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Analysis of Power Quality Improvement in the Grid Connected Renewable Energy based System with UPQC Control Strategies

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Abstract:
This paper proposes an improved dq control strategy of the unified power quality regulator to alleviate the voltage and current abnormalities in the three-phase system. Renewable energy integration and non-linear loads will reduce the power quality of the system. Active power filters play a vital role in mitigating PQ interference. Aiming at current defects and reactive power compensation problems, an improved dq controller is proposed as a parallel controller. Propose an ANFIS-dq control strategy for series controllers to suppress voltage defects. Photovoltaic units are optimally connected to the DC link of UPQC to support control actions and provide active power. The renewable energy integratedwith UPQC is best commended by traditional PI and ANFIS controller research performance. The MATLAB / SIMULINK platform is used to analyse the proposed system performance.

Keywords: *Power Quality, Renewable Energy, UPQC, PI and ANFIS Controllers.*

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I. INTRODUCTION

The energy policy of India is largely defined by the country's burgee owing energy deficit and increased focus on developing alternative sources of energy, particularly nuclear, solar and wind energy [1]. About 70% of India's energy generation capacity is from fossil fuels, with coal accounting for 40% of India's total energy consumption followed by crude oil and natural gas at 24% and 6% respectively. Given India's growing energy demands and limited domestic fossil fuel reserves, the country has ambitious plans to expand its renewable and nuclear power industries. India has the world's fifth largest wind power market and plans to add about 20GW of solar power capacity [2] by 2022. With increasing applications of nonlinear and electronically switched devices in distribution systems and industries, power-quality (PQ) problems such as harmonics, flicker, and imbalance have become serious concerns. Renewable energy integration and non-linear loads can cause current and voltage harmonics, reactive power demand, and voltage disturbances (such as dips/swells). Fluctuations on the grid side will also affect the power quality [3]-[4]. The use of non-linear loads, power electronic control loads and inductive loads have a significant impact on PQ barriers [5]–[6]. Mainly passive filters have been replaced by active filters to deal with voltage and current abnormalities more effectively. Shunt APF compensates for current harmonics, reactive power requirements and current interference. The APF series solves voltage disturbances such as dips/swells and harmonics[7]–[8]. UPQC combines the characteristics of series and parallel APFs. UPQC joint alleviates abnormal voltage and current. The series part of UPQC deals with voltage defects, and the shunt part deals with current defects[9]-[12]. In the literature, control strategies such as DC link controller, pq, dq, and Icosø are proposed for shunt APFs in parallel [13]–[16]. Similarly, PWM controller, instantaneous reactive power theory, synchronous reference frame theory, phase-locked loop and power angle controlare proposed for series APF in the text [17]-[20]. In this paper, PV fed UPQC is considered for the performance analysis of power quality and simulated in MATLAB software.

II. DESCRIPTION OF PROPOSED SYSTEM

The Unified Power Quality Controllers (UPQC) is another recent best choice for mitigating voltage and current abnormalities on distribution power line. The schematic diagram of UPQC is shown in Fig.1 below. UPQC consists of two Voltage Source Inverters (VSI) series and shunt, tied back to back with each other sharing a common dc link. These devices consist of a shunt and a series transformer, which are connected via two voltage source converters with a common DC-capacitor. In order to mitigate harmonics commenced by

nonlinear load, the shunt inverter injects a current. The series inverter of UPQC is employed in voltage control mode as it supplies and injects voltage in series with line to realize a sinusoidal, distortion free voltage at the load terminal.
The load L1 and L2 are a nonlinear/sensitive load which needs a pure sinusoidal voltage for proper operation while its current is non-sinusoidal and contains harmonics.

