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MITIGATION OF POWER QUALITY PROBLEMS USING PV-UPQC IN A DISTRIBUTION SYSTEM

[1]Pothumahanty Sai Jyothi

[1]Assistant professor

[1]Chaitanya Engineering college, kommadi, Visakhapatnam, India

Abstract: Power quality issues such as current and voltage harmonics, voltage sag / swell has become major reasons for power failure and power quality degradation in current times. Renewable energy sources are now consuming most of the energy for a day. Power demand is also growing due to an abnormal growth of consumers of electrical energy. There are problems with power quality. As a result, in the installation of custom power devices is a major consideration for improving these power quality issues. This paper therefore, deals with the enhancement power quality problems by means of a Photo-Voltaic -Unified Power Quality Compensator (PV-UPQC) interface with the UPQC DC-link via a DC-DC step up converter. The PV array is interfaced with the UPQC DC-link by means of a DC-DC boost converter. Maximum power extracted from the PV array by means of MPP control is fed to boost the converter. The UPQC Shunt Voltage Source Converter compensates for issues with load power quality issues, such as current harmonics. Apart from this VSC shunt, it supplies the grid with effective active power from the SPV while retaining the DC voltage link at the preset voltage level. The VSC series compensates for issues with grid side voltage PQ such as voltage sag /swell and harmonics at different non-linear loads connected to the (PCC) load bus. The simulation and evaluation of PV-UPQC with various nonlinear load cases such as R-L load, personal computer, fluorescent lamp, television is performed in PSCAD under varying irradiation and grid voltage disturbances such as voltage sag / swell and load bus (PCC) harmonics was validated by IEEE std. 519-2014 and noted that the PCC's harmonics are within the limits.

Index Terms - Power Quality, UPQC, harmonics, solar PV, MPPT, boost converter.

I. INTRODUCTION

The increasing use of electronically generated loads and the combination of renewable energy sources such as solar and wind power are an important problem in the recent power distribution system [1]. Several devices known as custom power devices are used to mitigate power quality problems [2]-[5] Such as DSTATCOM (Static Compensator Distribution), Unified Power Quality Conditioner (UPQC) and Dynamic Voltage Restorer (DVR). UPQC incorporates the features of the Shunt and series compensators. UPQC was divided into various categories based on topology, shunt compensator position, control technique, etc.,[4].

This paper analyzes the output UPQC for different varying irradiation, grid voltage disturbances of a single-phase PV-UPQC and at different cases of non-linear loads at PCC. The design and performance analysis of a single-phase PV-UPQC is tested for the above mentioned power quality issues in this paper. Including harmonics of various non-linear loads are verified for R-L load, personal computer, fluorescent lamp and television.

II.SYSTEM CONFIGURATION OF PV-UPQC AND DESIGN

A. STRUCTURE OF PV-UPQC

The structure of the PV-UPQC is shown in Fig.1. The compensator which is connected at load side is called as shunt compensator. The compensator which is connected at the grid side is known as series compensator. The right shunt structure configuration is most commonly used configuration as it results in the flow of sinusoidal currents through the series converter which results in lower rating of series compensator. The shunt compensator operates in current control mode compensating for the load power quality problems. The shunt converter also maintains DC-link voltage and injects active power from the PV array. The series compensator operates in voltage control mode and compensates for the grid voltage power quality problems such as harmonics and sags/swells. The PV array is interfaced with the DC-link of UPQC through a boost DC-DC converter.

