A New Unified Power Quality Conditioner for Grid Integration of PV System and Power Quality Improvement Feature Distribution System

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***Abstract*—Unified power quality conditioner (UPQC) is one of the most advanced flexible AC transmission system (FACTS) devices that can simultaneously and independently control both the real and reactive power Quality in a transmission line. The utilization of UPQC can result in significant reliability benefits in modern power systems. This paper proposes a reliability network model for a UPQC, which incorporates the network behavior without and with renewable operating modes. The proposed model divides the UPQC operating modes into four states, namely network without UPQC, with UPQC, power system network without renewable energy sources under UPQC state and finally in order to improve the power quality in power system networkwith PV as renewable energy source under UPQC. The final model also incorporates un-effected source current due the impact of load variationswith UPQC in order to decide appropriate load curtailment in the reliability evaluation process. The performance of the proposed model is verified using a test system, and compared with different reliability models of UPQC. Various operating schemes, such as power system network with and with UPQCand with res based UPQC are used to illustrate the advantages of the developed models, and to examine the impacts of UPQC to improve power quality in power system network MATLAB/SIMULINK software is used.**

Keywords—Power Quality, UPQC, Load Variation, Voltage Sags, Renewable Energy Source.

I. INTRODUCTION

The demand of efficient and high quality power is escalating in the world of electricity. Today's power systems are highly complex and require suitable structure of new effective and reliable devices in deregulated electric power industry for flexible power Quality control. In the late 1980s, the Electric Power Research Institute (EPRI) introduces a new approach to solve the problem of designing, controlling and operating power systems, the proposed concept is known as Flexible AC Transmission Systems (FACTS) [1]. It is reckoned conceptually a target for long term development to offer new opportunities for controlling power in addition to enhance the capacity of present as well as new lines [2] in the coming decades. Its main objectives are to increase power transmission capability, voltage control, voltage stability enhancement and power system stability improvement. Its first concept was introduced by N.G.Hingorani in April 19, 1988. Since then different kind of FACTS devices have been recommended. FACTS controllers are based on voltage source converters and includes devices such as Static Var Compensators (SVCs), static Synchronous Compensators (STATCOMs), Thyristor Controlled Series Compensators (TCSCs), Static Synchronous Series Compensators (SSSCs) and Unified Power Quality Conditioner (UPQC).Among them UPQC is the most different and efficient device which was introduced in 1991. In UPQC, the transmitted power can be controlled by changing three parameters namely transmission magnitude voltage, impedance and phase angle. Unified Power Quality Conditioner (UPQC) is the most promising version of FACTS devices as it serves to control parallely all three parameters (voltage, impedance and phase angle) at the same time. Therefore it is chosen as the focus of investigation. For the last few years, the focus of research in the FACTS area is mainly on UPQC. Many researchers have proposed various approaches of installing UPQC in power systems [3, 4, 5]. The concepts of characteristics have been broadly reported in the literature [5]. The impact of load variations on source current is analyzed with the proposed UPQC with and without PV as renewable energy source circuit configuration shown in fig.1.

II. OPERATING PRINCIPLE OF UPQC

The UPQC is the most versatile and complex of the FACTS devices, combining the features of the STATCOM and the SSSC. The main reasons behind the wide spreads of UPQC are: its ability to pass the real power quality bi-directionally, maintaining well regulated DC voltage, workability in the vast range of operating conditions etc.The basic components of the UPQC are two voltage source inverters (VSIs) sharing a common dc storage capacitor, and connected to the power system through coupling transformers. One VSI is connected to in shunt to the transmission system via a shunt transformer, while the other one is connected in series through a series transformer. The DC terminals of the two VSCs are coupled and this creates a path for active power exchange between the converters. Therefore, a different range of control options is available compared to STATCOM or SSSC.