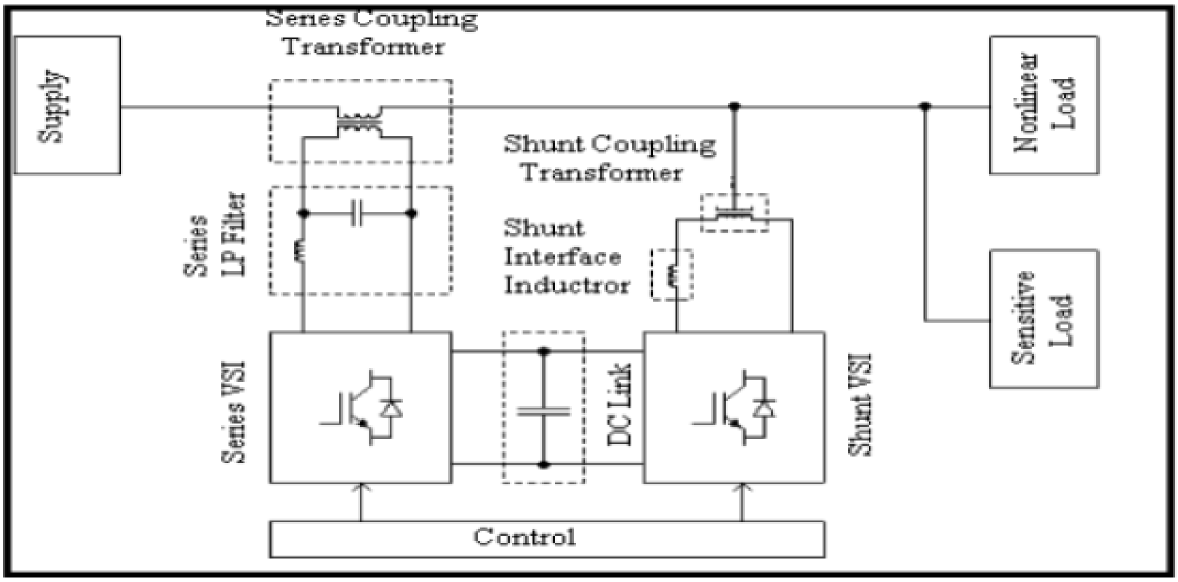


Figure1: Schematic diagram of UPQC

Renewable source is integrated at common DC link of two converters for aiding UPQC working in alleviation of Power Quality issues. The model can utilize the photovoltaic source in an effective manner.The UPQC acts as power quality mitigating device and power conditioning device for PV integration. The fig.2 shows integrated PV source at DC link delivers required power to UPQC for mitigating the current as well as voltage imperfections. The PV unit works as DC link voltage stabilizer and delivers the part of real power to load. Several maximum power point tracking algorithms are now available for tracking maximum solar energy. Ease of less parameters and uncomplicated feedback make the P&O as most preferred algorithm. For evaluating the performance of the proposed PV fed UPQC, controlled voltage source is considered. To produce desired supply voltage distortions, six different sinusoidal signals are considered and clubbed together. Finally, a unit vector template control algorithm has been used to control the operation of active filters for proposed PV grid connected UPQC to fulfill the standard specifications of voltage sag, voltage swell and current harmonics are injected into the grid.

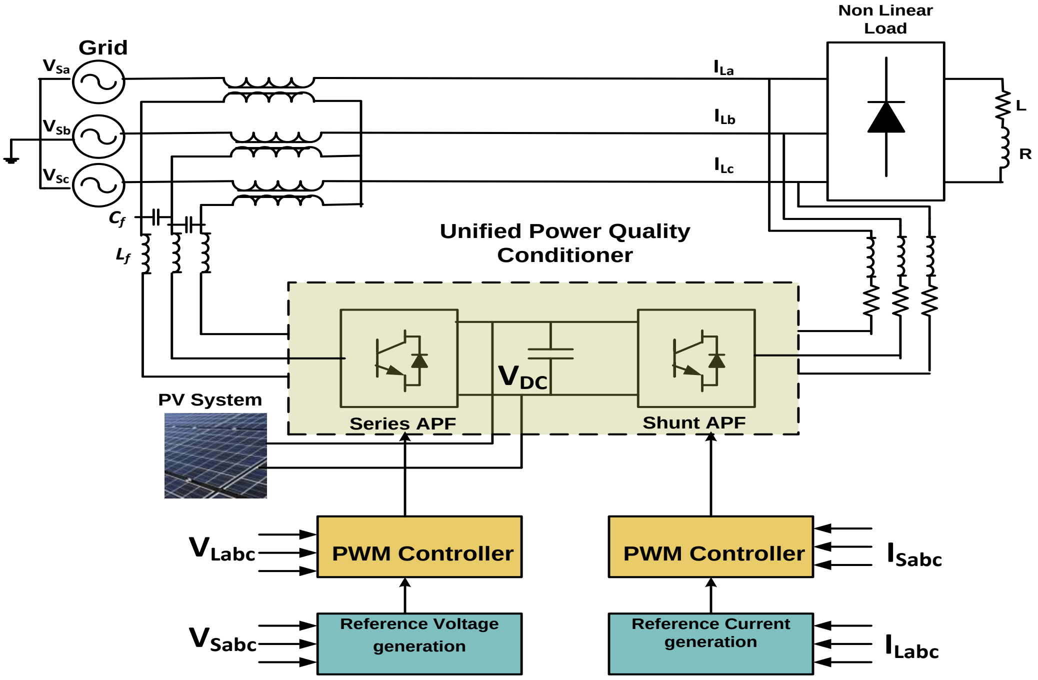


Figure2: Proposed System of PV fed UPQC

III. PROPOSED CONTROL STRATIGIES

3.1 Shunt Control Strategy

Fig.3 below shows the modified DQ control strategy. In this control strategy, the power supply current (I_{sa}, I_{sb}, I_{sc}), power supply voltage (V_{sa}, V_{sb}, V_{sc}), load current (I_{La}, I_{Lb}, I_{Lc}), and DC link voltage$V_{dc}$are initially sensed.