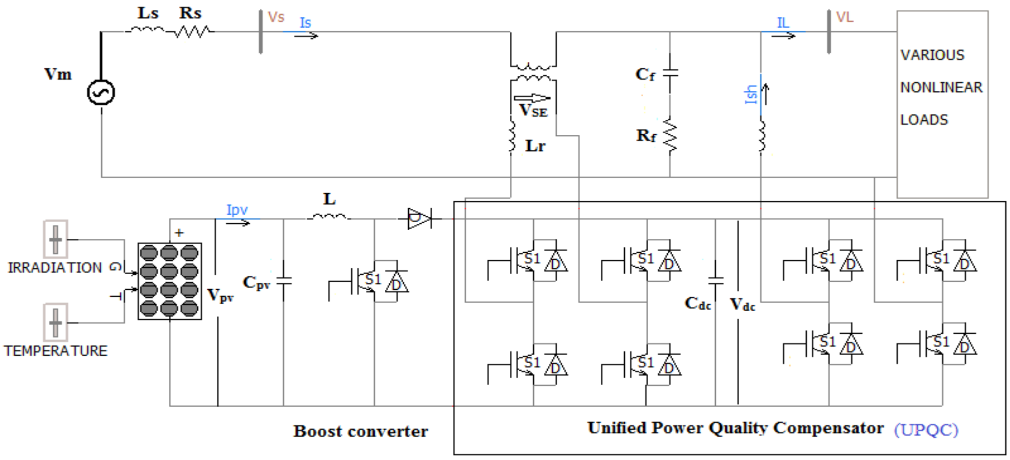

Fig.1. Detailed System Configuration of Single-Phase PV-UPQC

B. DESIGN OF PV-UPQC

The design procedure for PV-UPQC begins with the proper sizing of following components such as PV array, DC link capacitor and DC-Link voltage level. The specifications of solar PV module used to realize PV array is given in Table-I. The PV array module parameters are given in Table-II. The other components to be designed are the inductors for series and shunt compensators and series injection transformer for the series compensator [1].

Table I
Solar PV module specifications

Parameters	**Values**
Maximum Power (P)	270.95W
Open Circuit Voltage (V_{oc})	39.8V
Short Circuit Current (I_{sc})	10.018A
Voltage at Maximum Power Point (V_{mpp})	34.7V
Current at Maximum Power Point (I_{mpp})	9.5A

Table II
PV array module specifications

Parameters	**Values**
Maximum Power (P)	8.5kW
Open Circuit Voltage (V_{oc})	415V
Short Circuit Current (I_{sc})	30.03A
Voltage at Maximum Power Point (V_{mpp})	357.7V
Current at Maximum Power Point (I_{mpp})	29.5A
Parallel strings	4
Series Modules Per String	12

III CONTROL OF PV-UPQC

The PV-UPQC has three major subsystems such as, shunt compensator, series compensator and boost DC-DC converter. The boost converter is used to increase the output solar voltage to meet the precise or required DC bus voltage.

A. Control of Boost Converter

The boost converter is a power electronic DC-DC converter, which is used to steps up voltage (while stepping down current) from its input (supply) to its output (load). The maximum output power from the PV system obtained from maximum power point tracking [MPPT] technique is fed to boost converter. There are different MPPT techniques include perturb and observe [P&O], incremental conductance [INC], and other algorithms [6]-[7].

B. Control of shunt compensator:

The compensator which compensates for load current harmonics as well as injecting the power from the PV array into the grid is known as shunt compensator. A detailed discussion regarding various control algorithms for shunt compensator is presented in [3]. Its objective is to maintain the grid current sinusoidal and unity power factor. [8].

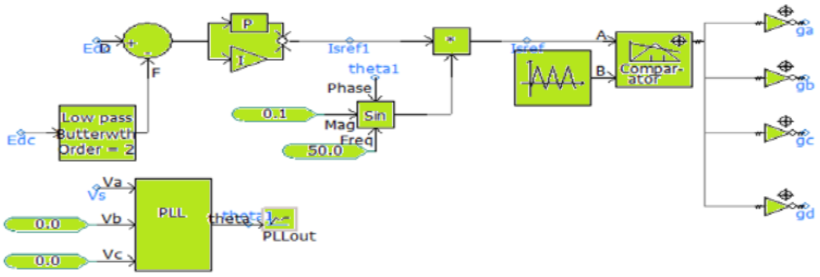

Fig.2. Control structure of shunt compensator

C. Control of series compensator:

The series compensator operates in voltage control mode. Various control ideas have been reported in the literature [9].

