

FLC-based integration of UPQC-enabled solar PV systems into the grid

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Abstract

Voltage stability in integrated photovoltaic (PV) distribution systems is crucial for enabling the efficient operation of all linked equipment in the distribution network. Maintaining voltage profiles is one of the difficult issues in PV integration. The major goal is to sustain a load with a constant voltage profile of 22 kVA. It is decided to use a single-phase PV integrated distribution system. The usage of differential inverters in the unified power quality conditioner's dynamic voltage restorer (DVR) and distribution static synchronous compensator (D-STATCOM) is new (UPQC). Syncing a 10 kW solar PV system with the distribution grid is the goal. system employing this brand-new UPQC with a fuzzy controller. It derives the best control method for the UPQC with battery energy storage system. For the PV integration and to improve the voltage stability of the distribution system, a 20 kVA UPQC is created. The total harmonic dispersion of the system is decreased by assuming constant values for the distribution system's frequency, voltage, and reactance/resistance ratio.

INDEX TERMS: DVR, PV, D-STATCOM, UPQC.

1. Introduction

The utility should supply power at the rated voltage and frequency meeting the power quality (PQ) standards. The present-day PQ issues include high reactive power consumption due to low power factor loads, the low harmonic current burden due to non-linear loads such as converters, battery chargers, mercury vapour lamps, computers, welding sets, arc furnace, etc. Moreover, the loads in distribution supply may not be in a balance due to single-phase loads. photovoltaic (PV) system is a renewable energy source and is pollution free. Integration of PV will reduce the general energy requirement and losses in the distribution system. Although there are studies that explore the possibility of PVs providing reactive power [1, 2], the most common equipment on the market is deficient in its ability to supply reactive power to the system. Measures to mitigate these PQ issues is the need of the hour in the power sector. Unified PQ conditioner (UPQC) is a compensating device widely used for PQ improvement of the system. It has two Voltage Source Inverter (VSIs), namely distribution static synchronous compensator (D-STATCOM) and dynamic voltage restorer (DVR). Dynamic compensation of reactive power is essential in the system and D-STATCOM is an excellent choice for the above compensation, as it will work with extra active filtering functionality. The DVR is mainly used to eliminate voltage-sag and swell, the two VSIs connected in differential mode (DM) and the differential inverter is explained in one of the sections separately.

This paper presents the integration of solar PV to the grid using UPQC. The PQ indicates voltage quality and frequency stability. The frequency of the Indian grid is stable but the voltage profile requires improvement in certain areas. If the voltage changes by 1%, the power will vary by 2% for impedance type loads. Similarly, if the demand/generation changes by 5%, the frequency changes by 1 Hz for the integrated national (India) Grid. The output power of lights and induction motor will be affected with frequency deficiency.

IEEE standard 1159(1995) governs the PQ of low tension (LT) voltage and currents of the power supply. The allowable dip limits are from 10 to 90%, which last for 0.01 to 0.06 s. The classifications in dip are temporary, instantaneous and momentary. When earth fault occurs in one of the lines, there will be a rise in voltage (swell) in other phases [3]. It is possible to realise active power compensation with the energy storage device at the input of the inverter [4, 5].

The conventional methods of reactive power compensation are using fixed capacitors or reactors, controlled capacitors or reactors, static volt-ampere reactive (VAR) compensators, tap-changing transformers, excitation control of generators etc. These methods suffer from the dynamic adjustment of reactive power. The shunt reactors are in use for reducing line over-voltage and shunt connected capacitors are connected to improve voltage when the system load is high. Shunt capacitors and reactors are not useful in maintaining voltage under dynamic load variations and will not support or provide real power requirement. Usually, D-STATCOM injects reactive power to the grid with proper scheduling of load compensation. Also, active power can be injected into the line if the DC link of D-STATCOM makes use of battery energy storage system (BESS).

To maintain the voltage at any node or bus in a power system, balancing of the reactive power generation and demand at that node or bus is essential. If any mismatch occurs, there will be a change in voltage. Unlike frequency, the voltage is a local parameter to be analysed. Each node or bus plays a role in balancing reactive power. Moreover, the voltage in a bus is inversely proportional to the fault level of that bus. The voltage profile of a power system depends on the *V–Q* sensitivity. It should be positive in all buses and nodes to maintain voltage stability. If it is found negative in any one node or bus, then the system enters in voltage instability mode [6]. The issue of voltage sag and swells would be taken care of by DVR with good design and control strategy.

