



## **GRID-CONNECTED PVUPQC SYSTEM POWER QUALITY IMPROVEMENT BY USING THE ANN CONTROLLERS**

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### **ABSTRACT**

In this study, a unified power quality controller (UPQC) based on artificial neural networks is suggested. The UPQC in the power system balances the voltages on the grid and at the load. For its functions with grid integration of PV, such as voltage sags/swells, unit power factor adjustment, voltage, and current harmonic cancellation, this study uses a Unified Power Quality Conditioner (UPQC) based on an ANN controller. Solar energy is a renewable energy source that is connected to the grid. The Perturb and Observe (P&O) method is used to monitor the solar panels' maximum output. In a power distribution network, the supply voltage and load voltage are both compensated for simultaneously using the UPQC system. Ones included in the unit vector template control algorithm includes a phase-locked loop (PLL) mechanism that is responsible for avoiding multiple zero crossings during highly distorted grid voltage detection. A unit vector template control with a PLL- based control algorithm is applied to the shunt and series inverters of PV grid-connected UPQC. The grid and load voltage unbalances are regulated and the Total Harmonics Distortion (THD) of the grid and load voltages are controlled by the UPQC via an Artificial Neural Networks (ANN) controller. In addition to normalizing voltage and current disturbances, the proposed controller has the functions of phase detection and perfect grid synchronization.

### **INTRODUCTION**

When severely distorted loads are present on the consumer side, the power system becomes contaminated and different problems with power quality develop. The enhancement of power quality has recently drawn researchers' attention. Power quality enhancement opportunities are greatly expanded by the power electronic interface system's incorporation of renewable energy into the grid. Unbalanced and severely distorted load circumstances, grid side voltage quality concerns, and current perturbations brought on by loads are the main points of attention. Compensating systems are necessary for the elimination of the power quality problems. As stated in the literature [1]–[3], a distinct category of power conditioners has been utilized in response to various forms of power quality difficulties. Power conditioners with their many types have reportedly been reported as bespoke power devices. Dynamic voltage restorer (DVR) and Distribution static compensator (DSTATCOM) are developed specially for voltage quality issues and current quality issues respectively [4]–[5]. However, Unified Power quality conditioner (UPQC) combines the functionality of both DVR and DSTATCOM [6], [7]. The UPQC configuration has back-to-back connected DVR and DSTATCOM, with a common DC-Link. Therefore UPQC become capable to deal with current and voltage quality issues perfectly. Considering many factors of micro-grid's energy supply, solar energy is an ideal green energy for sustainable development strategy in china. At the same time, global energy experts believe that the solar energy will become one of the most important energy in future. Photovoltaic power generation system has a large proportion in micro-grid and distribution system with micro-grid [9-10]. At the same time, with the development of science and technology, most of precision electronic instruments and digital electrical equipment are used in micro-grid and distribution system with micro-grid. The reliability and power quality of microgrid's power supply is put forward higher requirements. In the micro-grid with photovoltaic generation as a source, due to the existence of intermittent nonlinear loads, in particular, a static converter operating in a switching mode, and other nonlinear loads such as electric arc furnace, welding machine, transformer, rotating motor and so on. Because of these nonlinear loads, a large amount of reactive power is consumed, the power factor of micro-grid is reduced, the voltage and power loss are increased. At the same time, the different frequency and amplitude harmonics in the microgrid are produced. It will cause



the damage of the distributed generation equipment. The harmonics pose a great threat to the security, stability and economic operation of micro-grid and micro-grid distribution system. At present, in the micro-grid and power distribution system with micro-grid, the active power is usually only provided to the grid by Photovoltaic power generation system. That is, the DC power of the PV array is converted to the same phase and frequency AC power as the power grid, and to ensure that it has a high-power factor. The special capacitor is usually used for the load reactive power compensation. Active Power Filter and passive filter are usually added to control the harmonics in micro-grid. This will increase the investment of power system, so that the structure of power grid is complicated. At the same time, new power quality problems are brought by the additional equipment. Various topologies for Photovoltaic (PV) grid integration with active filtering capability are reported in [8]-[10]. The integration of Solar PV with UPQC is also reported in [11], [12]. However, PV-UPQC topology is very few in literature. Interfacing of solar energy to the grid through UPQC, increases the utilization and functionality of UPQC. In this case part of the load power is supplied by PV. Literature survey reports about only a few papers about this PV-UPQC configuration. Thereby a detail analysis and performance evaluation is needed. The control algorithm for UPQC has been studied and implemented in literatures includes instantaneous reactive power theory, synchronous reference frame algorithm, unit vector template algorithm [12]-[14]. To make PV-UPQC systems become more sensitive towards highly distorted conditions of load and source voltage, this paper introduces a modified SRF control algorithm. In this paper the design of PV-UPQC system is along with proposed controller is discussed. The solar PV is interfaced with UPQC through DC-DC boost converter at the DC-link. To extract maximum power from PV Perturb & Observe (P&O) MPPT algorithm [15] is utilized in the present system. Conventional systems with traditional PLL behave properly under normal distortions, but it becomes helpless during high distortions. Therefore this paper proposes an improved PLL mechanism for highly distorted load and voltage conditions, which work along with APF control algorithm.