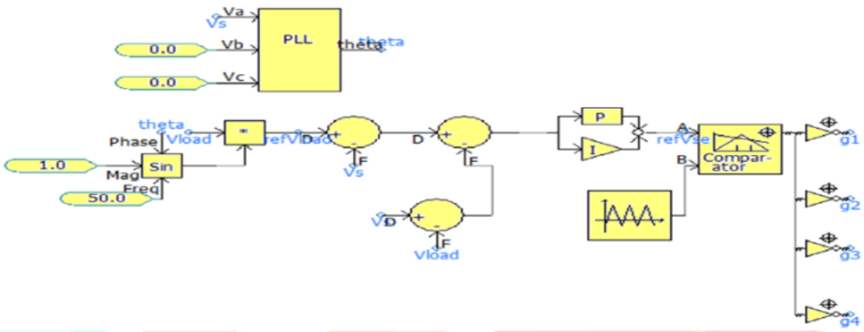

Fig.3. Control structure of shunt compensator

IV. SIMULATION RESULTS:

PV-UPQC's dynamic performance is evaluated using PSCAD software to simulate the PV-UPQC system. The main aim of the system to perform and observe at varying irradiation, grid voltage disturbances and for various nonlinear loads at PCC.

A. PERFORMANCE OF PV-UPQC UNDER VARYING IRRADIATION:

The performance of PV-UPQC at varying solar irradiation is shown in below results. The various sensed signals are grid voltage (V_S), grid current (I_S), load voltage (V_L), load current (I_L), shunt compensator current (I_{SH}), DC link voltage (V_{DC}), PV array (P_{PV}) and irradiation (G).

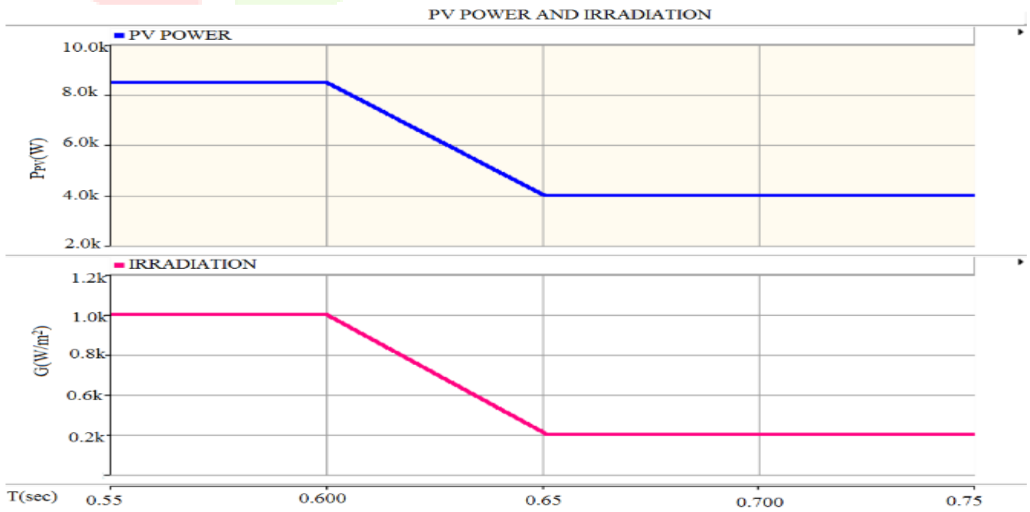

Fig.4 (a) PV Power and Irradiation

From the figure 4(a), the solar power at PV array is gradually decreases from 8.5 kW to 4.0 kW due to variation of irradiation at 1000 W/m^2 to 400 W/m^2 for duration of 0.6s to 0.65s during a period of 0.55s to 0.75s and later becomes constant from 0.65s.

