POWER QUALITY IMPROVEMENT IN THE GRID-CONNECTED PVUPQC SYSTEM BY THE ANN

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***Abstract*— An Artificial Neural network-based Unified Power Quality Controller (UPQC) is proposed in this paper. An unbalanced grid voltage and Load voltage are compensated by the UPQC in the power system. This work involves the use of a Unified Power Quality Conditioner (UPQC) based on an ANN controller for its functions with grid integration of photovoltaic, such as voltage sags/ swell, unit power factor correction, voltage, and current harmonic cancelation. The Renewable energy source solar energy is connected to the grid. Here, we have studied the voltage quality improvement methods by using Dynamic Voltage Restorer (DVR), and Unified Power Quality Conditioner (UPQC) using two different controller Strategies. The sensitive equipment might be damaged by harmonics, voltage sag, and swell. These devices are vulnerable to Interference with other elements of the system resulting in input voltage changes. As a result, in the contemporary period, Power quality is becoming more important as the number of sensitive and costly electronic devices grows. To overcome the challenges of non-standard voltage, the Dynamic Voltage restorer (DVR) and Unified Power Quality Conditioner (UPQC) device has been extensively utilized to keep the load voltage stable. The controllers used are Proportional Integral Controller (PIC). A PI Controller calculates an error value as the difference between a measured variable and desired set point. The power system network with the proposed PQ control scheme is investigated and assessed under various scenarios to compensate for severe balanced, unbalanced (voltage sags and swells), and load change and the THD of the Power system was controlled by the UPQC.**

***Keywords*— Unified Power Quality Controller (UPQC), Artificial Neural network (ANN), Dynamic Voltage Restorer (DVR), Proportional Integral Controller (PIC), voltage sags and swells.**

1. INTRODUCTION

The presence of highly distorted loads at the consumer side makes the power system polluted and various power quality issues arise. Power quality improvement has become major point of focus for researcher nowadays. The integration of renewable energy to the grid with power electronic interfacing system also provides a wide area for power quality improvement. The current perturbations introduced by the loads, grid side voltage quality issues; unbalanced and highly distorted load conditions are major point of focus. Elimination of the power quality issues requires compensating systems. According to various types of power quality issues, special category of power conditioners has been used as reported in the literature [1]-[3]. The custom power devices have been reported as power conditioners with its various categories. 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 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, and unit vector template algorithm [12]-[14]. To make PV-UPQC systems become more sensitive towards highly distorted conditions of load and source voltage, this project introduces a modified SRF control algorithm. In this project 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 & Obserb (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 project proposes an improved PLL mechanism for highly distorted load and voltage conditions, which work along with APF control algorithm.

2. 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.

3. 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

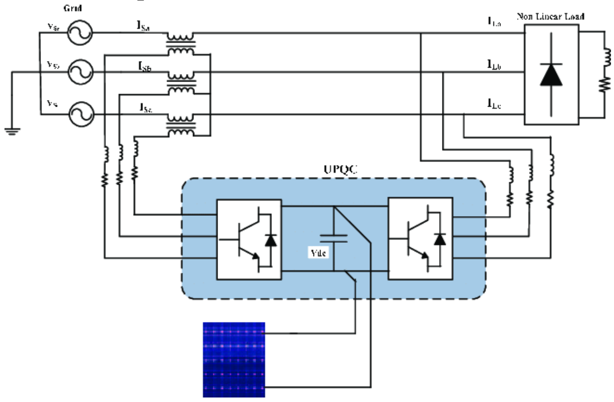


Fig: 1 Block diagram of a typical PV tied UPQC

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. 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.

A. 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 Vdc is presented as

$$V_{dc} = \frac{2\sqrt{2}V_L}{\sqrt{3}m}$$

Where 'm' represents the depth of modulation selected as 1 and V_L represents line voltage of the system.

4. 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 project introduces a new SRF methodology with an advanced PLL scheme. The proposed SRF scheme for the PV-UPQC is shown in Fig. 2.

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.