### Literature review

According to IEEE, flexible AC transmission system (FACTS) provide effective control of AC transmission system parameters (IEEE, 1997). It ensures enhancement in power transfer capability added with controllability. Generally, FACTS controllers that are employed in DG integrated grid for PQ improvement, are thyristor controlled LC compensator (TCLC) (Wang and Lam, 2017), distribution static compensator (DSTATCOM) (Lee et al., 2013; Mishra and Ray, 2016), and unified power quality conditioner (UPQC) (Dash and Ray, 2017). TCLC compensates reactive power and it also maintains THD of the system, but it has large computational burden on controllers. DSTATCOM is used to control the voltage fluctuations only. It does not have control command on harmonics. Among all, the UPQC can compensate most PQ related issues (voltage sag, swells and fluctuations and harmonics control) in both the modes of operation of DGs, i.e., grid connected and islanded mode (Han et al., 2006). However, UPQC needs a proper control algorithm for the generation of voltage and current reference signals for working out compensatory control. According to IEEE, flexible AC transmission system (FACTS) provide effective control of AC transmission system parameters (IEEE, 1997). It ensures enhancement in power transfer capability added with controllability. Generally, FACTS controllers that are employed in DG integrated grid for PQ improvement, are thyristor controlled LC compensator (TCLC) (Wang and Lam, 2017), distribution static compensator (DSTATCOM) (Lee et al., 2013; Mishra and Ray, 2016), and unified power quality conditioner (UPQC) (Dash and Ray, 2017). TCLC compensates reactive power and it also maintains THD of the system, but it has large computational burden on controllers. DSTATCOM is used to control the voltage fluctuations only. It does not have control command on harmonics. Among all, the UPQC can compensate most PQ related issues (voltage sag, swells and fluctuations and harmonics control) in both the modes of operation of DGs, i.e., grid connected and islanded mode (Han et al., 2006). However, UPQC needs a proper control algorithm for the generation of voltage and current reference signals for working out compensatory control. According to IEEE, flexible AC transmission system (FACTS) provide effective control of AC transmission system parameters (IEEE, 1997). It ensures enhancement in power transfer capability added with controllability. Generally, FACTS controllers that are employed in DG integrated grid for PQ improvement, are thyristor controlled LC compensator (TCLC)

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**UPQC SYSTEM CONFIGURATION**

The configuration block diagram of system considered is presented in Fig.1. The system comprises of a shunt voltage source converter and a series voltage source converter. Both shunt VSC and series VSC are connected by a common DC link capacitor. Shunt VSC part of PV-UPQC is connected at the load side through interfacing inductors. Similarly Series VSC connected in series with the grid through coupling inductors. The series transformer of PV-UPQC system is employed for injecting the voltage signal generated by series VSC. The shunt VSC is connected at the point of PCC at the load side to compensate the load current harmonics and to feed the PV power to load the suggested technique effectively eliminates the targeted lower order harmonics at different modulation indices by proper selection of switching angles and same time the higher order harmonics are suppressed.