Analysis of the literature review that follows in a separate section shows that the design parameters of LCL filter, BESS, DVR, D-STATCOM and UPQC are missing in most of the proposals. Conventionally, grid-tied inverters for PV integration is in place. In this research work, the author aims to mitigate the gap by developing a new UPQC using differential inverters for both DVR and D-STATCOM for PV integration with the design of all the necessary parameters.

II. LITERATURE SURVEY

FLC-based integration of UPQC-enabled solar PV systems into the grid is a rapidly growing research area. Here are some recent research papers on this topic:

[1] "Fuzzy logic controller based UPQC for harmonic suppression and reactive power compensation in grid-connected photovoltaic system" by N. P. Kumari et al. This paper proposes a fuzzy logic controller-based UPQC for harmonic suppression and reactive power compensation in a grid-connected photovoltaic system.

[2] "A Fuzzy Logic Controller Based UPQC for Power Quality Improvement in Grid-Connected Solar PV Systems" by S. K. Singh et al. This paper proposes a fuzzy logic controller-based UPQC for power quality improvement in grid-connected solar PV systems. The proposed system is tested using MATLAB/Simulink.

[3] "Design and Implementation of Fuzzy Logic Controller based Unified Power Quality Conditioner for Solar Photovoltaic System" by M. G. Mehar and S. S. Rathore. This paper presents the design and implementation of a fuzzy logic controller-based UPQC for a solar photovoltaic system. The proposed system is tested using a hardware setup.

[4] "Design of Fuzzy Logic Controller for Unified Power Quality Conditioner for Solar PV System Integration with Grid" by P. V. Ramakrishna and M. K. Sai. This paper proposes a fuzzy logic controller for a UPQC for solar PV system integration with the grid. The proposed system is tested using MATLAB/Simulink.

[5] "Fuzzy logic controller-based UPQC for grid-connected photovoltaic systems with voltage and frequency control" by M. Mohammadi et al. This paper proposes a fuzzy logic controller-based UPQC for grid-connected photovoltaic systems with voltage and frequency control. The proposed system is tested using MATLAB/Simulink.

Overall, these studies demonstrate the potential of FLC-based control for integrating UPQC-enabled solar PV systems into the grid. However, more research is needed to optimize the design and implementation of these systems for practical applications.

II. METHODOLOGY

PV-integrated distribution system and UPQC

The UPQC is one of the custom power devices which consists of D-STATCOM and DVR. D-STATCOM is in shunt connection with the distribution line. The primary function lies in injecting or absorbing the reactive power set by the controller. It is possible to achieve unity power factor in source current if the D-STATCOM pumps entire reactive power and losses. Using the best control algorithms, we obtain proper tracking (injected current is the same as that of the reference current) and total harmonic distortion (THD) reduction of source current. So, the current reference generation is significant in the control strategy. D-STATCOM injects or absorbs active power with the BESS in the DC link.

DVR is connected in series with the line and used for sag and swell mitigation. The load voltage remains constant irrespective of disturbances in current or voltage. UPQC, a combination of DSTATCOM and DVR, is used for PQ improvement of the system. Patel *et al*. [7] presented a novel control, namely synchronous reference frame theory-based power angle (PAC) for UPQCDG to integrate solar PV system to the grid effectively. Reactive power sharing of load between series and active power filters with a better kVA utilisation and good PQ is a major advantage.

"In this method fuzzy is added to series controller. The total harmonic distribution values will be reduced, and reactive power is increased, and load voltage is stable."