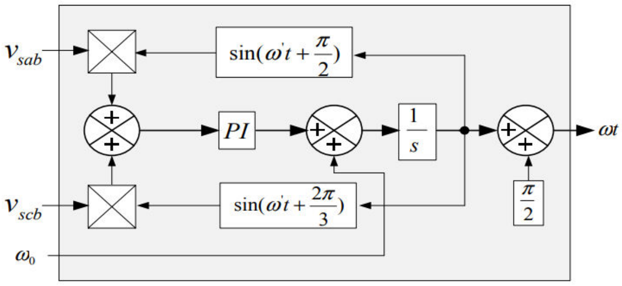


Fig: 2 Improved PLL Scheme

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. 8.3. The grid voltage is sensed and converted to d-q-0 frame with the utilization of matrix D presented in (8). The obtained sdv and sqv contains the oscillating components sdv~ and sqv~ as well as average components sdv and sqv. These component inclusions are due to the unbalanced grid voltage with harmonics. The presence of oscillating components sdv~ and sqv~ 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 s0v. The d-axis component includes both average and oscillating components presented in (5).

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

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

$$v_{sd} = \bar{v}_{sd} + \tilde{v}_{sd}$$

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.

5. CONTROL REFERENCES OF SERIES & PARALLEL INVERTERS BY ANN:

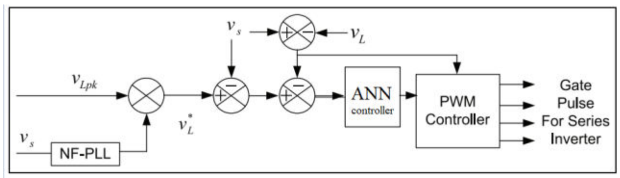


Fig: 3 Control structure of ANN

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]. 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.

With a low-pass filter or high-pass filter, these quantities can be filtered easily. The filtering of the signal dc extraction in the α-β 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/our 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 α-β transformation. The stationary frame quantities are then moved from the phase-locking loop into synchronous rotating frames using cosine and sinus function (PLL). Often called d-q approach is the traditional SRF algorithm. The 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.

In the experiment, source voltage $vs(k)$ is first measured and compared with an estimated voltage $vfund_{est(k)}$. 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 $\mathrm{Cos}(k\omega\Delta t)$) vectors as shown in equation (7).

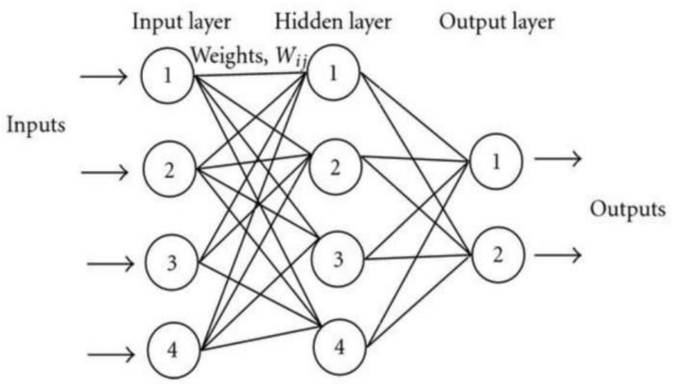


Fig: 4 ANN structure

The source voltage $vs(k)$ is calculated and compared with an approximate $vfund\_est(k)$ 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 ft) or cosine cos(k ft) vector by weight, as shown in the Equ (7) for weight W updates or amplitude W_{11} and W_{21}.

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

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, $e(k) = vs(k) - vfund\_est(k)$ is the error among estimated and measured voltage signal, and α is learning rate.

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

$$vfund_{mag(k)} = \sqrt{W_{11}^2 + W_{21}^2}$$

The iteration continues until $vfund_{est(k)} = vs(k)$ actual magnitude of the $vs(k)$ is twisted at this moment and finally divided between $vs(k)$ calculated to generate the desired synchronisation signal $\sin(k\omega\Delta t + \theta)$ please note that a unit representation of instant source voltage is the desired synchronisation signal generated in this way.