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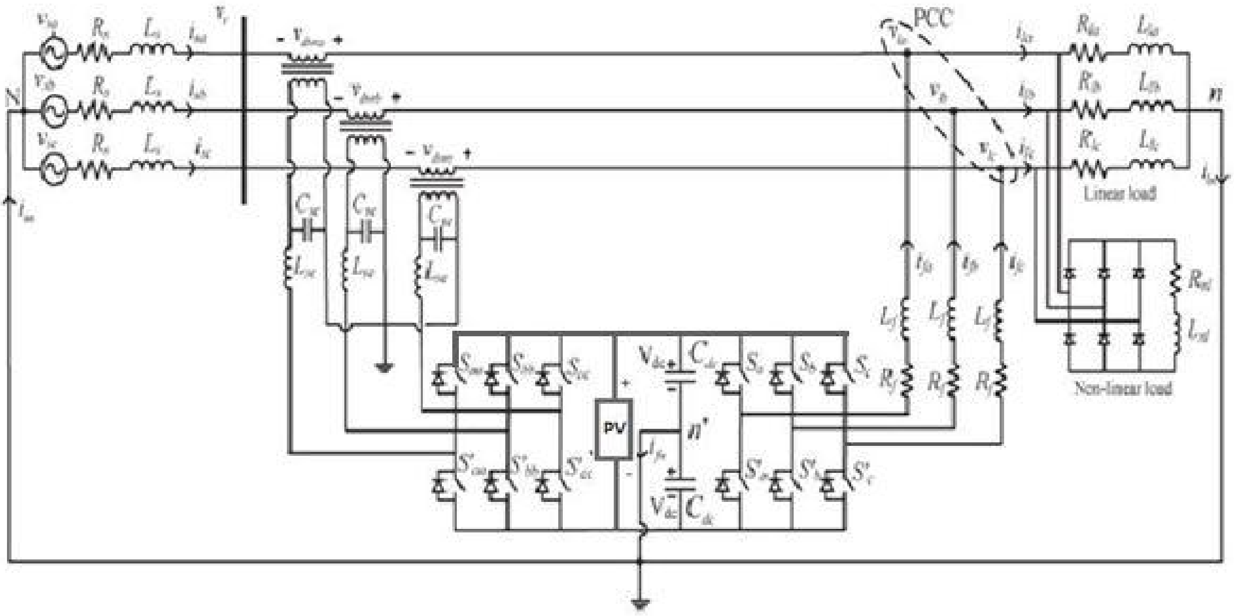

Fig. 1.Equivalent circuit ofVSI topology-based UPQC with PV Cell

The UPQC can be used to control the Quality of active and reactive power through the transmission line and to control the amount of reactive power supplied to the transmission line at the point of installation. The series inverter is controlled to inject a symmetrical three phase voltage system of controllable magnitude and phase angle in series with the line to control active and reactive power flow on the transmission line. So, this inverter will exchange active and reactive power with the line. The reactive power is electronically provided by the series inverter, and the active power is transmitted to the dc terminals. The shunt inverter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor constant. So, the net real power absorbed from the line by the UPQC is equal only to the losses of the inverters and their transformers. The remaining capacity of the shunt inverter can be used to exchange reactive power with the line so to provide a voltage regulation at the connection point. Among the DC link a PV cell has been used

III. PV Array Modeling & Characterstics

The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can powerlights, motors, and other loads. The modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more currentThe PV array is made up of number of PV modules connected in series called string and number of such strings connected in parallel to achieve desired voltage and current. The PV module used for simulation study consists of polycrystalline cells.

A. PV Model

The electrical equivalent circuit model of PV cell consists of a current source in parallel with a diode as shown in Fig.2.

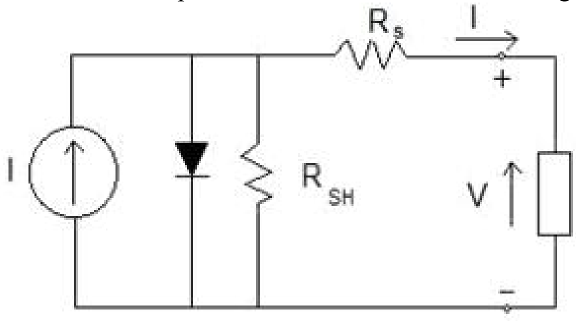

Fig. 2.Electrical Equivalent Circuit Model of PV Cell

IV. Generation of Refernce Currents

UPQC is operated in such a way that the sourcecurrents are balanced, sinusoidal, and in phase with respectiveterminal voltages. Also, average load power and losses inthe VSI are supplied by the source. Since, source consideredhere is non-stiff in nature, direct use of terminal voltagesto calculate reference currents will not provide satisfactorycompensation. Here, three phase reference currents (i^*_{f2a}, i^*_{f2b}, i^*_{f2c}) are generated using instantaneous symmetricalcomponent theory [9] to satisfy all aforementioned load compensation conditions simultaneously and are given as follows:

$$i^{*}_{fsa} = i_{la} - i^{*}_{sa} = i_{la} - \frac{v^{+}_{ta1}}{\Delta^{+}_{1}} (P_{lavg} + P_{loss})$$

$$i^{*}_{fsb} = i_{lb} - i^{*}_{sb} = i_{lb} - \frac{v^{+}_{tb1}}{\Delta^{+}_{1}} (P_{lavg} + P_{loss}) \quad (1)$$

$$i^{*}_{fsc} = i_{lc} - i^{*}_{sc} = i_{lc} - \frac{v^{+}_{tc1}}{\Delta^{+}_{1}} (P_{lavg} + P_{loss})$$

where, v^{+}_{tal}, v^{+}_{tbl}, and $v^{+}_{tc1}$are fundamental positive sequencevoltages at the respective phase load terminal and $\Delta^{+}_{1}=(v^{+}_{tal})^{2}+(v^{+}_{tbl})^{2}+(v^{+}_{tcl})^{2}$. Here, Pl_{avg}represents average loadpower and P_{loss}represents the total looses in the inverter.Average load power is calculated using a moving averagefilter for better performance during transients and can havea window width of half cycle or full cycle depending uponthe type of harmonics present in the load currents. Totallosses in the inverter P_{loss}, computed using a proportionalintegral(PI) controller, helps in maintaining the dc link voltage($vdc1 + vdc2$) at a predefined reference value (2 *Vdcref*) bydrawing a set of balanced currents from the source and isgiven as follows:

$$P_{loss} = K_p e + K_i \int e\,dt \quad (2)$$

Where, *Kp*, *Ki*, and $e = 2Vdcref-(vdc1+vdc2)$ are proportionalgain, integral gain, and voltage error of the PI controller respectively.An error current control signal, $u(t)$ is obtained by subtractingactual filter injected currents at load side from the referencefilter currents. $u(t)$ is regulated around a predefined hysteresisband h using hysteresis current controller (HCC) and IGBTswitching pulses are generated according to relationship givenbelow:

If $u(t) \geq h$, then upper switch of a leg is TURN ON andlower switch is TURN OFF.

Else If $u(t) \leq h$, then upper switch of a leg is TURN OFFand lower switch is TURN ON.

V. MATLAB MODELING & SIMULATION RESULTS

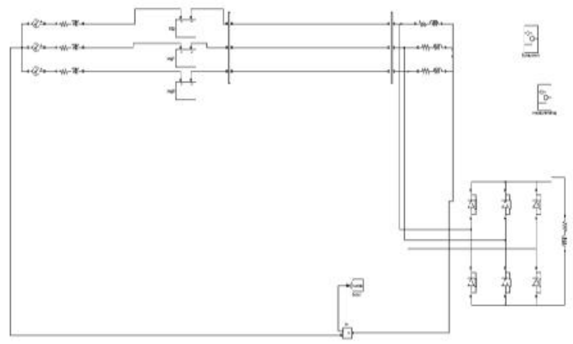

Fig. 3. Simulink model of power system network without UPQC

Below figure shows the source current with harmonics and source voltage with distortions.

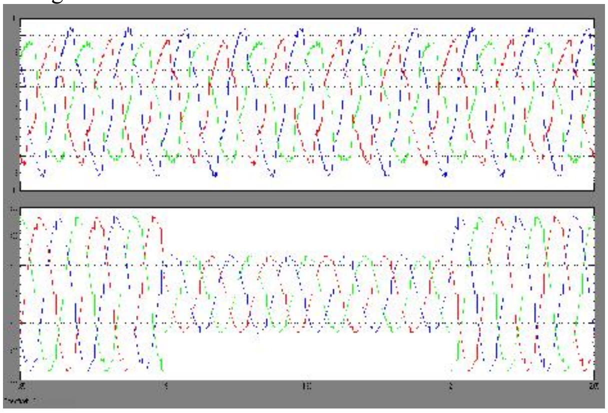

Fig. 4.Simulated wave form of Source current and Source voltage without UPQC.