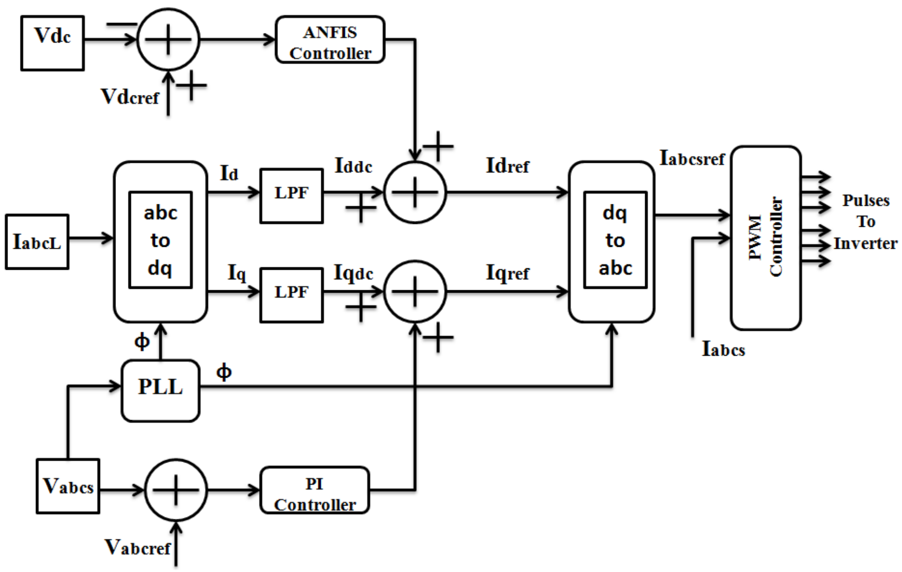


Figure3: Shunt Controller of UPQC

Later, using the equation (1) convert the load current from abc-frame to dq-frame.

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\emptyset & -\sin\emptyset & \frac{1}{2} \\ \cos(\emptyset - \frac{2\Pi}{3}) & -\sin(\emptyset - \frac{2\Pi}{3}) & \frac{1}{2} \\ \cos(\emptyset + \frac{2\Pi}{3}) & \sin(\emptyset - \frac{2\Pi}{3}) & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \quad \text{----- (1)}$$

These i_d and i_q components pass through the filter to obtain a constant Dc component. i_{ddc} is combined with the loss component, which is generated by tuning the DC link error signal to obtain the reference current i_{dref}. The loss component and the direct axis reference current are given in Equations (2) and (3).

$$i_{ln} = i_{l(n-1)} + k_{pd}(V_{de(n)} - V_{de(n-1)} + k_{id}V_{de(n)} \quad \text{------ (2)}$$

$$i_d^* = i_l + i_{ddc} \quad \text{------ (3)}$$

Similarly, i_{qdc} is combined with the tuning power supply voltage error signal to obtain the reference current I_{qref}, as shown in Equation (4). These reference i_{dref} and i_{qref}currents are converted back to the abc-reference system using inverse Park Transformation, and they are the final reference currents given by equation (5).

$$i_{qrn} = i_{qr(n-1)} + k_{pq}(V_{te(n)} - V_{te(n-1)} + k_{id}V_{te(n)} \quad \text{----- (4)}$$

$$i_q^* = i_{qr} + i_{qdc} \quad \text{----- (5)}$$

The PWM controller is used to generate gating pulses based on the difference between the reference source current and the actual source current. Based on the strobe pulse, SHAF injects current into the PCC to suppress the harmonics in the current and compensate the required reactive power.

3.2 Series Control Strategy

Here, the purpose of the series controller is to reduce voltage sags, swells and interruptions. It can also compensate for voltage harmonics. The recommended series voltage controller is shown in Fig4. First, use the following equation to convert the source voltage to the synchronous dq0 reference frame.

$$V_{s1}^{dq0} = T_s * V_{s1}^{abc} = V_{s1p} + V_{s1n} + V_{s10} + V_{s1h} \quad \text{----- (6)}$$

Among them, V_{s1p}, V_{s1n}, V_{s10} and $V_{s1h}$are positive, negative, zero sequence and harmonic components, respectively. The purpose is to get the sinusoidal voltage, so the dq0 reference system of the load voltage has,

$$V_{L1}^{dq0} = T_s * V_{s1}^{abc} = \begin{bmatrix} U_m \\ 0 \\ 0 \end{bmatrix} \quad \text{----- (7)}$$

$$\text{Where Ts} = \begin{bmatrix} \cos\emptyset & -\sin\emptyset & \frac{1}{2} \\ \cos(\emptyset - \frac{2\Pi}{3}) & -\sin(\emptyset - \frac{2\Pi}{3}) & \frac{1}{2} \\ \cos(\emptyset + \frac{2\Pi}{3}) & \sin(\emptyset - \frac{2\Pi}{3}) & \frac{1}{2} \end{bmatrix} \quad \text{----- (8)}$$