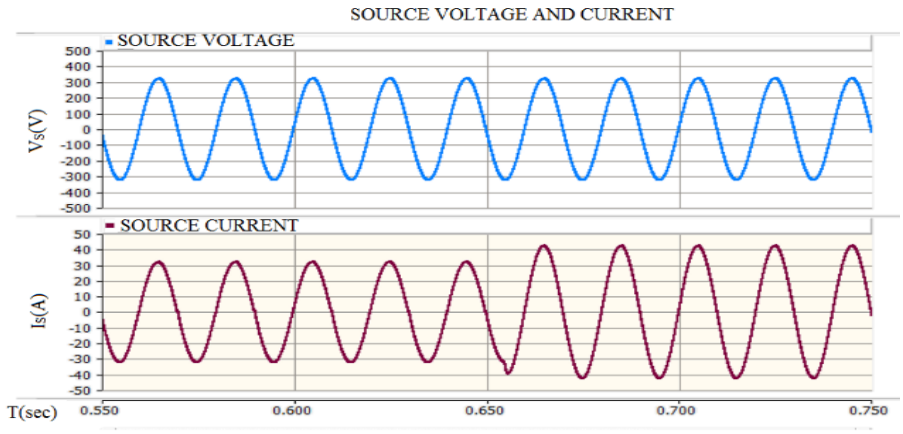

Fig.4 (b) source voltage and current

From the figure 4(b), the rated voltage is measured and the current increases after 0.65s because PV array performance decreases and, due to irradiance variance, the load draws more effective current from the grid.

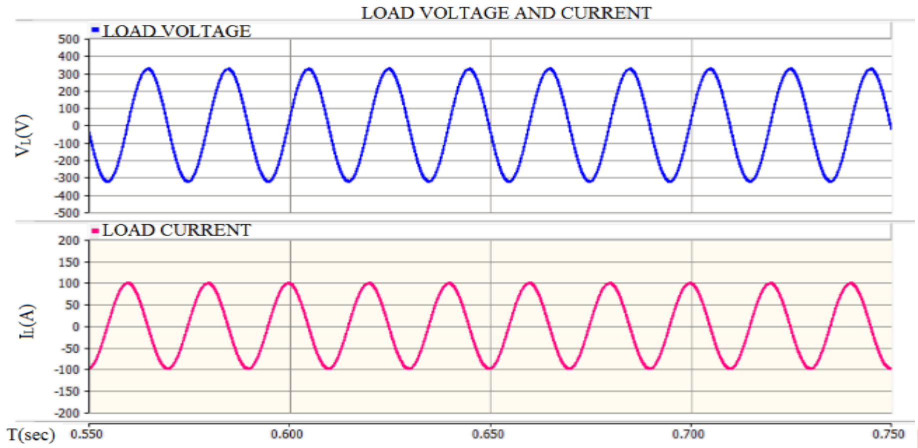

Fig.4 (c) load voltage and current

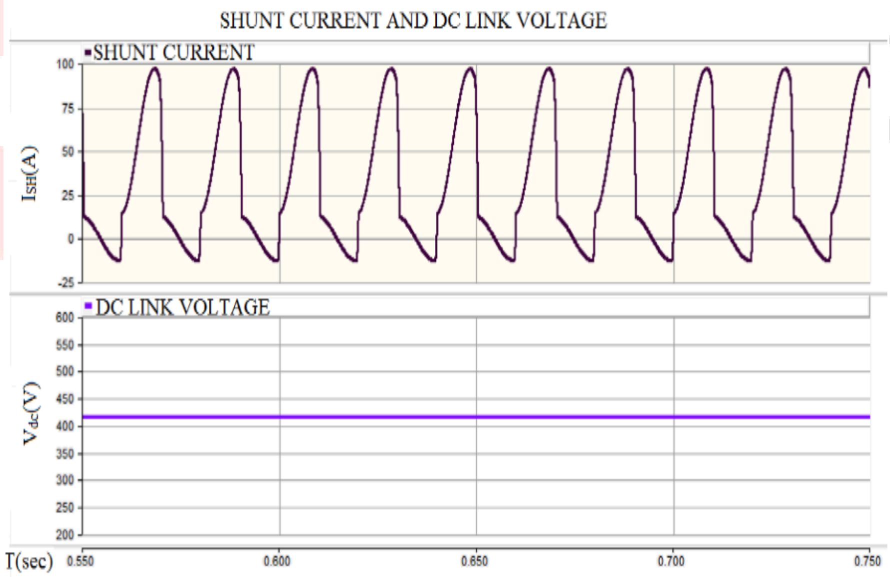

Fig.4 (d) load voltage and current

From the figure 4(c), by varying irradiation the measured voltage and current at load side doesn't vary, the values are same as that of the source side. Similarly, from the figure 4(d), the shunt current is varied, and desired value of DC link voltage is 415V obtained during a period 0.55s to 0.75s