Below figure shows the load current drawn by diode bridge rectifier and RL loads

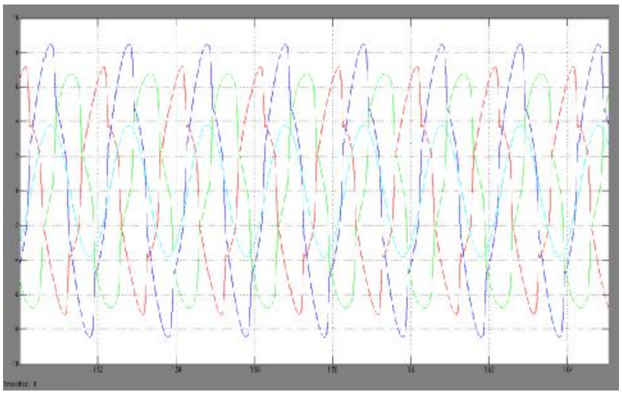

Fig. 5.Simulated wave form of the load current.

Below figure shows the source voltage, compensating voltage and load voltage under Sag applied from 1.9 sec to 2 sec without UPQC.

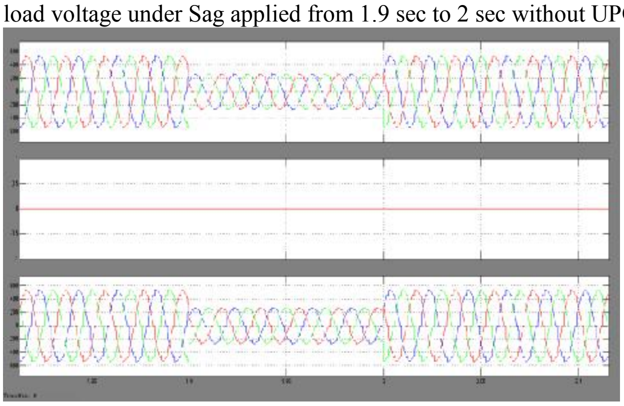

Fig. 6.Simulated output wave form of Source voltage, Compensating Voltage and Load Voltage without UPQC.

Below figure shows the simulink model of the power system network with UPQC

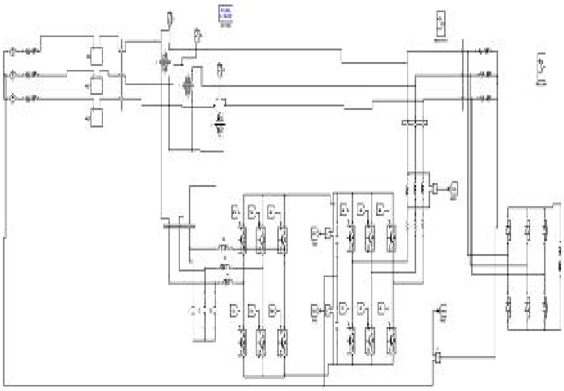

Fig. 7. Simulink model of power system network with UPQC.

Below figure shows the source current without harmonics and source voltage without distortions due to UPQC

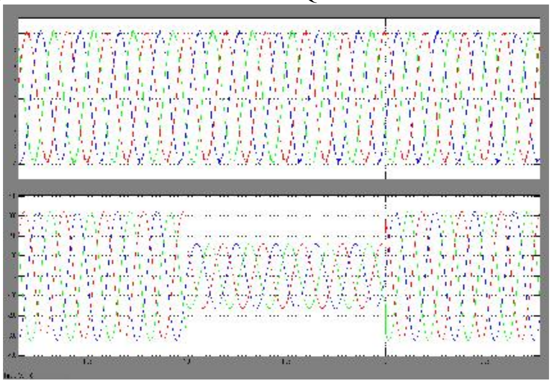

Fig. 8.Simulated wave form of Source current and Source voltage with UPQC.

