Power Quality Improvement by Utilizing Efficient Controllers for Unified Power Quality Conditioner in Grid Connected Renewable Energy Systems

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Abstract: *Power quality is a common problem faced by the bulk and domestic consumers, however bulk consumers like industries uses sensitive equipments and the domestic consumers use power electronic component based equipments. Due to the demand of power, renewable power is integrated with the electric grid in order to match the demand on electric power The integration of renewable power and the usage of the power electronic sensitive equipments raises the power quality issues Several custom power devices are used to improve the quality of power however an unified power quality conditioner (UPQC) using an artificial Neuro fuzzy inference system (ANFIS) controller for enhancement of power quality in a grid connected to the renewable energy system is presented in this paper.- Two renewable energy sources like wind and fuel cells along with a non-linear load were considered to be integrated into an electric grid. This article presents a solution for the mitigation to power quality issue that may arise due to the renewable power and the nonlinear loads improvement in power quality using an ANFIS controller UPQC with a conventional (PI) controller. Simulation studies were carried out to analyze the effect of the power quality events at the point of common coupling (PCC) in the grid connected renewable energy systems*

Key words: *Unified Power Quality Conditioner (UPQC) ANFIS, Power quality, PI, Renewable energy system.*

I.Introduction

Power electronic devices are used in large numbers to enhance the performance and function of industrial and domestic loads. The power quality events like voltage waveform distortions will occur frequently. The challenge is to maintain the power quality. The integration of renewable energy systems increases the complexity of power quality maintenance. This article focuses on the power quality issues that may occur during the integration of renewable power [1-2].

The common power quality events that may happen during the integration of renewable power were voltage sag, flickers, and waveform distortions. Traditionally passive filters were used to eliminate waveform disturbances. However the active power filtering method dominates the passive filter. Several methods have been proposed to control the active filter [3-8]. In previous methods the instantaneous power theory (p-q) is used to generate the reference currents. It has become a challenging task to reduce the harmonics and to keep under permissible limits. Electric grids need to employ advanced technologies minimizing impacts on the environment. System security, safety, environment, power quality, cost of supply, and energy efficiency are taken into an account while introducing new trends in technology. Various power quality controllers such as a series compensator (DVR), shunt compensator (like DSTATCOM) and UPQC are used to control the power quality problems. A shunt controlled devices DSTATCOM is employed for power factor correction and harmonics elimination, however ,it offered solution for the power quality issues raised due to linear and nonlinear loads [9]. Among Unified Power Quality conditioner (UPQC) gives a better solution for power quality issues [10].

The custom power devices that possess current and voltage source converters requires a control system to have a better function. The control techniques are suitable for the voltage and current source converters. The grid interfacing inverter is controlled by a hysteresis current control scheme which suits for the different types of load [11]. Though the current control scheme produces favorable solutions, current fed pulse width modulation inverter dominated and met the harmonic current requirement for the non-linear load [12,13]. A synchronous reference frame control is introduced for a capacitor supported DVR to eliminate power quality issues [14].A PI controlled UPQC is introduced with the induction generator to study the impact of the power quality issues.[15]The other device voltage fed pulse width modulator inverter provided an enhanced performance at low switching frequencies that helps to eliminate harmonics. A fuzzy controller based active power filter working with a renewable power sources controlled the voltage source converters efficiently under steady state and transient conditions, though it does not offer and power quality solution it leads to implement and such ANFIS based controller [16].

In a renewable energy system using wind turbines the wind speed is variable or intermittent in nature and results in flickers. A robust tracking controller has been proposed to reduce the uncertainties and load variations [17]. Using a series active filtering method the neutral current harmonics present in a solar photo voltaic system is eliminated. It removes the harmonics across the load [18]. Fuel cells are developed for mobile power generation and static applications. The development of such fuel cells is used for low power appliances in industries and for resident applications when fuel cells operate as a standalone system, it may undergo for transient disturbances.If they were integrated with the electric grid it may experience some grid disturbances [19].

The paper is structured as follows: section II provides the theory of the proposed controller. Section III describes the system considered for investigation and section (IV) provides the structure of Unified Power Quality Conditioner (UPQC) model. Simulation results are presented in section (V).