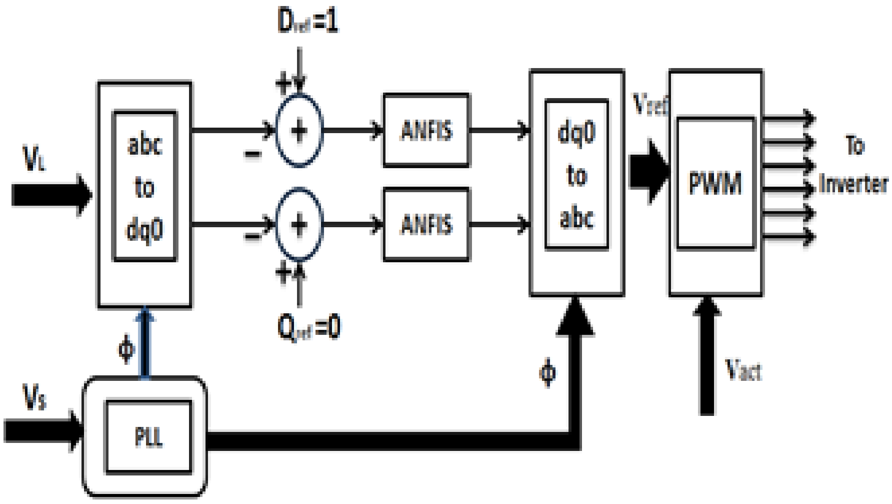


Figure4: Series Control Strategy of UPQC

The compensation dq0 reference frame voltage is given by the following formula,

$$V_{dq0}^{ref} = V_{s1}^{dq0} - V_{L1}^{dq0} \quad \text{----- (9)}$$

This compensation voltage is again converted back to the abc-reference frame. Use SPWM to generate gate pulses to compensate for load voltage disturbances.

3.3 Maximum Power Point Trackingusing P&O Method

The MPPT technique is utilized to improve the productivity of solar power generation. In the present work, The DC-DC boost converter also allows us to implement different MPPT control strategies, including an interface between Photovoltaic and inverter. PV inverters need a constant DC input voltage to work under optimal conditions. The boost converter circuit is utilized as an impedance coordinating gadget between the information and the yield by changing the obligation cycle. A significant preferred position of the boost converter is the high or low voltage that is acquired from the accessible voltage as per the application. The MPPT is used to calculate the duty cycle to obtain the maximum output voltage, and the output of the converter is a response that depends on the duty cycle. The perturbation and observation (P & O) method was used in this work to obtain the maximum power from the PV as described below.

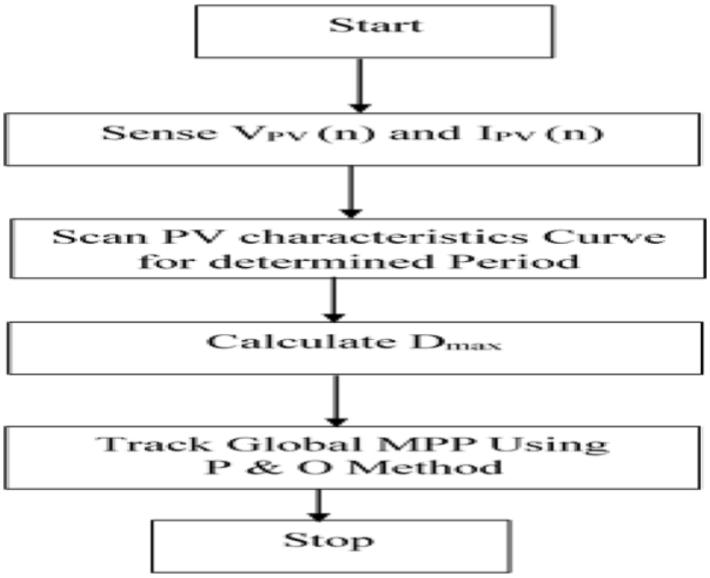


Figure5: Flow Chart of P&O Method

3.4 ANFIS Control Strategy

The ANFIS controller utilizes the adaptive learning function of the neural network and the fuzzy inference mechanism. The Neuro-Fuzzy combination has proven its ability to fine-tune the error signal. Here, ANFIS learning is a two-way learning process. The forward learning process uses least square error learning. Back propagation learning is used for back propagation. In the current ANFIS model, 3 fuzzy language values (low, medium, and high) are selected for a single output and two input variables as shown in the fig.6 below.