B. PERFORMANCE OF PV-UPQC UNDER GRID VOLTAGE DISTURBANCES:

PV-UPQC's dynamic response to the grid voltage harmonics and sag / swells condition. Irradiation (G) at 1000W / m2 is constant. The specific sensed signals are grid voltage (V_S), series compensator voltage (V_{SE}), grid voltage (I_S), load voltage (V_L), load current (I_L), shunt compensator current (I_{SH}), and DC link voltage (V_{DC}).

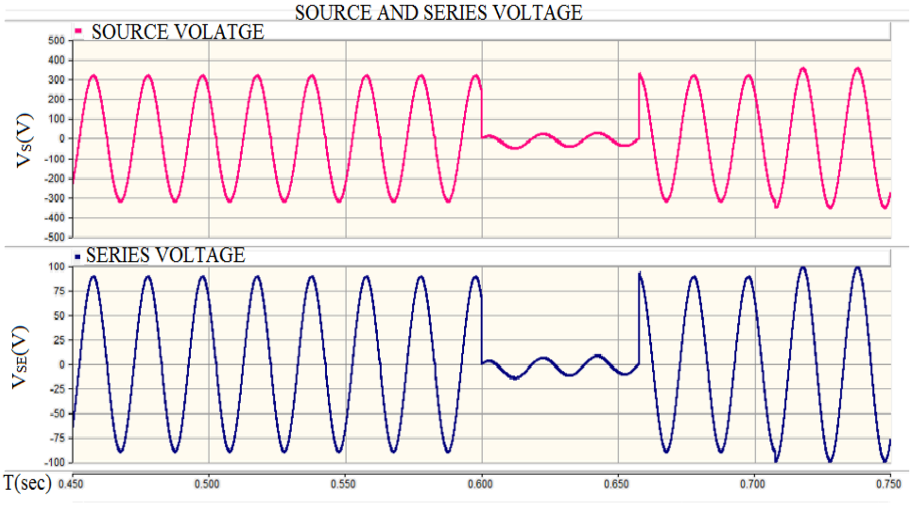

Fig.5 (a) source voltage and series voltage

From Figure 5(a), there is a voltage drop from 0.6s to 0.65s and a voltage swell from 0.7s to 0.75s in the measured voltage. Likewise, the series voltage compensator compensates the grid voltage by injecting Vse in the opposite phase with the grid voltage disturbance to retain the voltage at the rated voltage level.

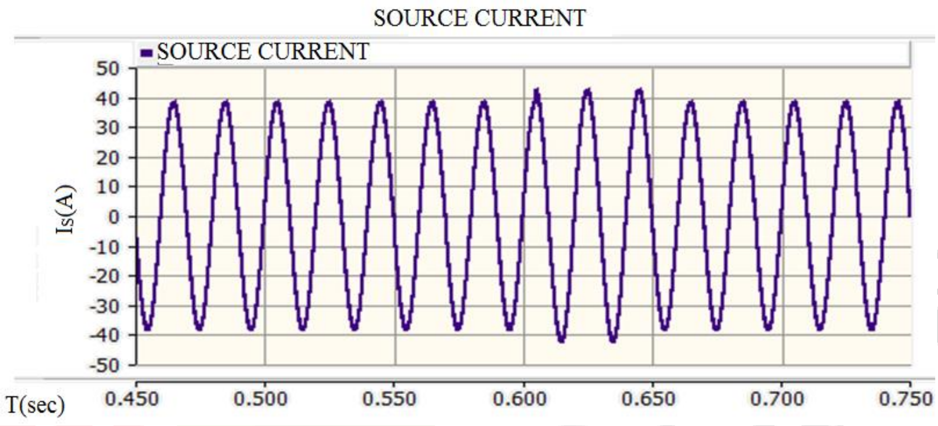

Fig.5 (b) source current

Above figure 5(b), it shows that the value of source current at the grid rises during 0.6s to 0.65s because of short circuit in the source side and varied during a period 0.45 to 0.75s.