6. SIMULINK MODEL AND RESULT POWER QUALITY IMPROVEMENT IN THE GRID-CONNECTED PVUPQC SYSTEM BY THE ANN:

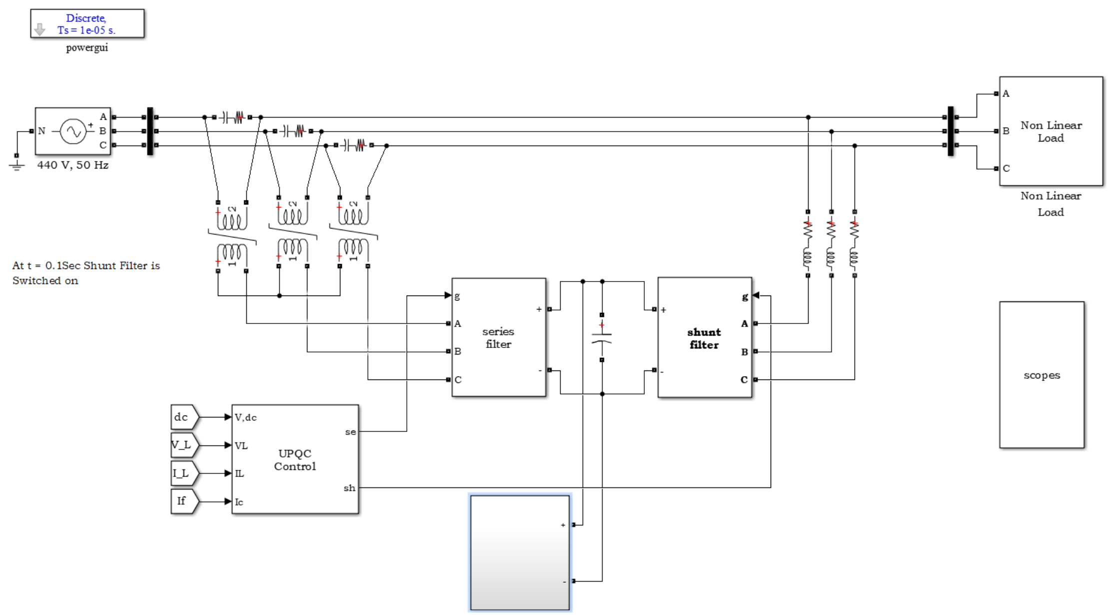


Fig 5. Simulation Block Diagram of the Proposed System

The structure of the PV-Battery-UPQC system is shown in the above fig. The system is designed as a three phase system. The PV-Battery-UPQC consists of a shunt active power filter and a series active power filter connected back-to-back with a common DC-bus. The system is designed such that the shunt APF is connected with the load side and the series APF is connected with the source side, whereas the PV and battery are connected directly to UPQC with DC-link. The series APF is operated in voltage controlling mode for mitigation of voltage related problems such as sag/swell and shunt. APF is operated in current control mode for the mitigation of current related problems such as harmonics and unbalancing. The shunt and series are connected to the grid by interfacing inductors. The series injected transformer is connected for injecting of the compensated voltage required for the mitigation voltage problem in the grid. A non-linear load is used which consists of a bridge rectifier.