II.THEORETICAL BACKGROUND

1. Instantaneous active and reactive power theory (p-q)

In a three phase system a set of voltages and current are transformed from one plane to another (ABC-αβ0).

$$\begin{bmatrix} V_0 \\ V_d \\ V_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_0 \\ I_d \\ I_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (2)$$

Generalized instantaneous power, P (x)

$$P(x) = V_a i_{la} + V_b i_{lb} + V_c i_{lc} \quad (3)$$

The p-q formulation defines the generalized instantaneous power, P (x), and instantaneous reactive power vector, q (t) in terms of the α-β-0 components as

$$P(x) = V_\alpha i_\alpha + V_\beta i_\beta + V_0 i_0 \quad (4)$$

$$q(x) = \begin{bmatrix} q_\alpha \\ q_\beta \\ q_0 \end{bmatrix} = \begin{bmatrix} \begin{vmatrix} V_0 & V_\alpha \\ I_0 & I_\alpha \end{vmatrix} \\ \begin{vmatrix} V_\alpha & V_\beta \\ I_\alpha & I_\beta \end{vmatrix} \\ \begin{vmatrix} V_\beta & V_0 \\ I_\beta & I_0 \end{vmatrix} \end{bmatrix} \quad (5)$$

$$q(x) = \|\vec{q}(x)\| = \sqrt{q_\alpha^2 + q_\beta^2 + q_0^2} \quad (6)$$

$$\begin{bmatrix} p \\ q_\alpha \\ q_\beta \\ q_0 \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta & V_0 \\ 0 & -V_0 & V_\beta \\ V_0 & 0 & -V_\alpha \\ -V_\beta & V_\alpha & 0 \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \\ I_0 \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \\ I_0 \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2 + V_0^2} \begin{bmatrix} V_\alpha & 0 & V_0 & -V_\beta \\ V_\beta & -V_0 & 0 & V_\alpha \\ V_0 & V_\beta & -V_\alpha & 0 \end{bmatrix} \begin{bmatrix} p \\ q_\alpha \\ q_\beta \\ q_0 \end{bmatrix} \quad (8)$$

Considering the above equations the orthogonal nature of the vectors $\vec{V}$ and $\vec{q}$ the reference current in the α-β-0 plane is

$$\begin{bmatrix} I_{s\alpha} \\ I_{s\beta} \\ I_{s0} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2 + V_0^2} \begin{bmatrix} V_\alpha & 0 & V_0 & -V_\beta \\ V_\beta & -V_0 & 0 & V_\alpha \\ V_0 & V_\beta & -V_\alpha & 0 \end{bmatrix} \begin{bmatrix} p \\ q_\alpha \\ q_\beta \\ q_0 \end{bmatrix} \quad (9)$$

The aim of the p-q strategy is to receive the source to deliver only the constant active power demanded by the load

$$P_s(x) = P_{L0}(x) + P_{L\alpha\beta}(x) \quad (10)$$

In addition, the source must deliver no zero-sequence active power $I_{s0ref}=0$ (so that the zero-sequence component of the voltage at the PCC does not contribute to the source power). The reference source current in the α-β-0 plane is therefore,

$$\begin{bmatrix} I_{s\alpha ref} \\ I_{s\beta ref} \\ I_{s0ref} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & 0 & V_0 & -V_\beta \\ V_\beta & -V_0 & 0 & V_\alpha \\ 0 & V_\beta & -V_\alpha & 0 \end{bmatrix} \begin{bmatrix} \overline{P}_{L\alpha\beta} + \overline{P}_{L0} \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (11)$$

$$\begin{bmatrix} I_{s\alpha ref} \\ I_{s\beta ref} \\ I_{s0ref} \end{bmatrix} = \frac{\overline{P}_{L\alpha\beta} + \overline{P}_{L0}}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha \\ V_\beta \\ 0 \end{bmatrix} \quad (12)$$

In order to maintain DC link voltage [14] constant, a PI (or FLC) branch is added to control the active power component. The PI (or FLC) controls this small amount of active current the controller regulates the current to maintain the DC link capacitor voltage. To achieve this, the DC link voltage is detected and compared with the reference voltage setting by control circuit and the difference is fed to the PI or FLC. According to the voltage difference, the PI (or FLC) decides the active current needed to maintain the DC link voltage. The output of the PI (or FLC) is an active current corresponding to the power flow needed to maintain the DC link voltage. It is used as a part of the reference current for the controller, which controls the inverter to provide the required compensation current. The illustration of an entire reference current generation by a conventional p-q method using a PI controller is shown in Fig. 1.