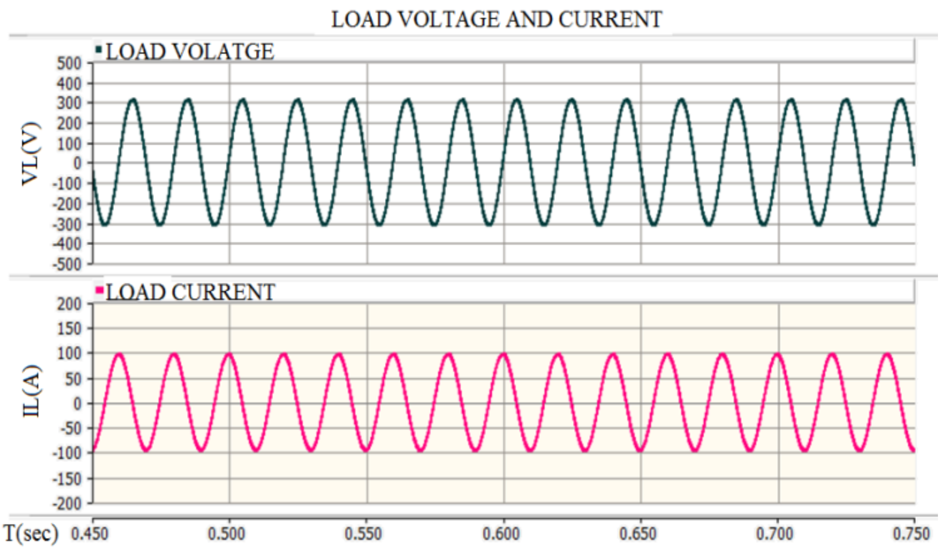

Fig.5 (c) load voltage and current

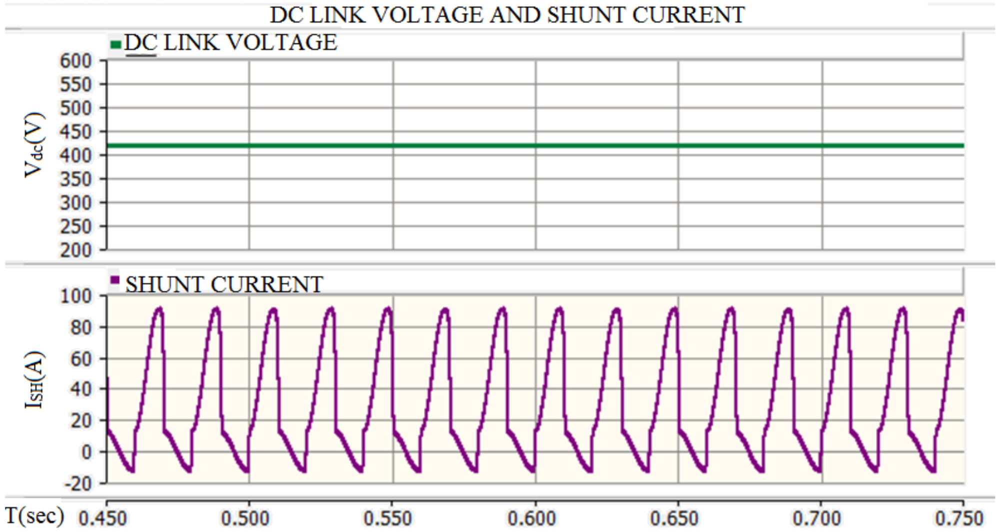

Fig.5 (d) load voltage and current

From the figure 5(c), under grid voltage disturbance also the measured voltage and current at load side doesn't vary, the values are same as that of the source side. Similarly, from the figure 5(d), the shunt current is varied, and the desired value of DC link voltage is 415V obtained during a period 0.45s to 0.75s.