A. Voltage at gird & load and UPQC injected voltage:

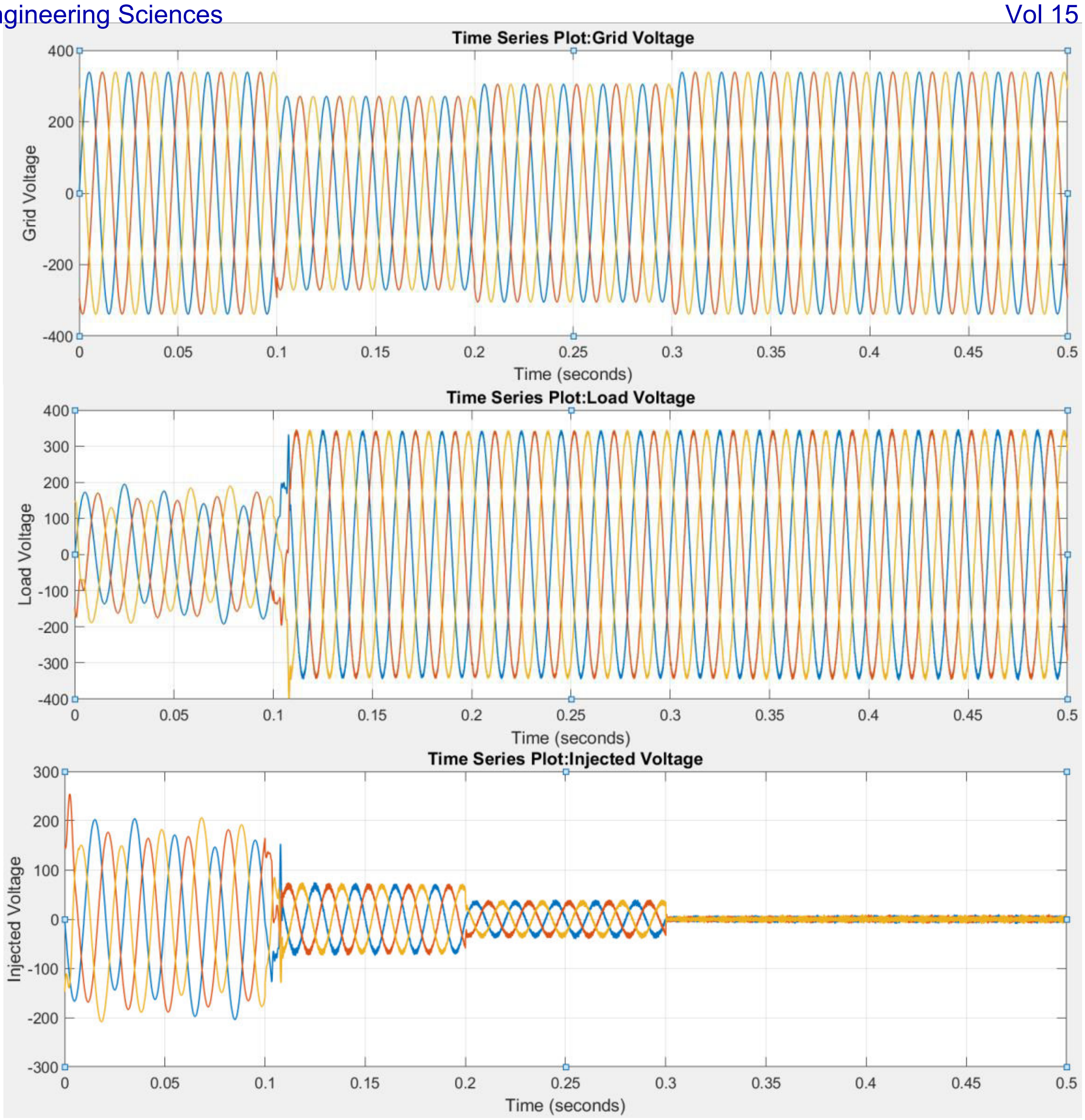
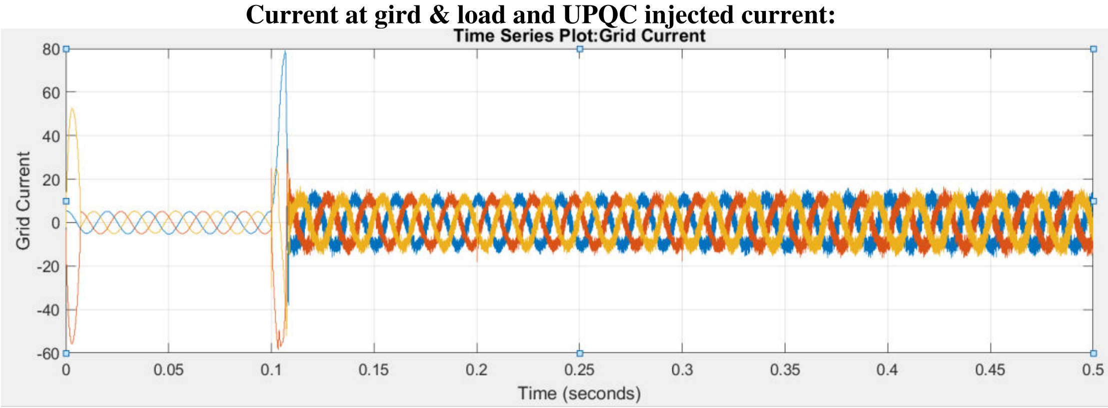


Fig: 6. simulated waveforms of the proposed control scheme. (a) Phase to neutral source voltage. (b) Load Voltage. (c) UPQC Voltage.

Figs. 6. Show Voltage waveforms with sag conditions with a negative sequence voltage superimposed on the supply voltage by the voltage flicker/imbalance. Fig waveforms before and after starting the shunt active filter Before starting the series active filter, the three-phase load Voltages include a negative sequence Voltage. After the UPQC Activated becomes T=0.1sec Voltages are controlled.