Differential inverter

The DM buck inverter consists of two dc–dc buck converters, as shown in Fig. 1, with two operating modes, namely the DM and the common mode (CM). DM transfers active power while the CM compensates the second-order ripple power arising from the differential mode. Fig. 2 shows the CM circuit diagram, which is self-explanatory. The design of components of the inverter is

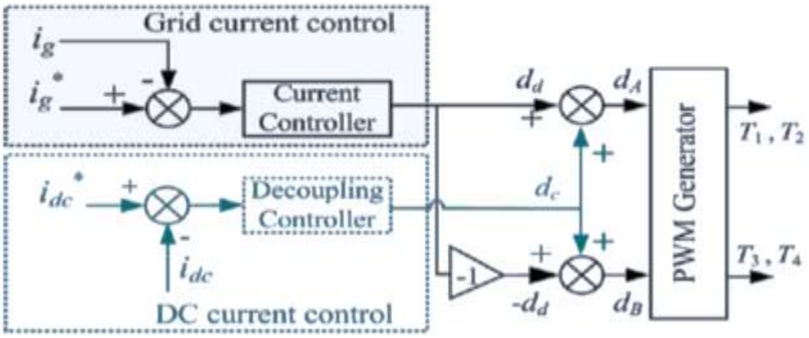

Figure.1: Control Structure of Differential inverter

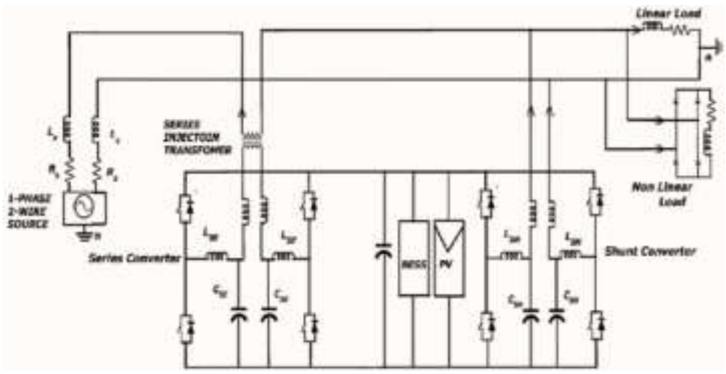

Figure.2: 1-phase UPQC using differential inverters

discussed separately in the following section [25]. The control strategy is also discussed in a separate section. Fig. 2 shows the control circuit of the differential inverter. This circuit has an additional DC compensation that achieves power decoupling. The battery current will be free from double frequency ripples and the life of the battery will be more if decoupling is employed. Moreover, the value of the ripple capacitor can be reduced.

Control strategy of UPQC

The schematic representation for the control strategy of UPQC is given in Fig. 3 using the circuit topology as per Fig. 2

Control of D-STATCOM

First of all, it is required to calculate the active power and reactive power of the load using a positive sequence power measurement tool available in the Simulink library. Adding the losses of the inverter to the active power and subtracting the PV power is required. The power so obtained is the power to be delivered by the source.

This is given to a PWM for pulse generation of pulse for leg A of the D-STATCOM. *U*REF is inverted and is provided as the second PWM generation pulse for leg B of the D-STATCOM. The generated voltage is filtered using the LCL filter, as shown in the circuit diagram. The D-STATCOM injects the active power of the PV source and the entire load reactive power demand (the DM connection takes care). The CM connection is used to circulate the ripple power through switches and capacitors. The filter capacitance generates the second-order frequency component of active power and is connected between the alternating current (AC) terminal and the negative side of the battery.

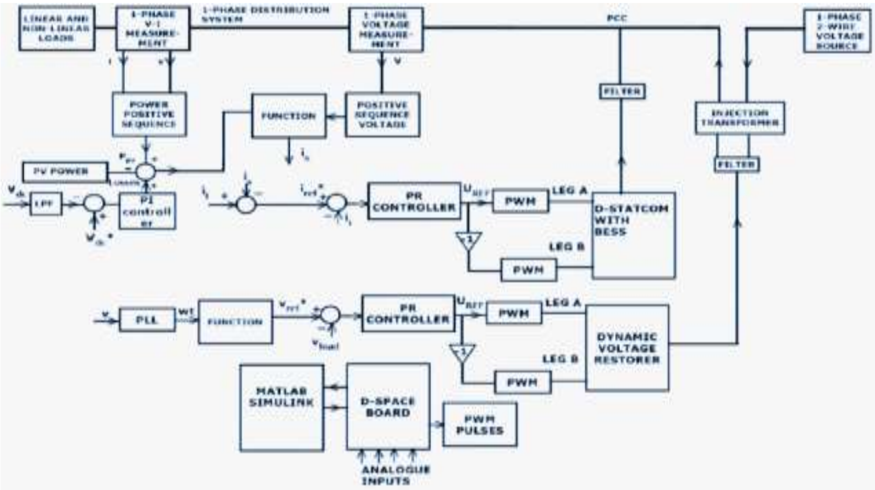

Figure.3: Control strategy for UPQC

Limitations:

FLC (Fuzzy Logic Control) can be a powerful tool for integrating UPQC (Unified Power Quality Conditioner)-enabled solar PV (Photovoltaic) systems into the grid, but there are several limitations that need to be considered:

a) **Complexity:** The integration of UPQC-enabled solar PV systems into the grid is a complex process that involves several components, including solar panels, inverters, UPQC, and control systems. FLC-based control can add another layer of complexity to the system, making it difficult to design and implement.

b) **Computational Requirements:** FLC-based control requires significant computational power, which can be challenging to implement in real-time systems. This can result in delays in response time, which can impact the overall performance of the system.

c) **Tuning Parameters:** FLC-based control requires the selection of appropriate control parameters, which can be challenging to tune. The selection of these parameters can impact the stability of the system, which can be a significant concern in grid-connected systems.

d) **Model Complexity:** FLC-based control requires a detailed model of the system, which can be challenging to develop. In addition, the accuracy of the model can impact the performance of the control system.

e) **Cost:** FLC-based control can be expensive to implement, which can be a significant barrier to widespread adoption.

f) **Maintenance:** FLC-based control requires ongoing maintenance to ensure that the system remains in optimal working condition. This can be challenging and expensive, particularly for large-scale grid-connected systems.

Overall, FLC-based integration of UPQC-enabled solar PV systems into the grid is a promising approach, but it requires careful consideration of the above limitations to ensure that the system is designed, implemented, and maintained correctly.