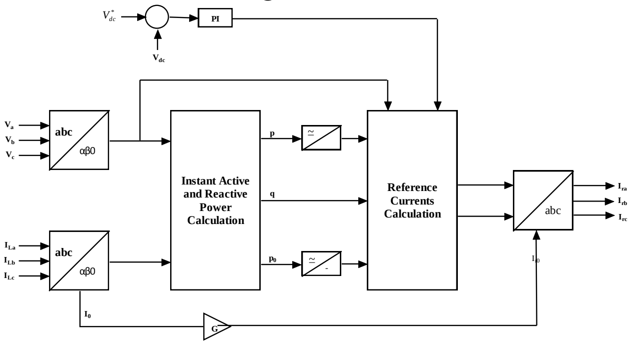

Fig. 1: Reference, Current extraction with a conventional p-q method using PI controller

2. Instantaneous active and reactive Current theory (i_d -i_d):

In this method the magnitude of the current is transformed and by using i_d and i_q components with framed p-q values. If the direction of the voltage space vector $\hat{v}$ And the direct axis component is in the same direction, the zero sequence component of the current remains invariable.Therefore the (i_d -i_d) method can be expressed as follows.

$$\begin{bmatrix} i_o \\ i_{d1} \\ i_{q1} \end{bmatrix} = \frac{1}{v_{\alpha\beta}} \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta & sin\theta \\ 0 & -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (13)$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{1}{\sqrt{v_\alpha^2 + v_\beta^2}} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (14)$$

Each current component **(i_d -i_d)** has an average value or DC component and an oscillating value.

$$i_{ld} = \left\{ \frac{p_{l\alpha\beta}}{v_{\alpha\beta}} \right\}_{dc} = \left\{ \frac{p_{\alpha\beta}}{\sqrt{v_\alpha^2 + v_\beta^2}} \right\}_{dc} \quad (15)$$

Since the current in phase with the voltage is referred at the point of common coupling, it is calculated by multiplying the above equation by a unit vector in the direction of the point of common coupling voltage space vector where the zero sequence component was neglected

$$i_{sdref} = i_{ld} = \frac{1}{v_{\alpha\beta}} \begin{bmatrix} v_\alpha \\ v_\beta \\ 0 \end{bmatrix} \quad (16)$$

$$\begin{bmatrix} i_{s\alpha ref} \\ i_{s\beta ref} \\ i_{s0ref} \end{bmatrix} = \left(\frac{p_{l\alpha\beta}}{v_{\alpha\beta}} \right)_{dc} \frac{1}{v_{\alpha\beta}} \begin{bmatrix} v_\alpha \\ v_\beta \\ 0 \end{bmatrix} \quad (17)$$

Thus the reference signals were generated using (i_d -i_d) method. The structure of the reference current generation is shown in Fig. 2.

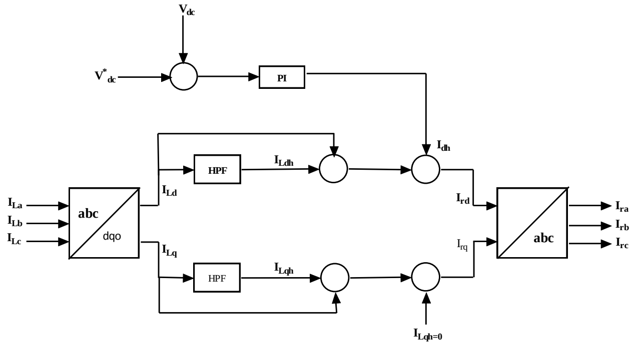

Fig. 2: Reference, Current extraction with a d-q method using PI controller

III.SYSTEM DESCRIPTION

Two renewable energy sources were integrated with an electric grid. The system is connected to a non-linear load and a UPQC is installed at PCC to minimize the power quality issues. The structure of the system is shown in Fig. 3.