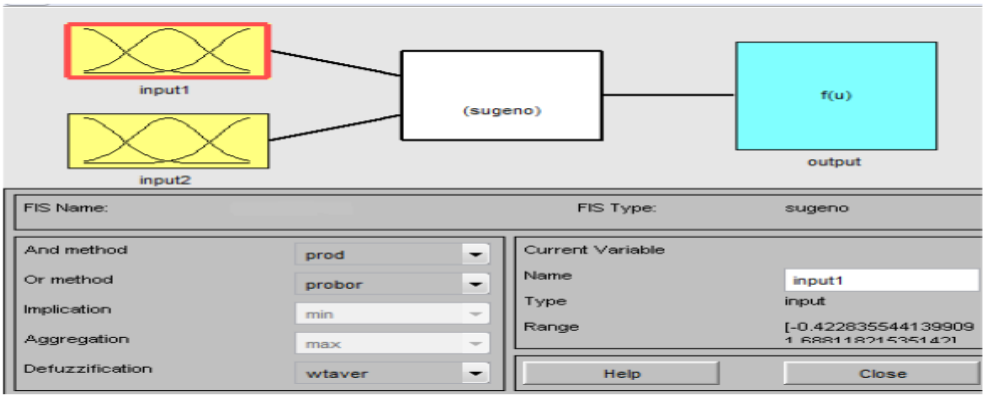


Figure6: ANFIS Membership Function

IV. RESULTS AND DISCUSSION

The proposed system comprises of three-phase voltage source inverter and interfacing inductance (Lf). The solar system is used for giving DC supply to the UPQC based VSI. The non-linear load is connected at PCC. The Photovoltaic system is connected at DC link of UPQC, for delivering the power required by the shunt and series compensation. The PV unit also maintains the DC link voltage as constant. The Simulation parameters are shown in Table 4.1 and Proposed PV fed UPQC system MATLAB/SIMULINK model is shown in Fig. 7.

Table 4.1 Specifications of proposed UPQC system

S. No	Parameters	Ratings
1	Source voltage	Three-phase, 230 volts, 50 Hz
2	load	Rl=10Ω, Ll=30mH
4	DC link	Vdc = 500 V
5	Solar battery	35V, 7.5A

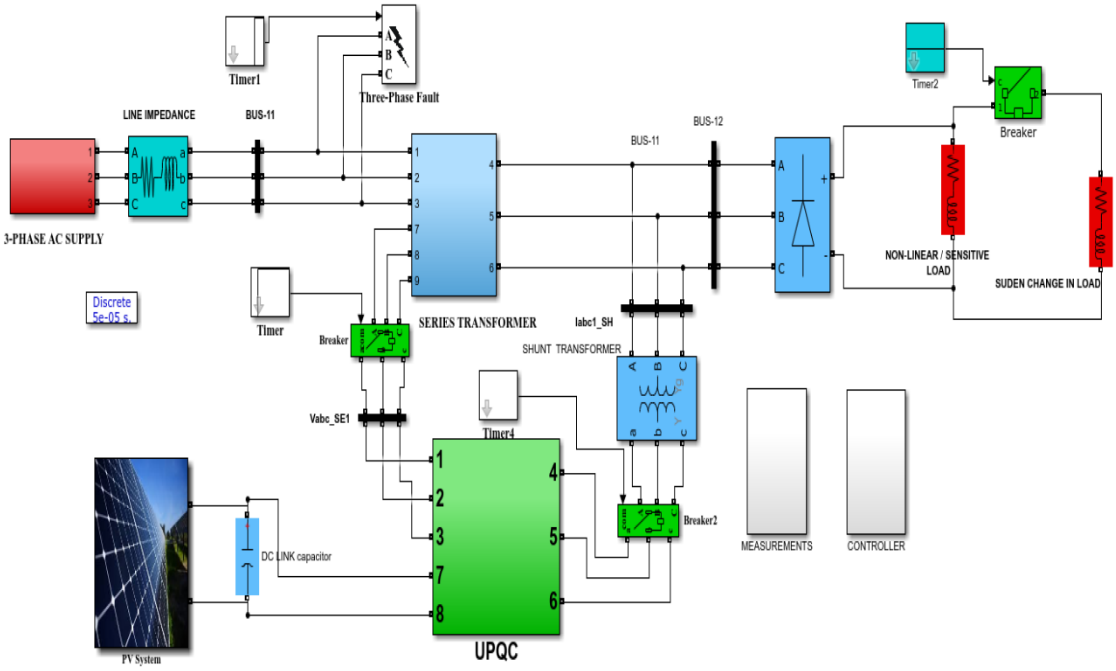


Figure7: Simulation Diagram of a Proposed PV fed UPQC System

4.1 Current and Voltage Curves

The non-linear load connected at PCC injects the harmonics and distorts the sinusoidal source current. Here, the proposed controller operates at t = 0.1 sec. When controller is on at t = 0.1 sec, the shunt controller injects the compensating currents in opposition to harmonics and nonlinearities at PCC. This causes suppression of harmonics and nonlinearities in current and source current becomes sinusoidal. It is observed that controller effectively maintains steady voltage across DC link even under voltage and current disturbances. Fig.8 shows the compensation of harmonics as well as non-linearity's in source currents.