Below figure shows the load current drawn by diode bridge rectifier and RL loads

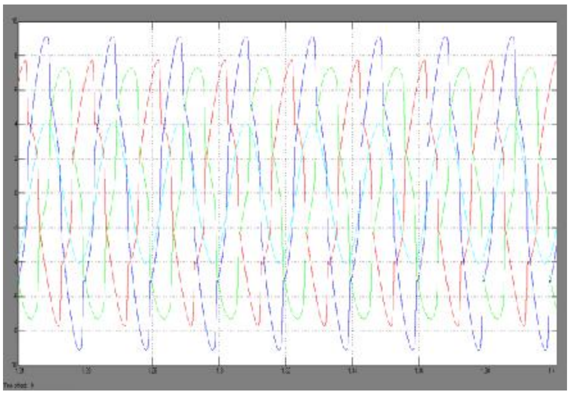

Fig. 9.Simulated wave form of the load current.

Below figure shows the source voltage, compensating voltage and load voltage under Sag applied from 1.9 sec to 2 secs with UPQC.

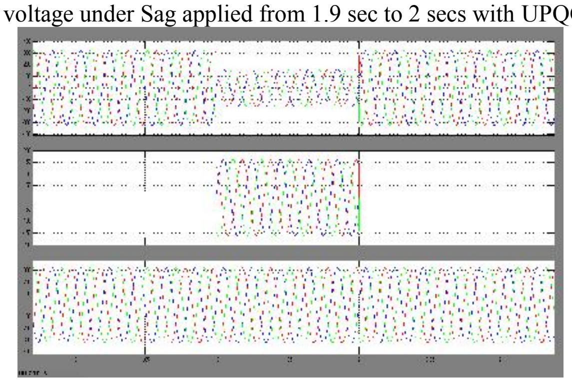

Fig. 10.Simulated output wave form of Source voltage, Compensating Voltage and Load Voltage with UPQC.

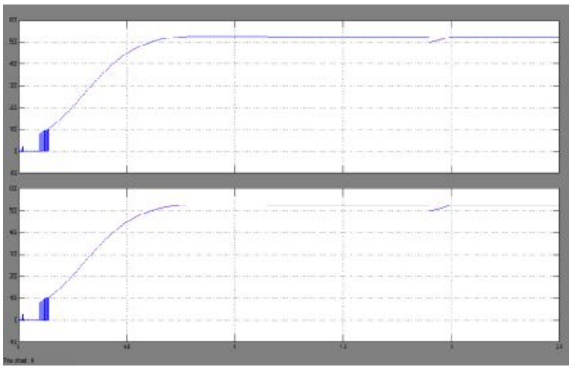

Fig. 11. Simulated output wave form of the Voltage across C1 and C2 capacitors.

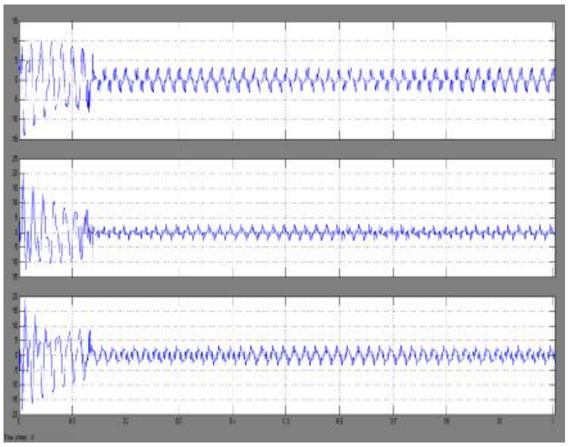

Fig. 12.Simulated output wave form of the filter side currents with UPQC.