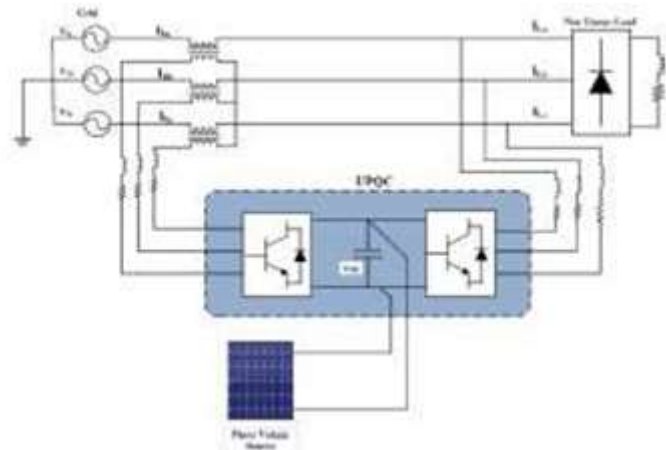


Fig1. Block diagram of a typical PV tied UPQC.

Also this innovative technique solve the smart grid PQ issues like sag, swell, flicker, active , reactive power and increase the overall grid performance. The proposed UCI -UPQC has the ability to improve both voltage and load current quality, including reactive component. It provides a multifunctional, high performance, and reliable solution for total power quality control. It is suitable for commercial, industrial, space, and military applications, as well as distributed power generation.

**DESIGN SPECIFICATION OF PV-UPQC**

There are various parameters involved in selection of appropriate specification of DC-bus voltage, sizing of DC-bus capacitor value, interfacing inductor of DSTATCOM and DVR, selection of inductor of DC-DC boost convertor and PV array design. A. Selection of DC-bus voltage: The DC- link capacitor present in the PV-UPQC is common to shunt inverter, series inverter as well as Solar PV array. The selection of DC-link voltage magnitude should be evaluated such that its value will be double the peak of phase voltage of the considered 3-ph system. Therefore  $V_{dc}$  is presented as

$$V_{dc} = \frac{2\sqrt{2}V_L}{\sqrt{3}m} \quad (1)$$

where „m“ represents the depth of modulation selected as 1 and VL represents line voltage of the

$$D = \frac{1}{\sqrt{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \sin(\omega t) & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ \cos(\omega t) & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \quad (2)$$

$$D^{-1} = \frac{1}{\sqrt{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \sin(\omega t) & \cos(\omega t) \\ \frac{1}{\sqrt{2}} & \sin(\omega t - \frac{2\pi}{3}) & \cos(\omega t - \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \sin(\omega t + \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \quad (3)$$

$$V_{sd} = \bar{V}_{sd} + \tilde{V}_{sd} \quad (4)$$

system.

### CONTROL ALGORITHM

Several active filtering methods have been presented in the literature with the SRF based control algorithm due to its easy implementation and efficiency. However this SRF methodology becomes helpless during highly distorted voltage and current perturbations. This paper introduces a new SRF methodology with an advanced PLL scheme. The proposed SRF scheme for the PV-UPQC is shown in Fig2.

#### A. Improved PLL Mechanism Phase Locked Loop

Algorithms are employed for phase detection of the grid voltages and for the extracting the fundamental system voltage signals. Various PLL techniques are introduced with controllers for better control of power conditioners. However, conventional PLL techniques are found to be less efficient for highly distorted system voltage conditions such as voltage sags, voltage swells. Therefore present paper introduces an improved PLL technique to extract the fundamental sequence of system voltage. As the power system become more polluted with voltage profile disturbances, UPQC performance and efficiency needs to be improved with advanced PLL circuit. The improved PLL evaluates three phase auxiliary total power by employing instantaneous three phase source voltages, which results in determination of transformation angle of supply grid voltage. The improved PLL technique is designed perfectly to operate properly during various distorted voltage conditions. The three phase grid voltages are sensed, measured and used as input signals for the PLL. The transformation angle is evaluated as output for PLL circuit. The evaluated line voltages are multiplied by auxiliary feedback currents along with unity amplitude and three phase auxiliary instantaneous active power is determined. The improved PLL technique can behave satisfactorily during distorted grid voltage conditions depending upon perfect tuning of PI gains of present PLL scheme.

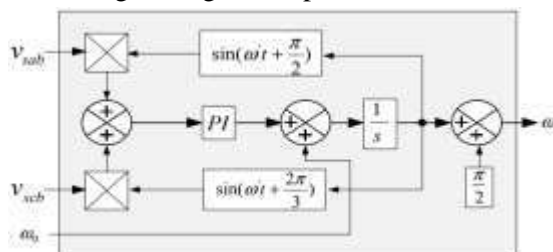


Fig.2 Improved PLL Scheme

The improved PLL circuit is implemented with SRF Control scheme for PV-UPQC in the present research work. The applied method has shown its effectiveness under highly distorted and unbalanced load conditions.