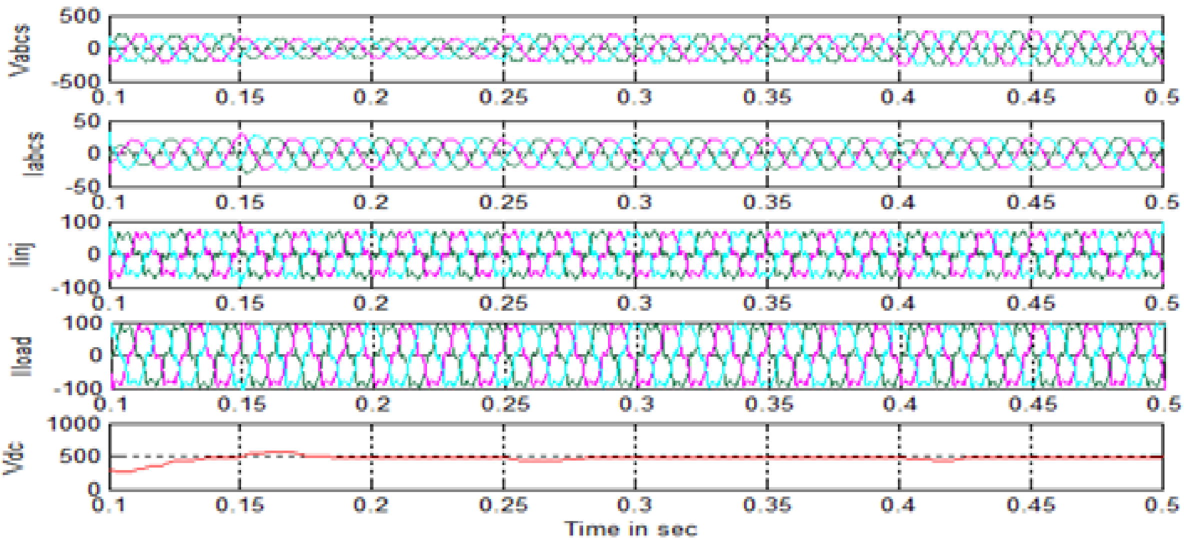


Figure7: Power supply voltage, power supply current, injection current, load current and Vdc profiles

Below Fig.8 shows the mitigation of sag as well as swell disturbances in load voltage. In the proposed system, the sag is created between t = 0.2 to t = 0.3 sec and swell is created between t = 0.35 and T = 0.45 sec. Series controller effectively injects the compensating voltage by using voltage injection transformer, which suppresses the sag and swell and delivers sinusoidal steady voltage to the load. This protects the loads from sag and swell disturbances effect on loads.

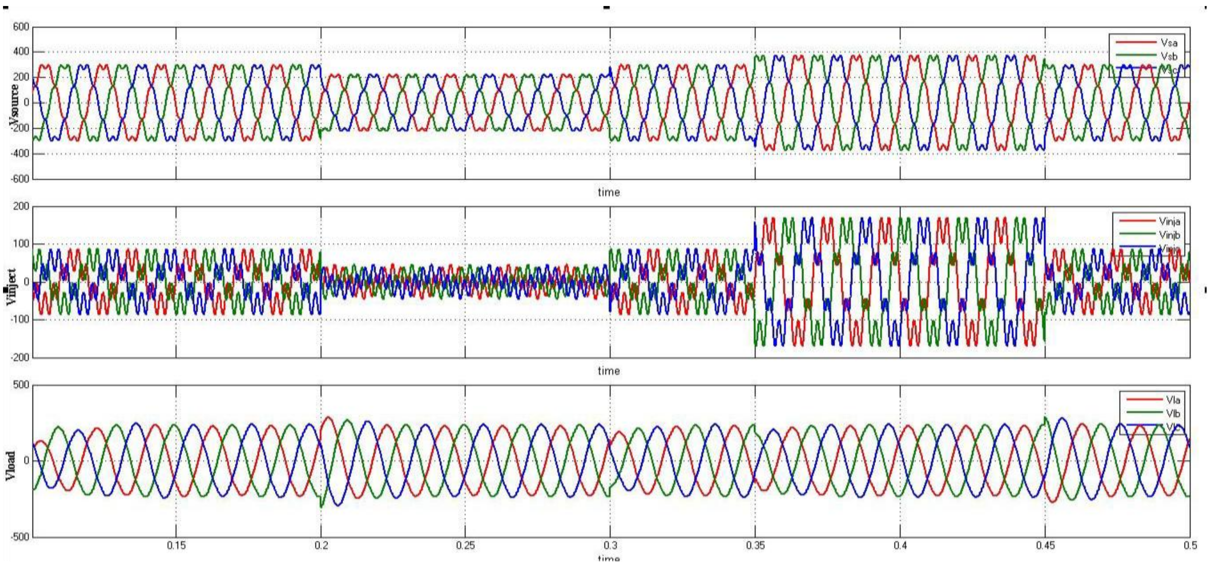


Figure8: Mitigation of sag as well as swell disturbances in load voltage

The Fig.9 below shows the compensation of distorted as well as unbalanced supply voltage effect on load. Here, the unbalanced sinusoidal voltages are created between t = 0.1sec and t = 0.2 sec. Similarly distorted unbalanced voltages are created between t=0.2sec and 0.3sec. SEC injects compensated voltages to suppress the abnormalities. Owing to the injection of compensating voltage sinusoidal balanced voltages are delivered to load.