IV. SIMULATION Results

Simulink

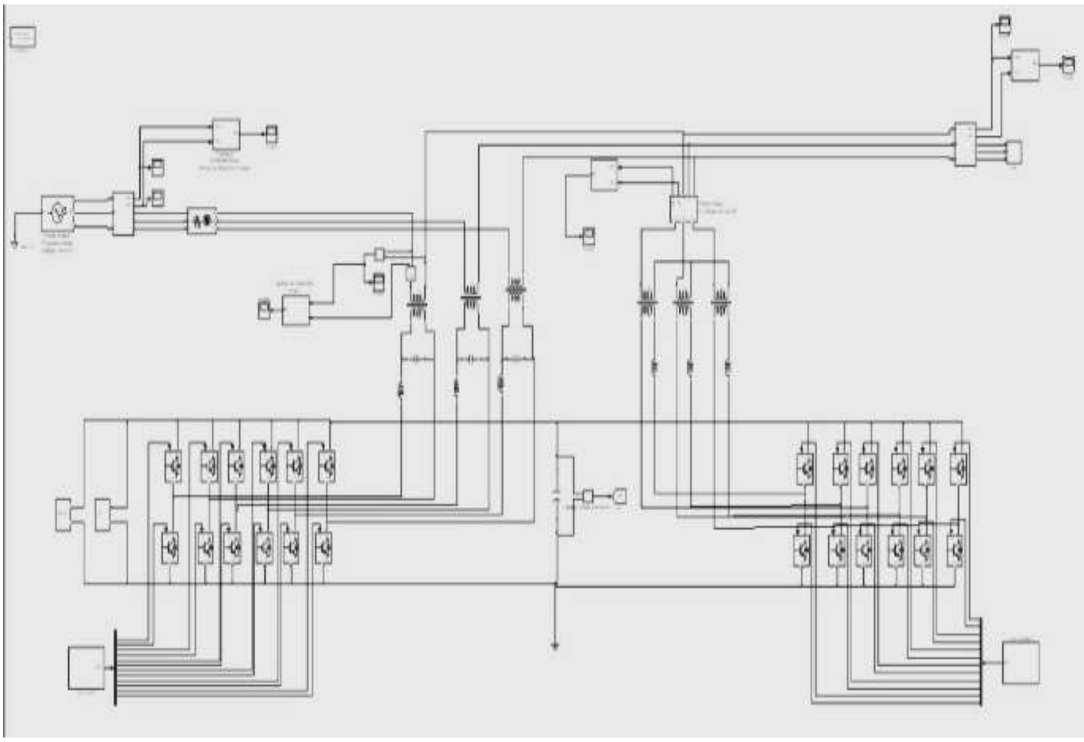

Figure.4: Proposed Simulink

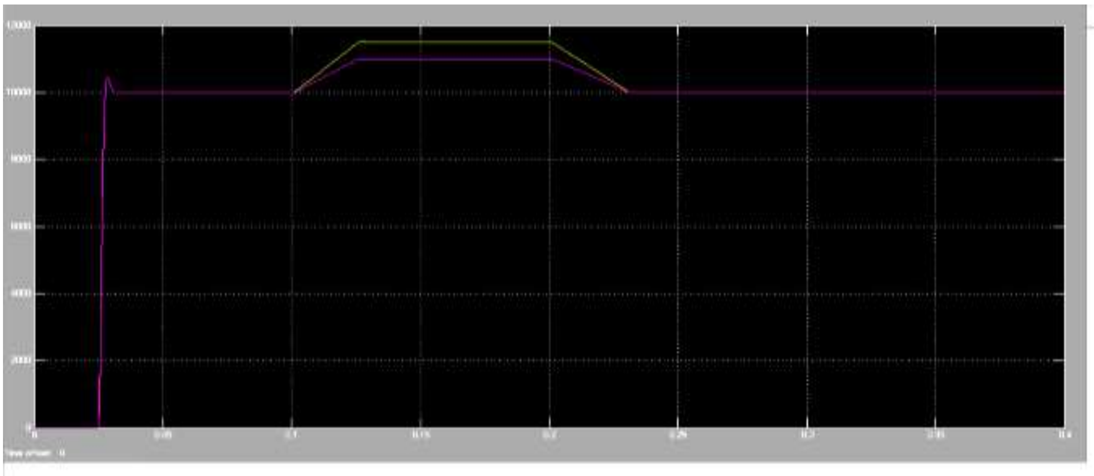

Figure.5: O/P response for Power of D-STATCOM & TIME

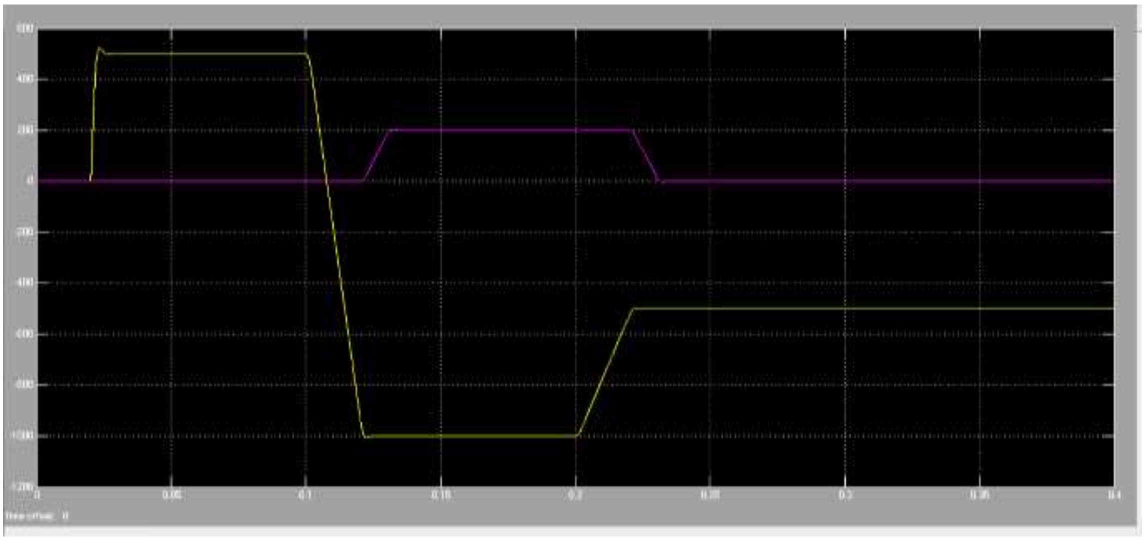

Figure.6: O/P response for Power of DVR & Time

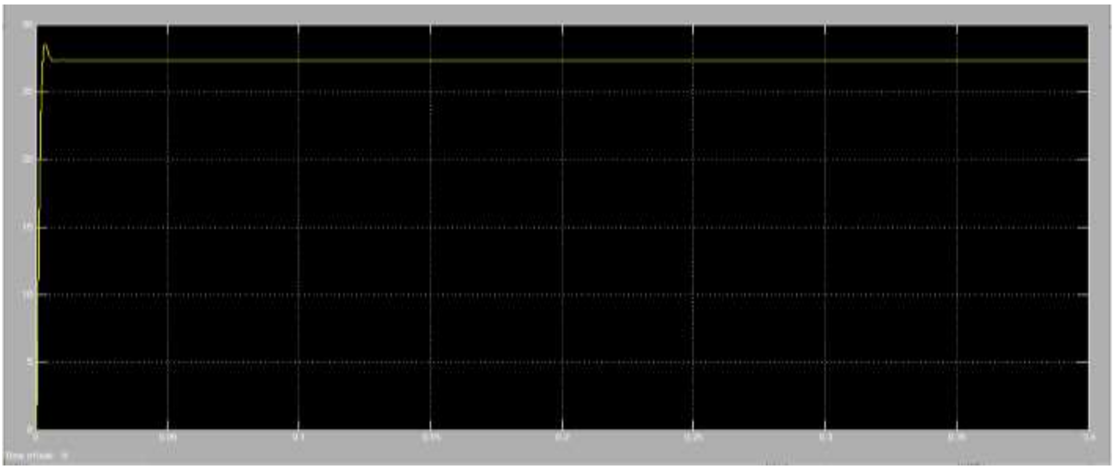

Figure.7: O/P response for PV current

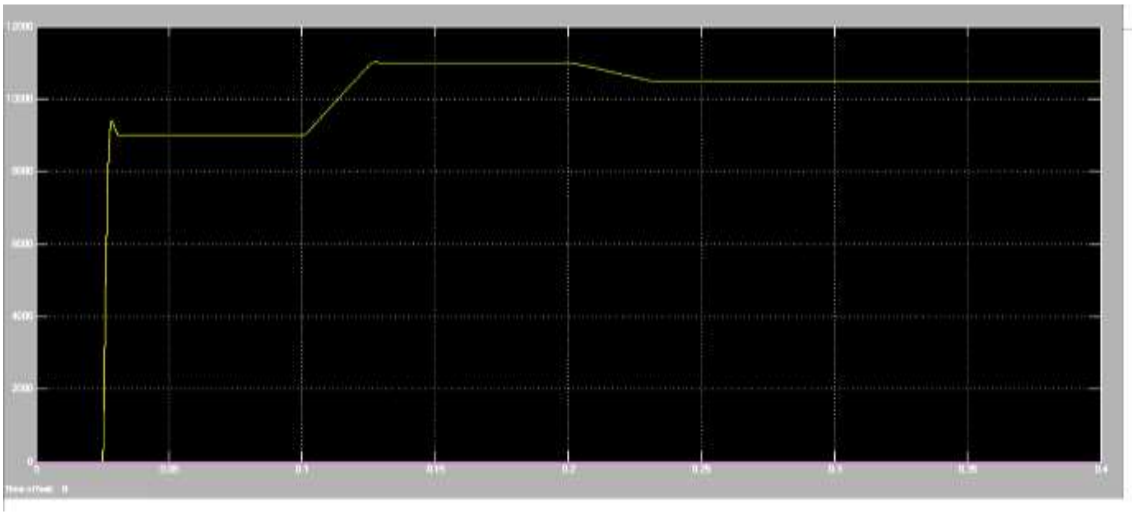