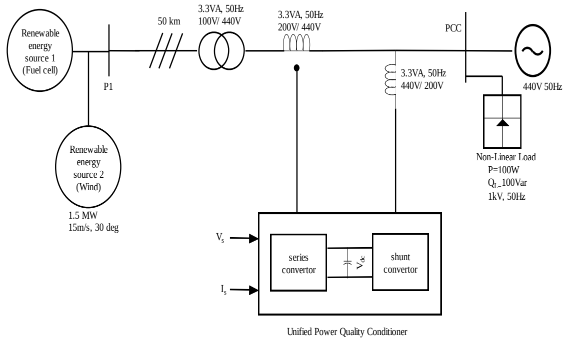

Fig. 3: Overall system

A. Modeling of renewable energy sources

1. PEM Fuel cell modeling

The fuel cell is an electrochemical device and so it is very essential to know about the electrochemical behavior of a fuel cell.

The following assumptions were made in modeling a PEM fuel cell.

1. One dimensional analysis of current density is made from normal to the anode and cathode.
2. O^{2-} is Conducting electrolyte and ideal gases.
3. H_2 fuels large quantity of O_2 at cathode (in air) PEM fuel cell performs best at temperatures (70-80) ^{o} C at a reactant partial pressure (3-5) ATM and a membrane humidity of ~ 100%.

2.Mathematical modeling of PEMFC system

The mathematical modeling of a PEM fuel cell is done as follows The molar flow of any gas (H_2) Through the valve and its partial pressure in the channel can be expressed as

$$\frac{q_{H2}}{P_{H2}} = \frac{K_{an}}{\sqrt{M_{H2}}} = K_{H2} \quad (18)$$

For hydrogen molar flow three significant factors, namely hydrogen input flow, hydrogen output flow and hydrogen flow during the reaction must be considered.[16]. The relationship among the three factors can be expressed as

$$\frac{d}{dt}P_{H2} = \frac{RT}{V_{an}}(q_{H2}^{in} - q_{H2}^{out} - q_{H2}^{r}) \quad (19)$$

The basic electrochemical relations between the hydrogen flow and the fuel cell produces current with the flow rate of reacting hydrogen which is derived by the equation:

$$q_{H2}^{r} = \frac{N_o I_{FC}}{2F} = 2K_r I_{FC} \quad (20)$$

Using equation (1) and (3),the Laplace transform the hydrogens partial pressure that is produced in the 's' domain

$$P_{H2} = \frac{\frac{1}{K_{H2}}}{1+\tau_{H2s}}(q_{H2}^{in} - 2K_r I_{FC}) \quad (21)$$

Where

$$\tau_{H2} = \frac{V_{an}}{K_{H2}RT} \quad (22)$$

The partial pressure of Water and oxygen can be obtained using the same procedure

The polarization curve for the PEMFC is obtained from the sum of Nernst's voltage, the activation overvoltage and the ohmic overvoltage.

Assume constant temperature and oxygen concentration of the fuel cell output voltage which may be given as

$$V_{cell} = E + V_{act} + V_{ohmic} \quad (23)$$

Where,

The Nernst voltage is expressed in the equation

$$E = N_o[E_o + \frac{RT}{2F}\log\left[\frac{P_{H2}\sqrt{P_{O2}}}{P_{H2O}}\right]] \quad (24)$$

The activation voltage is expressed as

$$V_{act} = -Bln(CI_{FC}) \quad (25)$$

Since it is considered that the partial pressure of oxygen, Hydrogen is constant

3. Wind energy generating system

In this configuration wind energy is generated different wind speed. The asynchronous machine used in the proposed scheme and do not require any separate field circuit. It supports constant and variable loads and has a natural protection against short circuit. The available power of wind energy systems is given by the equation (1)

$$P_{wind} = \frac{1}{2}\rho A U^3 \quad (26)$$

Where ρ is the air density in (kg/m^3), A (m^3) is the swept area out by turbine blade, and U_{wind} is the wind speed in m/s. As it is impossible to extract all kinetic energy of wind, only a part of it was taken as power coefficient (C_p) ,Thus the produced power is given by

$$P_{mech} = C_P P_{wind} \quad (27)$$

IV.STRUCTURE OF UPQC

Unified power quality conditioner (UPQC) is a combination of active shunt and active series device. It consists of two voltage source inverters connected back to back with each other, sharing a common DC link. The DC-link storage element (Dc-capacitor [2-3]) acts as active series and active shunt compensator; it splits the current and voltage of two bridges. It is used for single and three phase system [2-4] and it helps to eliminate the current and voltage harmonics. The structure of unified power quality conditioner is as shown in Fig. 4.