Below figures shows the simulink model of the power system network with variable load under normal Dc link based UPQC

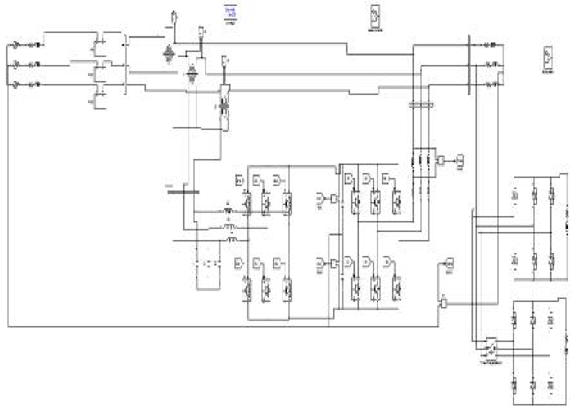

Fig.13. Simulink model of power system network with UPQC under normal Dc link.

Below figure shows the variations in source current without harmonics and source voltage without distortions with UPQC under normal Dc link

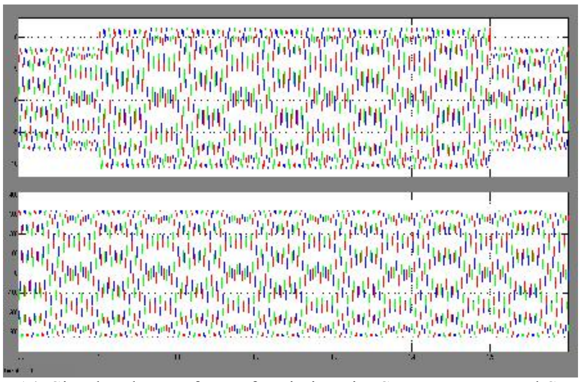

Fig. 14. Simulated wave form of variations in Source current and Source voltage with UPQC under normal Dc link .

Below figure shows the variation in load currents drawn by different diode bridge rectifiers and RL loads

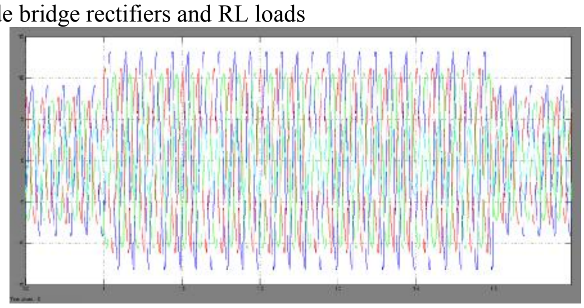

Fig. 15.Simulated wave form of the load current.

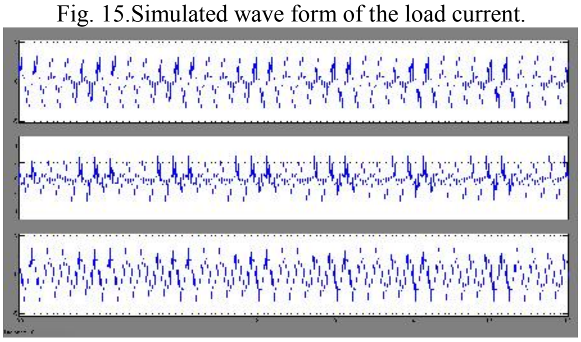

Fig. 16. Simulated output wave form filter currents not changing.

Below figure shows the power system network with UPQC with PV cell due to which even the variable loads drawing the un balanced currents the source currents will be in constant magnitude.

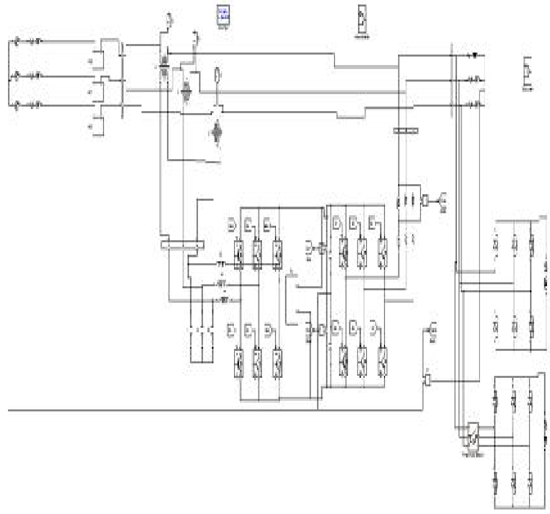

Fig.17.Simulink model of the power system network with UPQC under PV as Renewable Energy sources.