B. Current at gird & load and UPQC injected current:



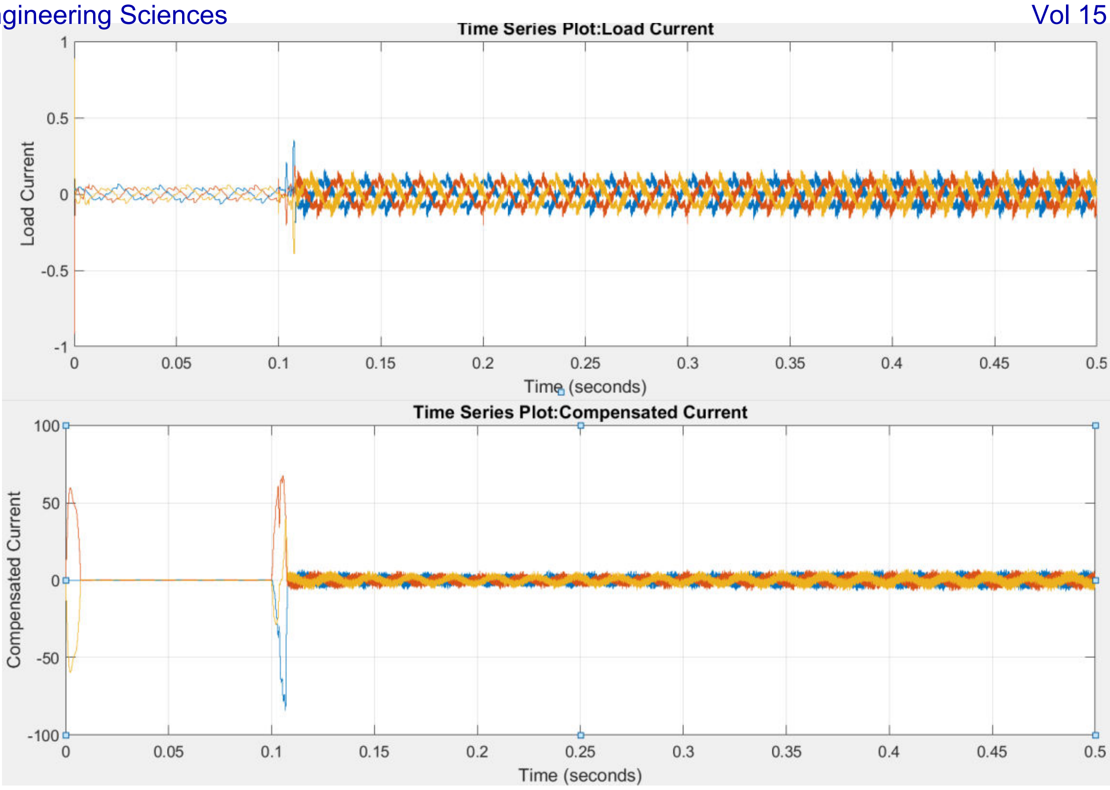


Fig: 7. Simulated waveforms of the proposed control scheme. (a) Phase to neutral source Current. (b) Load Current. (c) UPQC Current