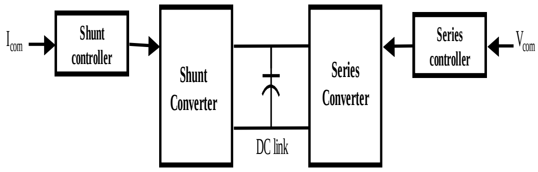

Fig. 4: Structure of UPQC

It requires a separate controller to activate the series and shunt convertor whose design are as follows

A. Series controller design

The series converter controller is as shown in Fig. 5. The objective of the proposed controller is to maintain an active power management through which quality of power is achieved. The ANFIS controller compensates voltage imbalances, harmonics, etc. The duty ratio of the converter switches are varied in power cycle, such that any combination of load is added to the grid

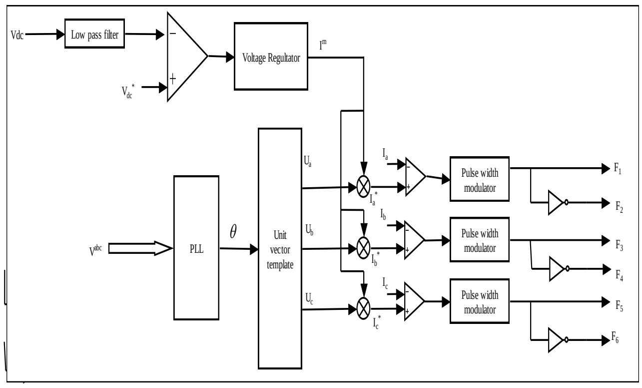

Fig. 5: Structure of Series Controller

The regulation of DC link voltage holds the information regarding the switch over of active power in between the renewable energy source and grid. Thus the dc link voltage regulator produces an active current I^m. The product of unity grid voltage vectors U^a, U^b, U^c produces the reference grid currents (I_a, I_b, I_c). The synchronizing angle of the grid is obtained as Θ from a phase locked loop (PLL) which is used to make the unity vector pattern as [16] – [18]

$$U^a = \sin(\Theta) \quad (28)$$

$$U^b = \sin(\Theta - 2\Pi/3) \quad (29)$$

$$U^c = \sin(\Theta + 2\Pi/3) \quad (30)$$

The actual DC link voltage (V_{dc}) is given through a first order low pass filter (LPF) to lessen the presence of switching ripples of the DC link voltage and in the generated reference current signals. The difference in this filtered DC link voltage and reference DC link voltage (V_{dc}^*) is given to a discrete PI regulator to maintain a constant DC link voltage under alternating generation and load condition.

The dc link voltage error $V_{dcdiff(n)}$ at n[th] sampling instant is given as

$$V_{dcdiff(n)} = V^{*}_{dc(n)} - V_{dc(n)} \qquad (31)$$

The output of discrete PI regulator at the n[th] sampling instant is given by

$$I^{m(n)} = I^{m(n-1)} + K_{i(dc)}\left(V_{dcdiff(n)} - V_{dcdiff(n-1)}\right) + K_{t(dc)} V_{dcdiff(n)} \qquad (32)$$

The difference in V_{dc} and the reference V^{*}_{dc} were given as an input to the ANFIS controller. The training data and the error with respect to the output signal are as shown in Fig. 5 (a-c).