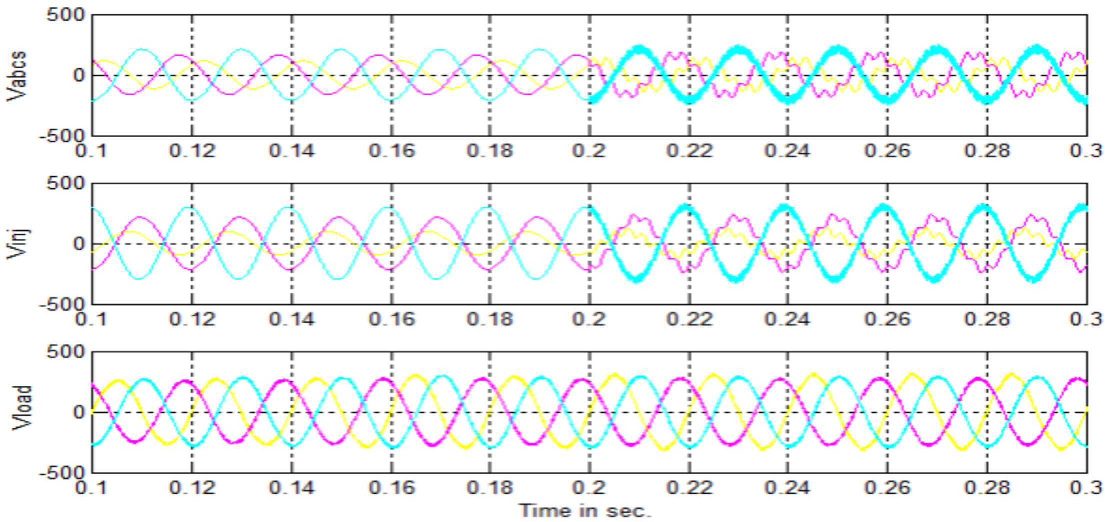


Figure9: Compensation of Unbalanced voltages on Line

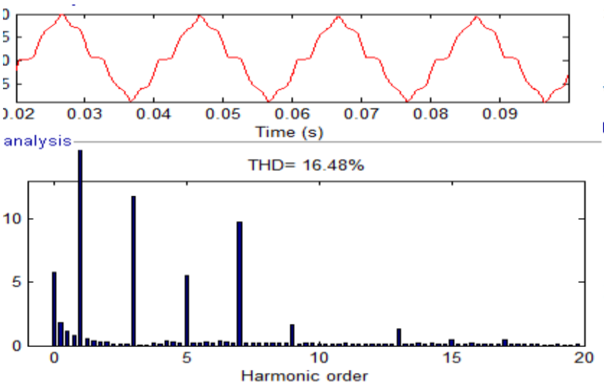
4.2 Current Harmonics Profile

The harmonics reduction is analysed under different conditions, like without UPQC, with PI-UPQC and ANFIS-UPQC.

Case 1:% THD of the supply current without UPQC is shown in Fig.10 (a). Due to the non-linear load, the power supply current %THD is greater.It is observed that % THD of supply current is 16.48% which is undesirable according to IEEE standards.

Case 2: The UPQC is integrated at t = 0.1 sec, post t = 0.1 sec, % THD of supply current with PI controlled UPQC is shown in Fig.10(b) reduced %THD of supply current with PI controller is 5.68%.

Case3: % THD of supply current with ANFIS controlled UPQC is utilized in replacement of PI controller. The % THD of supply current with ANFIS controller is shown in Fig.10(c). Reduced %THD of supply current with ANFIS control method is 3.8%.