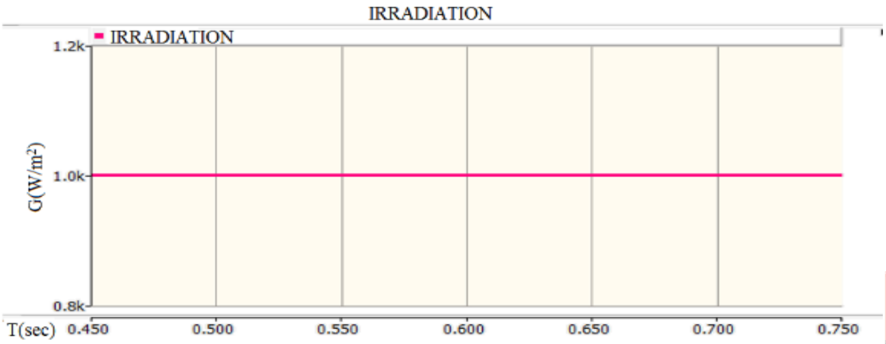

Fig.5 (e) Irradiation

It is clear from the figure 5(e), under grid voltage disturbance also the irradiation does not change. It is at 1000W/m^2 only during a period 0.45s to 0.75s.

C.PERFORMANCE OF PV-UPQC AT VARIOUS NON-LINEAR LOADS AT PCC:

Different non-linear loads are modeled to the proposed system to measure the system, which is capable of withstanding by mitigating harmonics and the performance of THD and TDD% are within the limits as per the requirement of IEEE-519-2014 standards. The PCC voltage loads current and grid current harmonic content is shown in Fig.6, Fig.7, Fig.8.

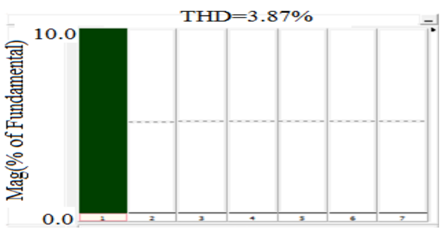

Fig.6. Voltage harmonic spectrum and THD at PCC

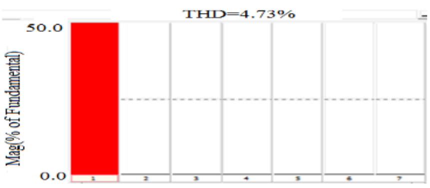

Fig.7. Grid Current Harmonic Spectrum and THD at PCC

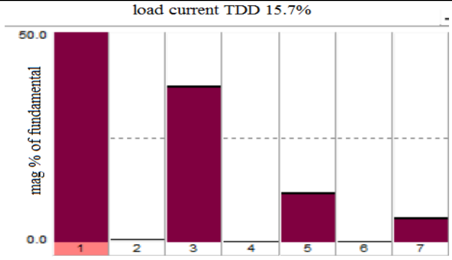

Fig.8. Load Current Harmonic Spectrum and TDD at PCC

A. CASE-1 PERSONAL COMPUTER: One of the most widely used electronic loads in modern life is personal computers. Especially when there are large applications in a distribution system, it produces harmonic current. [11].

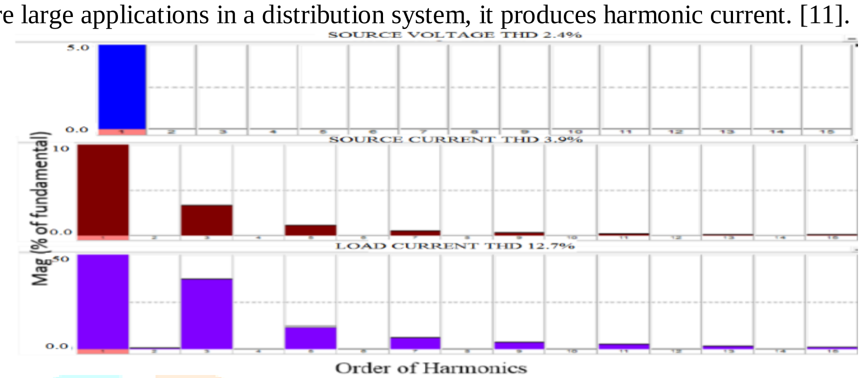

Fig.9.THD and TDD % at PCC Connected to Personal Computer

B. CASE-2 FLUORESCENT LAMP: Fluorescent lamps have negative performance of dynamic resistance, which allows a ballast to be used to reduce the current. The digital ballast uses a half-bridge inverter and an LC filter used to obtain the lamp's non-linear functionality. [11].