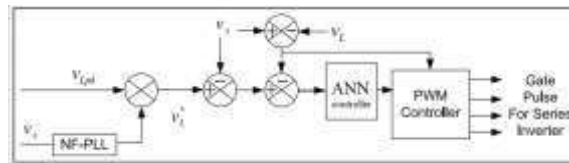
#### B. Reference signal generation for series APF



The control methodology implemented is based on SRF algorithm and improved PLL scheme presented in Fig.3. The grid voltage is sensed and converted to d-q-0 frame with the utilization of matrix D presented in (8). The obtained  $s_d v$  and  $s_q v$  contains the oscillating components  $s_d v \sim$  and  $s_q v \sim$  as well as average components  $s_d v$  and  $s_q v$ . These component inclusions are due to the unbalanced grid voltage with harmonics. The presence of oscillating components  $s_d v \sim$  and  $s_q v \sim$  shows the inclusion of harmonics and negative sequence components of the grid voltages due to distorted load conditions. The average component indicates about the presence of positive sequence components of the voltages. The unbalanced grid voltages refer to presence of zero sequence component  $s_0 v$ . The d-axis component includes both average and oscillating components presented in (5) The reference load voltages have been evaluated through the inverse transformation matrix  $-1 D$ . The grid voltage positive sequence component is passed through the low pass filter to obtain the average value. The zero and negative sequence part are considered as zero to eliminate the voltage harmonics, voltage unbalances and distortions. The load reference voltages and actual sensed load voltages are compared in sinusoidal pulse width modulation to generate the gate pulses.

**I. CONTROL REFERENCES OF SERIES & PARALLEL INVERTERS BY ANN**

Management of UPQC time domains Techniques are most commonly used in three-phase p-q theory and three-phase d-q theory or the synchronous reference system. In this mode the voltage and current signals are passed to the stationary (p-q'theory) or synchronous (d-q theory) frames in the ABC frame, so that the basic and harmonic quantities are released[13].



**Figure 3.** Control structure of ANN

Active and reactive spontaneous forces are calculated in p-q theory, while in d-q the current is handled regardless of the energy source. The interesting feature of these theories is that the real and reactive powers of basic elements (p-q theory) and of basic elements (d-q theory) are DC quantities. dc quantities. With a low-pass filter or high-pass filter, these quantities can be filtered easily. The filtering of the signal dc extraction in the  $\alpha\text{-}\beta$  reference frame is insensitive to any phase change error that occurs in the LPF. These cut-off frequencies of LPF or HPF can, however, affect the dynamic look of the controller[5]. In terms of distortion and/or unbalance in the supply voltages the initial p-Q phase theory has disadvantages. The unique p-q theory has been modified and commonly referred to as p-q-r[5] to solve these limitations. In addition, both p-q and d-q theories in three phases were altered to allow these methods to be extended for single-phase APFs like UPQC systems in a single-phase fashion. Input and output voltages of UPQC to regulate speed and distinguish the operation of the device by using a PI control are controlled by a d-q-o axis (SRF) dependent controller (d-q-o axes) When continuous check references (V&I) in the SRF based controller are authorized[1] the PI control contributes to a reduction in steady-state errors. In this sense, a-b-c to d-q is called the transformation of Park. The 3 phase PLL is used in combination with 3 phase PLL scheme with disturbances of the utility voltage, such as harmonics or imbalances. Since the controller mainly addresses d-q amounts, the device is very powerful. Using the traditional SRF method, harmonics found in supply voltages or current can be extracted. The distorted currents are initially transmitted to two-phase stationary coordinates for current harmonic compensation by means of an  $\alpha\text{-}\beta$  transformation. The stationary frame quantities are then moved from the phase-locking loop into synchronous rotating frames using cosine and sine function (PLL). Often called d-q approach is the traditional SRF algorithm. d-q-0 transformation equations, filters, and modified PLL algorithms are employed for the proposed SRF control system. This is a quick and



convenient solution, with reduced current calculation. It can also work on DSP platforms effectively. Thus, under unbalanced and skewed load conditions, UPQC is intensively improved by the proposed modified PLL algorithm. Artificial neural network models focused on the

neural brain structure are relative electronic models.