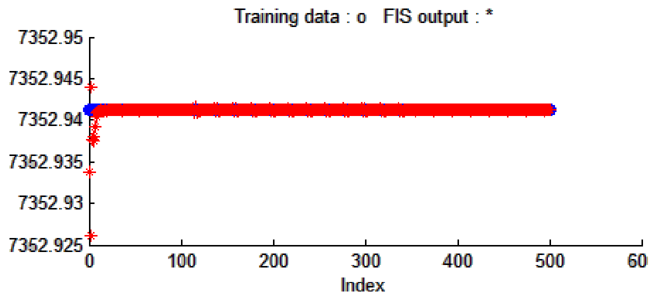

Fig. 5 (a): FIS Training data and output

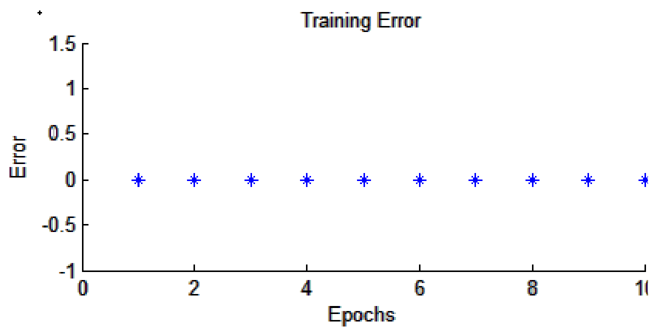

Fig. 5 (b): FIS Training error

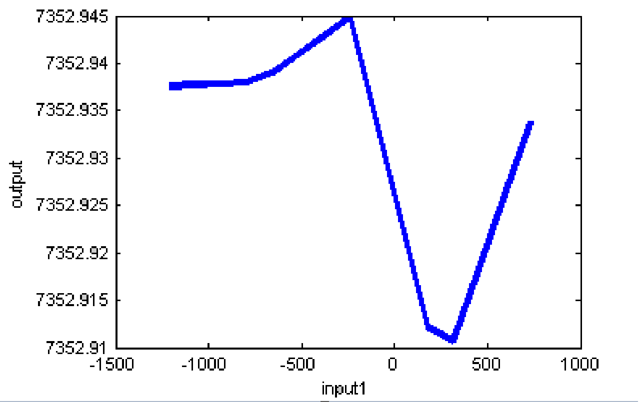

Fig. 5 (c): FIS surface

The instantaneous values of reference three phase grid currents are computed as

$$I^{*}_{a} = I^{*}_{m}.U_{a} \qquad (32)$$

$$I^{*}_{b} = I^{*}_{m}.U_{b} \qquad (33)$$

$$I^{*}_{c} = I^{*}_{m}.U_{c} \qquad (34)$$

The reference grid currents are (I_a^{*}, I_b^{*}, I_c^{*})

$$I_{adiff} = I^{*}_{a} - I_{a} \qquad (35)$$

$$I_{bdiff} = I^{*}_{b} - I_{b} \qquad (36)$$

$$I_{cdiff} = I^{*}_{c} - I_{c} \qquad (37)$$

The difference in currents is given to pulse width modulator. The pulse width modulator produces the firing pulses (F_1 toF_6) for the gate drives of series converter.

B. Shunt controller design

The power quality events sag/swell and harmonic distortions were traced using a traditional algorithm whose structure is as shown in Fig. 6.

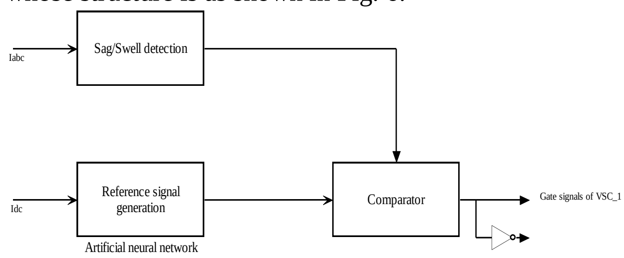

Fig. 6: Control algorithm of a UPQC for phase A

The proposed sag/swell detection scheme is a conventional method.Three phase currents Ia,Ib and Ic are transformed into dq plane (28). And the sag/swell depth is obtained (29)

$$\begin{bmatrix} Id \\ Iq \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\theta-\frac{2\pi}{3} & \cos\theta+\frac{2\pi}{3} \\ \sin\theta & \frac{\sin\theta-2\pi}{3} & \sin\theta+\frac{2\pi}{3} \end{bmatrix}\begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \qquad (38)$$

$$s_d = \left[1 - \sqrt{{I_d}^2 + {I_q}^2}\ \right] \qquad (39)$$

In this Fig.7 the block diagram of the dq transformation-based sag/swell detection method is shown. The three phase current is transformed into'd' and 'q' components. The square root of the sum of squares of these components is obtained. The value is subtracted from '1' (reference value) and the resulting value is filtered out with a low pass filter to extract the positive sequence component of the current. The filtered output is transformed to abc plane and subjected to a hysteresis comparator which generates the sag/swell detection signal. The detection signal is high when the sag/swell occurs. The block diagram of the controller is as shown in Fig. 7.