C. UPQC Series Active Filter Outputs:

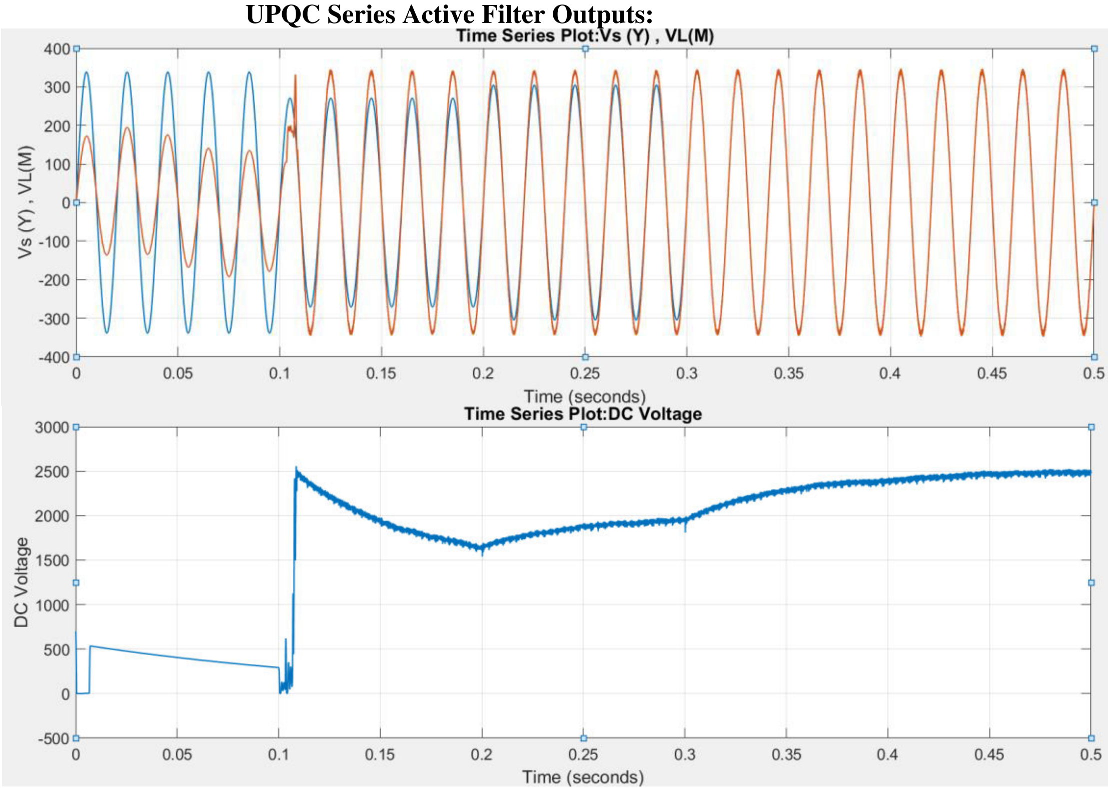


Fig: 8. Simulated waveforms of Series Active Filter (a) source voltage and Load Voltage. (b) Injected Voltage of the UPQC Voltage (c) Dc link Voltage.

Before starting the series active filter, the three-phase load currents include a negative sequence. After started, the negative sequence currents becomes because the negative sequence in the load terminal voltage is reduced.