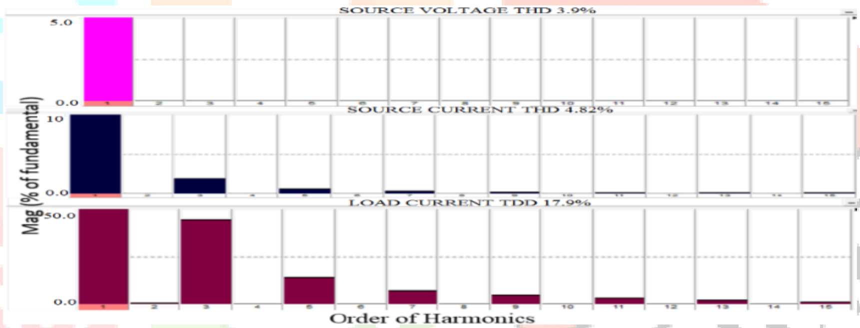

Fig.10.THD and TDD % at PCC Connected to Fluorescent Lamp

C. CASE-3 TELEVISION SET: The front-end power supply consisting of a single-phase condenser filtered bridge rectifier was designed for T.V sets. Such loads are rich in harmonics and have developed a pulse waveform with THD of almost 100%. [11].

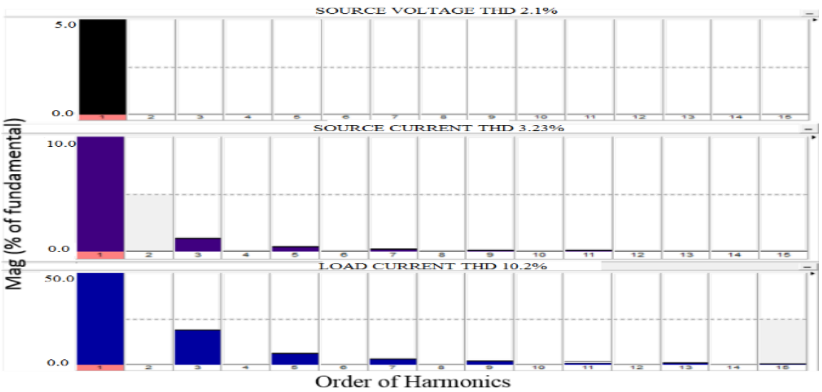

Fig.11.THD and TDD % at PCC Connected to Television

TABLE-III

THD AND TDD% of PV-UPQC at various nonlinear loads

NON-LINEAR LOADS	SOURCE VOLTAGE THD %	SOURCE CURRENT THD%	LOAD CURRENT TDD%
R-L Load	3.8%	4.73%	15.7%
Personal Computer	2.42%	3.91%	12.7%
Fluorescent Lamp	3.9%	4.82%	17.9%
Television	2.1%	3.23%	10.2%

V. CONCLUSION

The main aim of the paper is to mitigate the voltage sag/swell and Harmonics at load bus (PCC) using Solar PV integrated UPQC in a Distribution system. The sources for PQ distortions in the distribution system have been identified from the various research articles and their effects are effectively analyzed. The UPQC is a one promising custom power device which can mitigate multiple PQ problems of voltages and currents is installed in the distribution system to protect the load from PQ distortions. The system has been designed and its performance is simulated under circumstances of changing irradiation, grid voltage disturbance and at various non-linear loads at PCC. It is detected that the PV-UPQC increases energy performance compensating the existing load harmonics of the grid. This incorporates renewable solar PV array in addition to improving power quality, thereby increasing the usefulness of the proposed system. These results show that the stability of the system under large variation of irradiation from 1000W/m^2 to 400W/m^2. Under grid voltage disturbances also the system is stable at 1000W/m^2 irradiation. The harmonics of grid current, load current and PCC voltage at different case studies such as R-L load, personal computer, fluorescent lamp and television meet the requirement of IEEE-519-2014 standard.

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