Figure.8: O/P response for Source of active power and reactive power

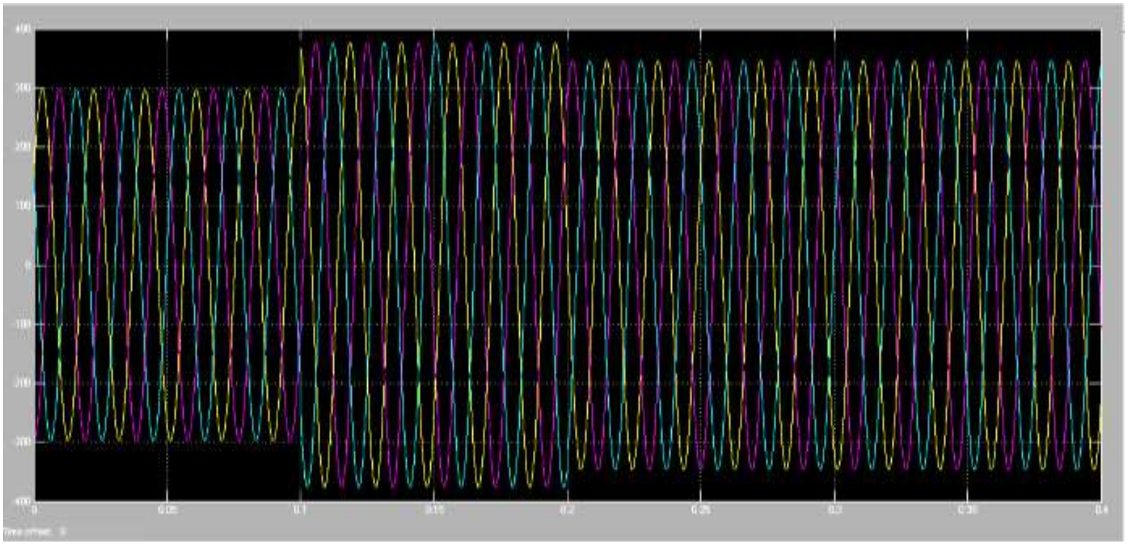

Figure.9: O/P response for Source voltage & current

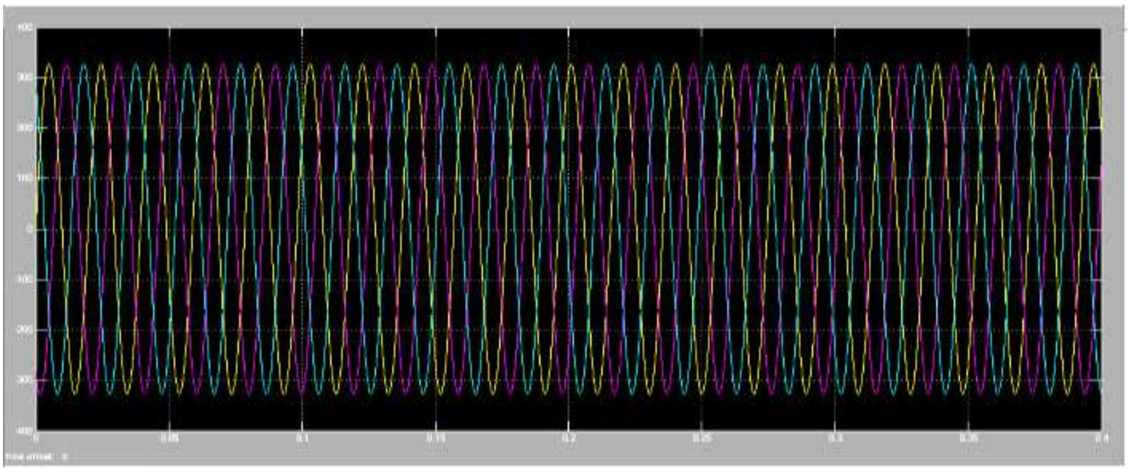

Figure.10: O/P response for Source voltage & time

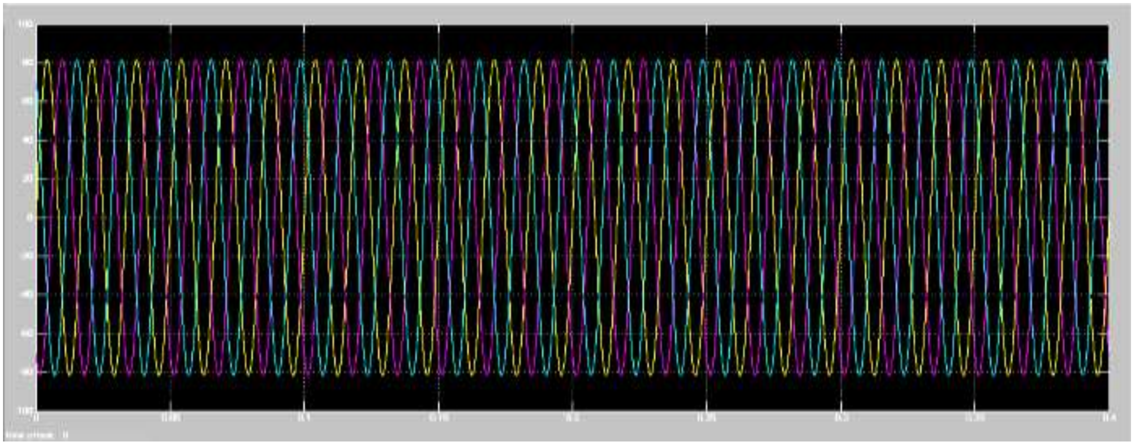

Figure.11: O/P response for Source voltage & load

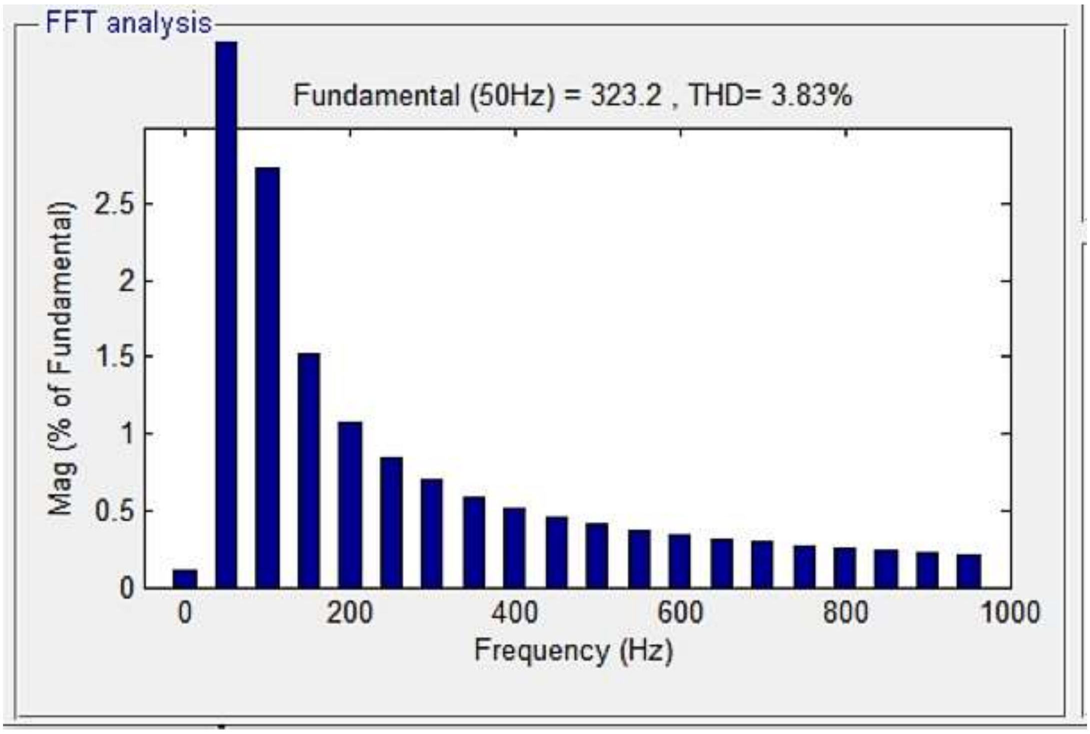

Figure.12: O/P response for FFT analysis

V. Conclusion

The study simulates a 20 kVA, single-phase UPQC (using a PV-integrated distribution system with fuzzy for design) with a reduced DC link voltage of 360V.Fuzzy controller is added to series controller. To reduce THD, reactive load compensation of 10 kVAR and taking away the unwanted harmonics from the source. The source draws only active power, and the simulation results validated the input power factor as unity. The model achieved a load voltage of 200 V irrespective of sag and swell, with an economic model. This new design would find application in PV-integrated distribution systems and PV generating companies which need to integrate the PV generation to the utility grid for maintaining PQ standards.

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