D. UPQC Shunt Active filter:

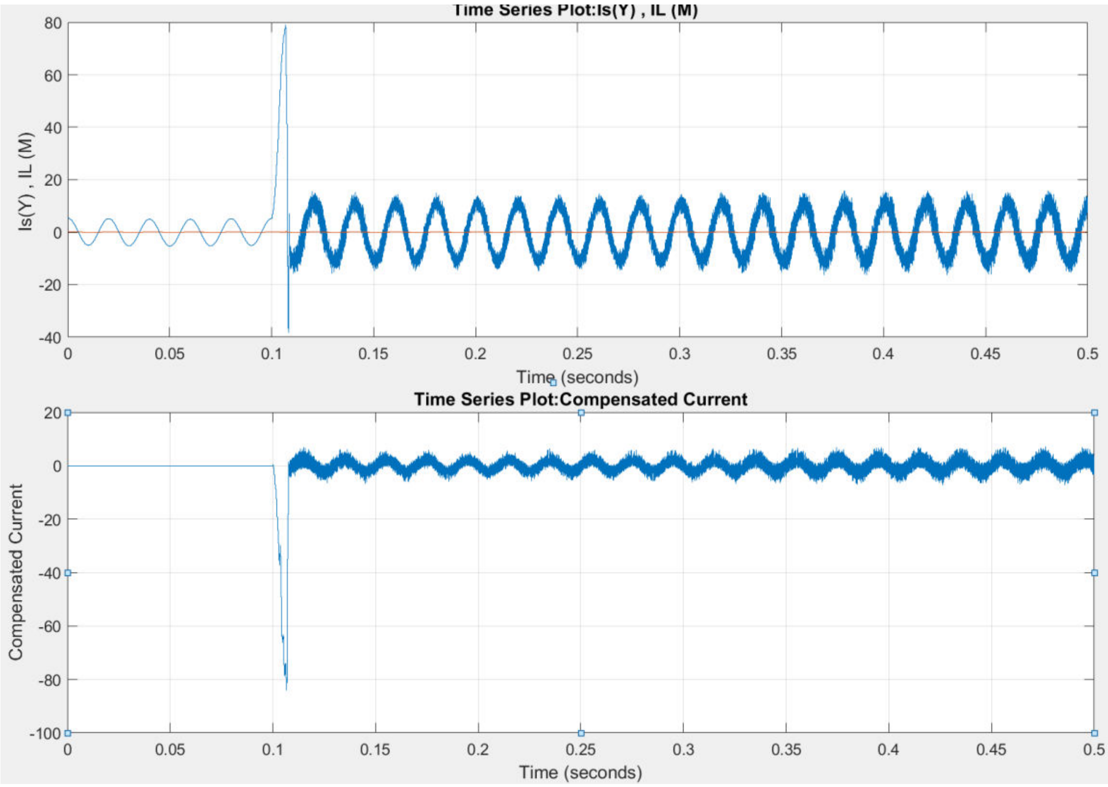


Fig: 9 (a) Grid Current & Current through Load in Amps (Phase A) (b) Current Injected in Amps (Phase A)

The shunt active filter injects ~AF into the supply, the amplitude of which fluctuates due to the voltage flicker in us. The variation of the dc link voltage is suppressed. This means that the shunt active filter returns almost all the active power drawn by the series active filter to the supply. If the shunt active filter is disconnected, the variation of the dc link voltages. Although the specific UPQC dealt with in this project provides no power factor correction in order to minimize the required rating of the shunt active filter, the general UPQC is capable of improving "power quality" as well as improving power factor.

A. Load Voltage THD% with the ANN controller

This project has dealt with the "unified power quality conditioners," the aim of which is not only to compensate for Voltage harmonics produced by nonlinear loads but also to eliminate Currents flicker/imbalance appearing at the receiving terminal from the load terminal.

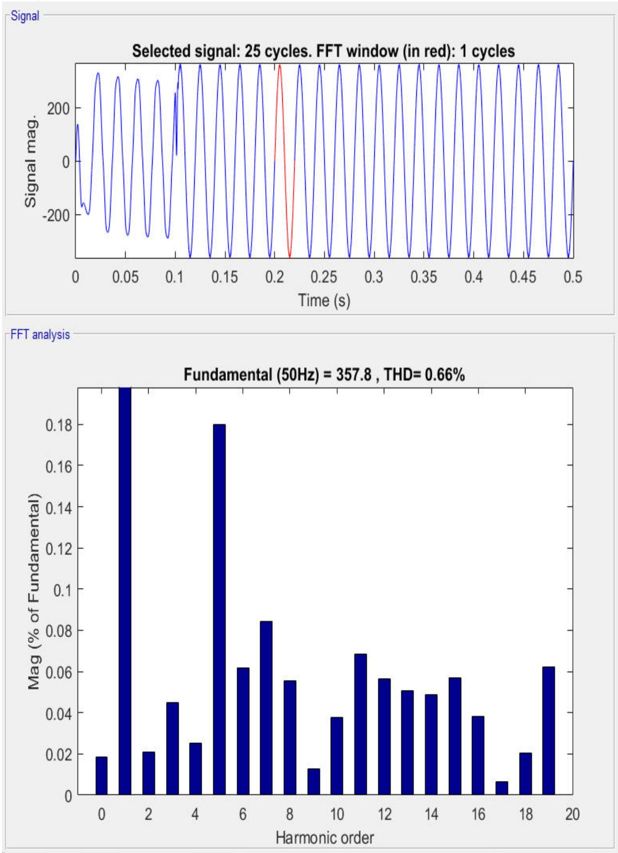


Fig: 10. Load Voltage THD% with the ANN controller

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 project 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.

FUTURE SCOPE

Proposed model of UPQC is to compensate source side and also load side problems using PI and Fuzzy logic controllers. The work can be extended to compensate total drop in the system using combined ANN control (Adaptive neuro networks controller) and some other Optimization techniques. It is worth noting that the paper's limitation lies in its inability to achieve significant improvements in load current THD, leaving room for future research to enhance the reduction of THD in load currents. In addition, neural network-based algorithms and different machine learning models can be implemented to test the power quality of devices as a scope of future research. Finally, the performance evaluation of UPQC will help to remove power quality problems in the future grid and enhance the grid performance and ensures electrical equipment safety.

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