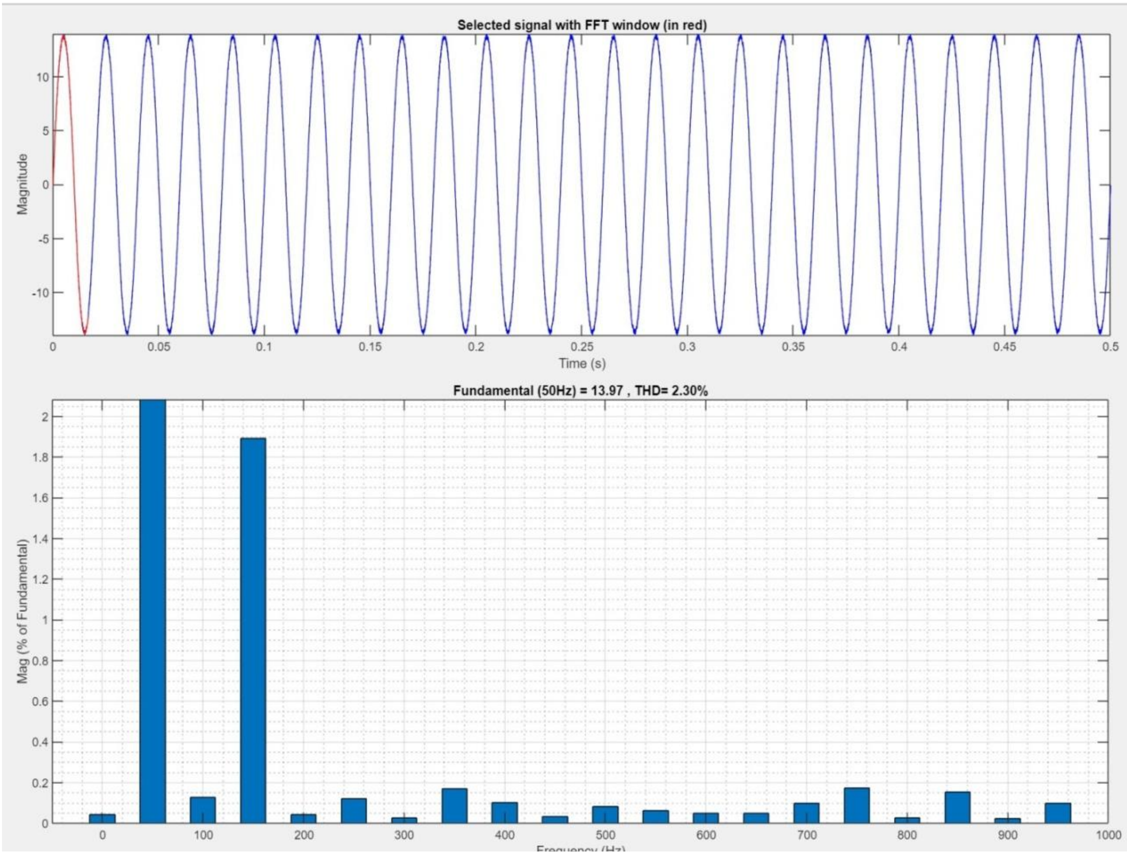


Figure 9: Source current with the traditional method (without the FLC)

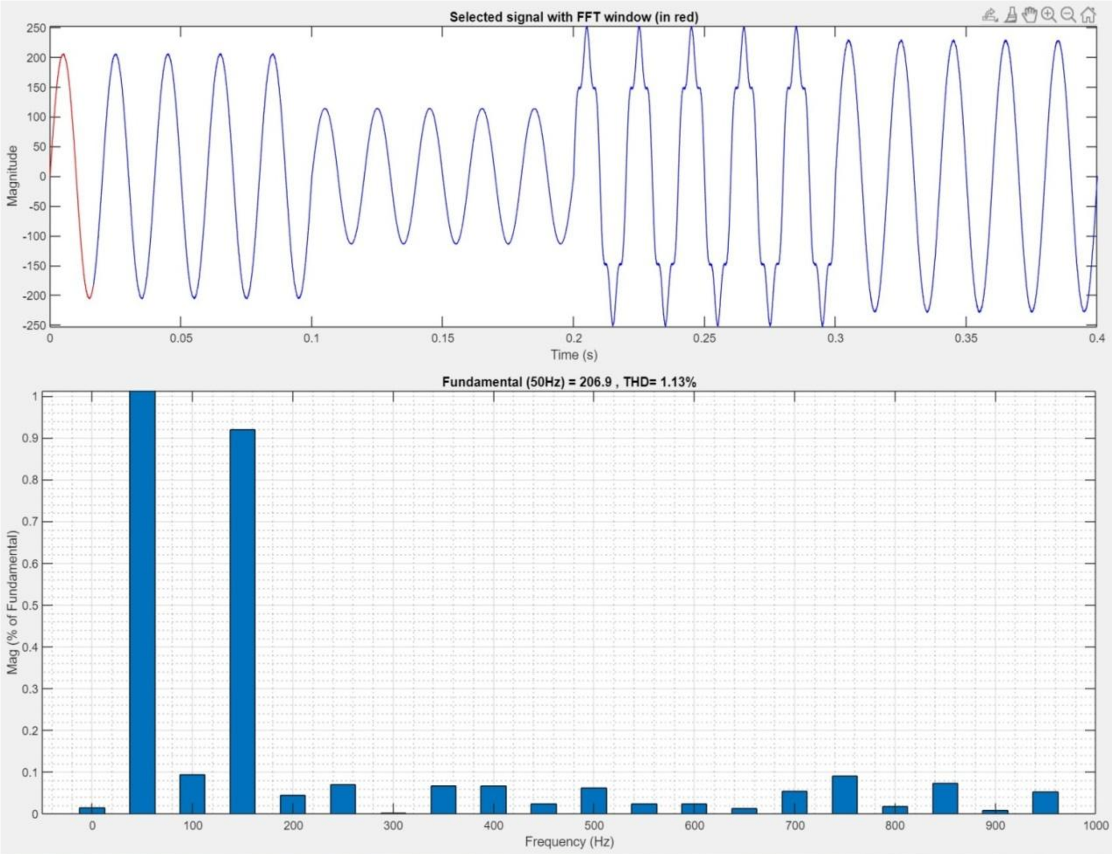


Figure 10: Source current with the proposed method.

From the above two figures, figure 9 and 10, it is observed that the steady state performance has been improved using FLC compared with the traditional method (without FLC) under ideal voltage input. Figures 9 and 10 show the THD values. In the traditional method the THD value is greater which is of 2.30% and in this proposed method the THD is greatly reduced to 1.13%.

IV. CONCLUSION

This arrangement takes advantage of the advantages of series and shunt converters with a single DC bus capacitor. To eliminate source voltage distortion, the left-series converter is used. To reduce the load current harmonics, the right-shunt converter is used. The abovementioned control mechanisms were truly tested under various source voltage variations, and their steady-state performance was compared to that of a typical (without FLC) control method. The voltage across the load or the voltage across the right-shunt inverter is found to be constant when the source voltage varies from the nominal value. As a result, the proposed PV-UPQC arrangement can be concluded to be a multitasking and universal device that is suitable under the influence of various power quality issues as well as an ideal source voltage scenario.

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