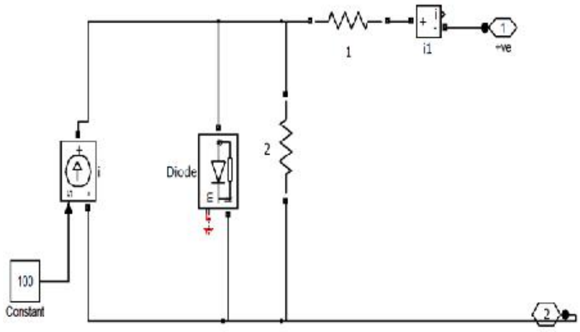

Fig.18.Simulink model of Photo Voltaic Cell for UPQC.

Below figure shows the balanced source current without harmonics and source voltage without distortions with UPQC under Pv cell

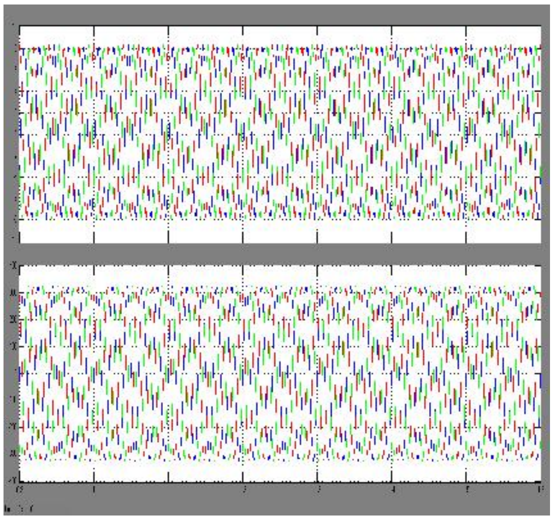

Fig. 19. Simulated wave form of constant Source current and Source voltage with PV cell based UPQC.

Below figure shows the variations in load currents drawn by different diode bridge rectifiers and RL loads

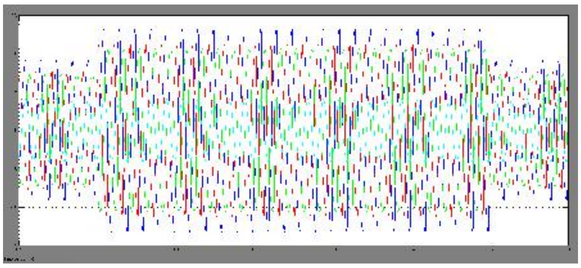

Fig. 20.Simulated wave form of the load current.

Below figure shows the filter currents changing its magnitude form 1 to 1.5 sec to reduce the variable load effects on the source currents.

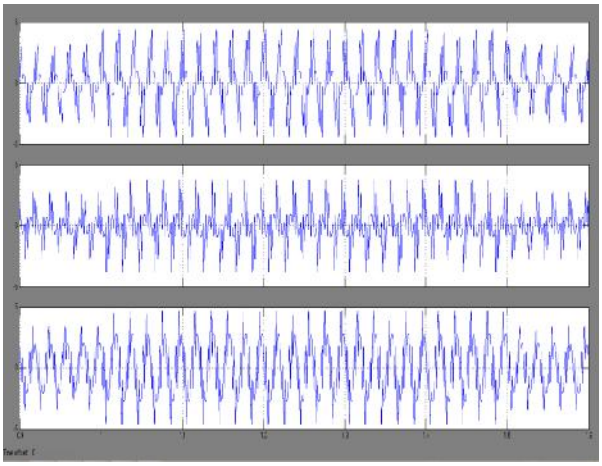

Fig. 21. Simulated output wave form filter currents changing to reduce variations of source currents.

VI. CONCLUSION

UPQC topology has been proposed in this paper which has the capability to compensate voltage sagsand current harmonics. The analysis has taken with and without UPQC under PV as renewable energy sources. The proposed method is validated through MATLAB simulation. This simulation study shows that the source current harmonics reduced with UPQC and final it has proven that the best among the 4 conditions is UPQC with PV as renewable energy source, which maintains the source currents with constant magnitude even the load currents are varying.

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