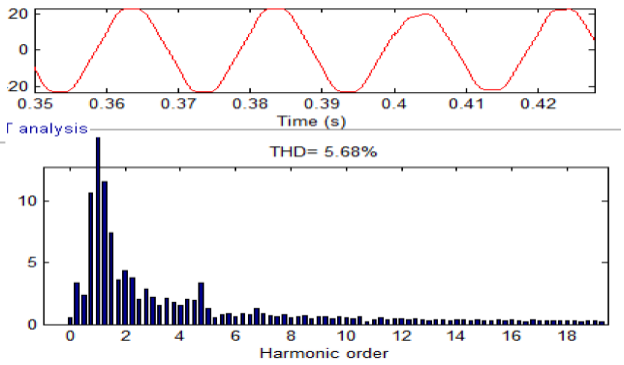


Figure10(a): Current %THD without Controller **Figure10(b): Current %THD with PI Controller**

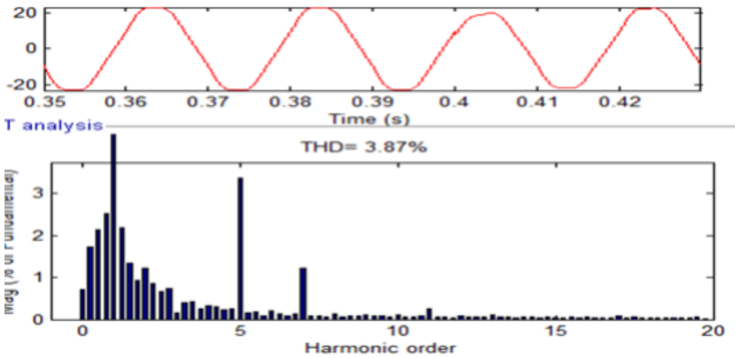


Figure10(c): Current %THD with ANFIS Controller

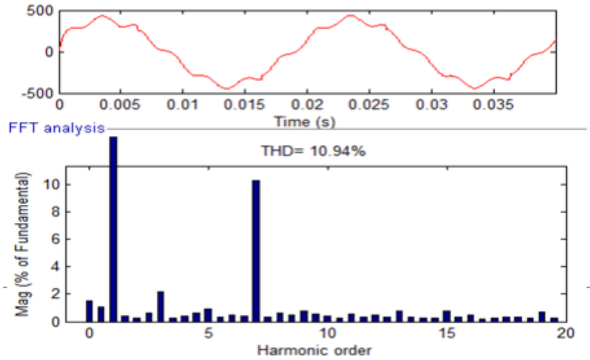
4.3 Voltage Harmonics Profile

A short duration voltage variations like voltage swells, voltage sags and interruptions are the most frequent and serious PQ problems which are analyzed with the proposed techniques.

Case1: % THD of Load Voltage without UPQC is shown in the fig.11(a) below.It is observed that % THD of load voltage is 10.94% which is not recommended by IEEE standards.

Case2: The UPQC is integrated at t = 0.1 sec, post t = 0.1 sec. The % THD of Load Voltage with PI controlled UPQC is shown in Fig.11(b). Reduced %THD of voltage with PI controller is 3.25%.

Case3:% THD of load voltage with ANFIS controlled UPQC is utilized in replacement of PI controller for further improvement. The reduced %THD of load voltage with ANFIS controller is 2.28% and is shown in Fig.11(c) below.



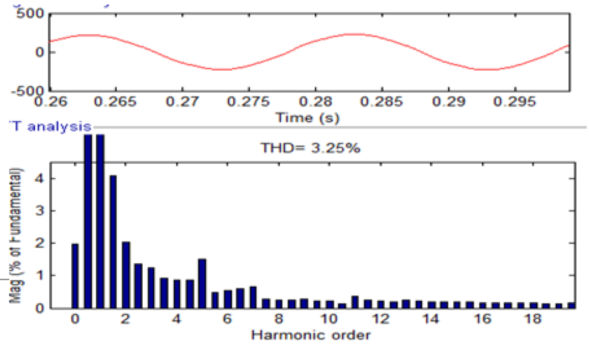


Figure11(a): Voltage %THD without ControllerFigure11(b): Voltage %THD with PI Controller

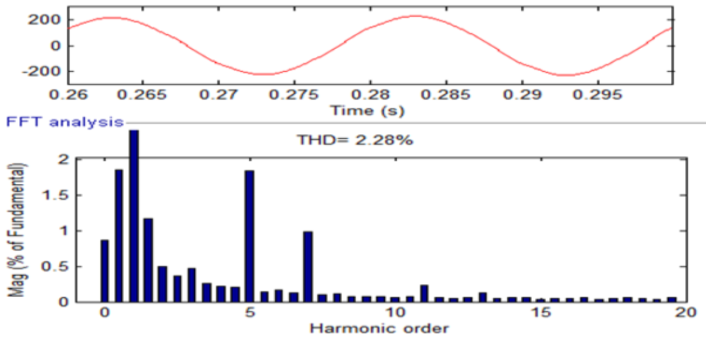


Figure11(c): %THD of load voltage with ANFIS Controller

V. CONCLUSION

In this paper, PI and ANFIS control strategies were proposed for UPQC with connected PV system. The proposed method effectively compensates non-linearities in load current as well as distortion in load voltages. The study discusses the MPPT technique, voltage control and current control of the system. The ANFIS controller gives better performance in current and voltage harmonics alleviation compared to traditional PI controller to obtain the range of IEEE standard as the %THD is less than 5%.

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