The brain learns essentially from experience[3]. It goes without saying that small energy-efficient packages will actually solve them outside the reach of existing computers. This brain modelling promises to also create computer solutions in a less technical way. The ANN consists of artificial neurons that interconnect. It is essentially a class of well-connected, very simple nonlinear elements which have the ability to learn[15]. ANN takes data samples to find solutions that saves time and resources instead of full data sets. Mathematical models for developing current data analytics technology are considered fairly simple ANNs.

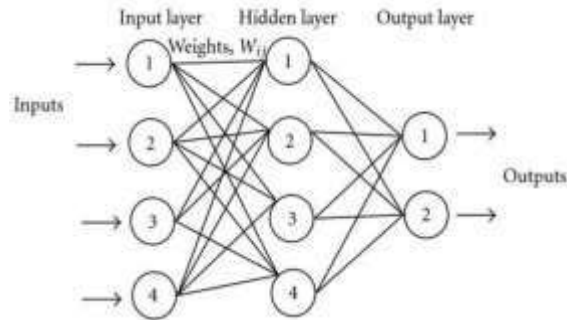


Figure 4. ANN structure

In the experiment, source voltage  $v_s(k)$  is first measured and compared with an estimated voltage  $v_{fund\_est}(k)$ . Note that  $k$  refers to the digital implementation sampling rate.  $E(k)$  is processed with an algorithm to change weight  $W$  or amplitude (coefficient)  $W_{11}$  and  $W_{21}$  of  $\sin(k\omega\Delta t)$  and  $\cos(k\omega\Delta t)$  vectors as shown in equation (7). The source voltage  $v_s(k)$  is calculated and compared with an approximate  $v_{fund\_est}(k)$  voltage ( $k$ ). Notice that the constant  $k$  refers to the digital sampling rate. Here,  $e(k)$  error results in an algorithm that updates the sine  $\sin(k\omega\Delta t)$  or cosine  $\cos(k\omega\Delta t)$  vector by weight, as shown in the Equ (5) for weight  $W$  updates or amplitude  $W_{11}$  and  $W_{21}$ .

$$W(k + 1) = W(k) + \left( \frac{\alpha e(k) Y(k)}{Y(k)^T Y(k)} \right) \quad (5)$$

Where,  $W = \begin{bmatrix} W_{11} \\ W_{21} \end{bmatrix}$  is weight-factor,  $Y = \begin{bmatrix} \sin(k\omega\Delta t) \\ \cos(k\omega\Delta t) \end{bmatrix}$  is fundamental sine and cosine components,  $e(k) = v_s(k) - v_{fund\_est}(k)$  is the error among estimated and measured voltage signal, and  $\alpha$  is learning rate.

At same time,  $W_{11}$  &  $W_{21}$  will be utilized to compute sudden magnitude  $v_{fund\_est}(k)$  of  $v_s(k)$  according to following approach.

$$v_{fund\_mag}(k) = \sqrt{W_{11}^2 + W_{21}^2} \quad (6)$$

The iteration continues until  $v_{fund\_est}(k) = v_s(k)$  actual magnitude of the  $v_s(k)$  is twisted at this

## II. SIMULATION RESULTS

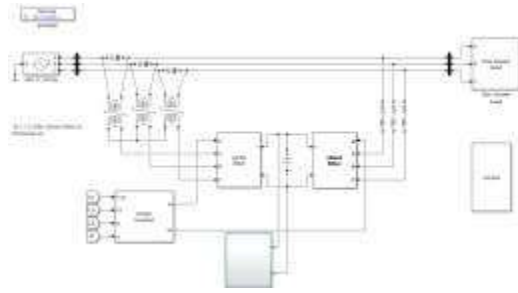


Fig5 Simulation Block Diagram of the Proposed System



Figure 6. Simulated waveforms of the proposed control scheme. (a) Phase to neutral source voltage. (b) Load Voltage. (c) UPQC Voltage.



Figure 7. Simulated waveforms of the proposed control scheme. (a) Phase to neutral source Current. (b) Load Current. (c) UPQC Current. UPQC Series Active Filter Outputs:

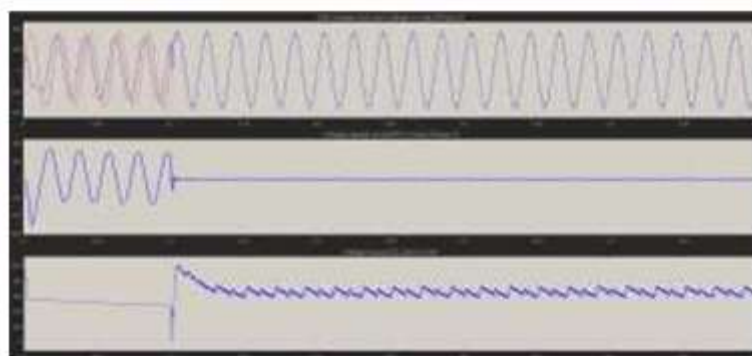


Fig9. Simulated waveforms of Series Active Filter

(a) source voltage and Load Voltage. (b) Injected Voltage of the UPQC Voltage (c) Dc link Voltage.

Shunt Active filter



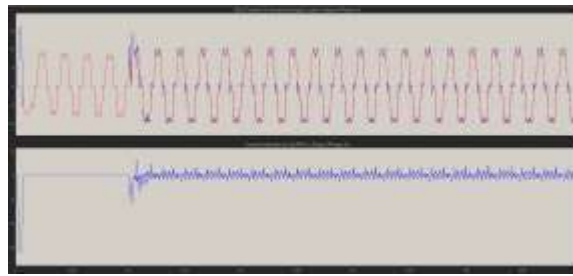


Fig 10. (a)Grid Current & Current through Load inAmps (Phase A) (b) Current Injected by ShAPF in Amps (Phase A)

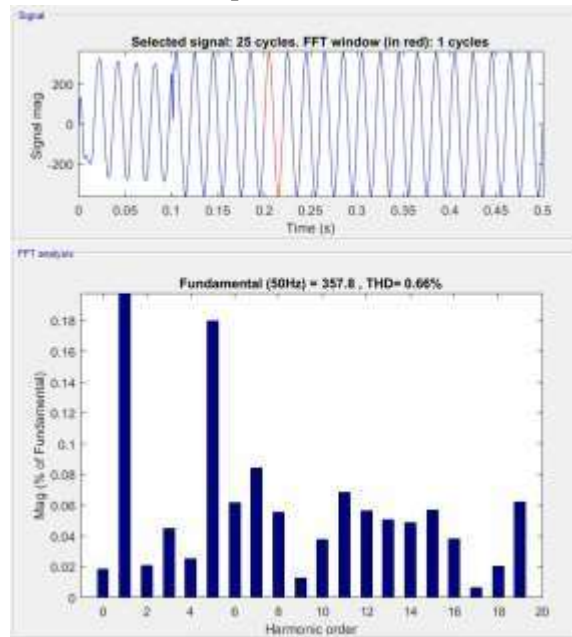


Fig11. Load Voltage THD% with the ANNcontroller

## CONCLUSIONS

The efficiency of variable offsetting of distortions of the current and voltage, as well as their combinations, for the PV UPQC with MATLAB/Simulink have been validated. The variable compensation is economical, in particular when there is a low ratings for VSIs used for power conditioning. The responsibility for the utility and the user can be assigned only by removing the cargoes produced by harmonics. UPQC is able to prevent distortion from the delivery system by means of Synchronous Reference Frame (SRF), series control strategies, and shunt conversion devices, including volume fluctuations, transients, distortions and harmonics at DC-link voltage. This paper describes a PV interface to the grid via UPQC to mitigate various disturbances in current and voltage. The problems of grid syncing and mitigation of power system disruptions in the presence of the traditional PLL-based regulation are seen in a highly skewed grid as difficult to mitigate in the mitigation phase. UPQC is thus simultaneously improving both voltage and current power issues. The recommended dual-unified power quality will meet the non-linear charging currents as well as ensure the sinusoidal charging voltage in all three phases. In the load and voltage disturbance at the source, the control was also very effective. In contrast to other planned systems the key advantage of the proposed control was the use of sinusoidal references for series and for shunt active filter control without the need of complicated calculations or co-ordinate transformations. To preserve the power efficiency, it minimises the total harmonic content of the load voltages. THDs are less than tactics without UPQC and with UPQC using the PI controller in the ANN controller.

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