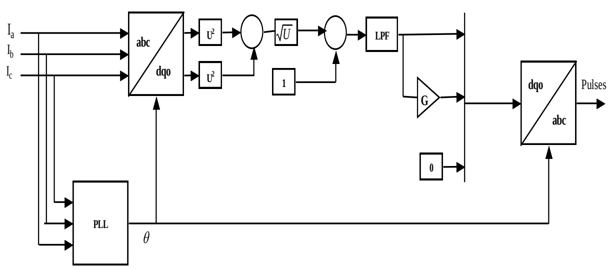

Fig. 7: Block diagram of the controller.

1. Reference, Current generation using ANFIS Controller

ANFIS tool is used as a soft computing technique for the shunt active filter to control the current based problems. The data are generated using FIS in Grid partition method, train the data in Hybrid method and epochs is 10 and membership function (triangular) is 5. Fuzzy Inference System (FIS) structure, training data, training data and output, training, error, surface are given in below Fig. 8.

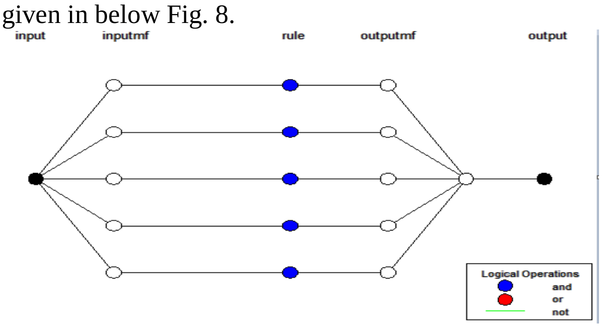

Fig. 8: FIS Structure

In this system single input and single output are considered. The current from the non-linear load is given as an input and the current from the resistive load is considered as a target output. Since the number of samples fed for training is 501. The training data for three phases are as shown in Fig. 9.(a-c)

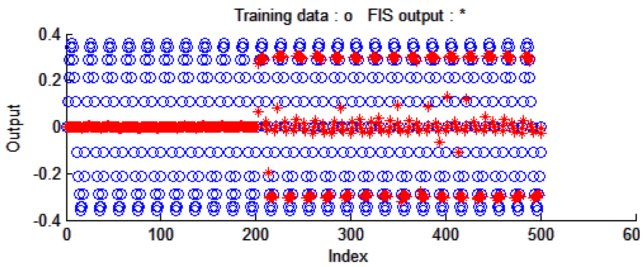

Fig. 9 (a): FIS Training data and output for Phase A

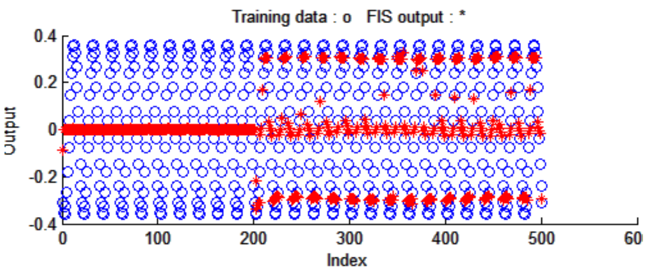

Fig. 9 (b): FIS Training data and output for Phase B

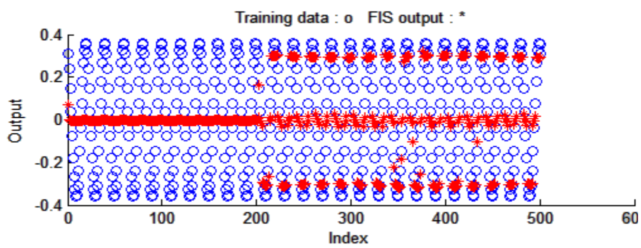

Fig. 9 (c): FIS Training data and output for Phase C

The training errors for the three phases are as shown in Fig. 10.(a-c)

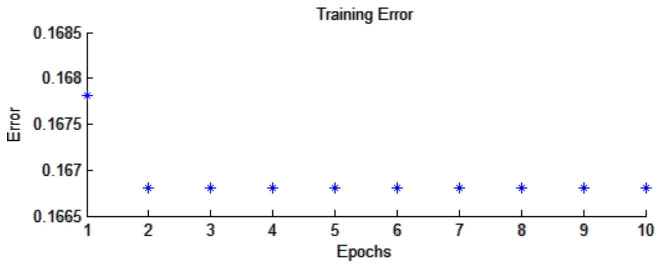

Fig. 10 (a): FIS Training error for Phase A

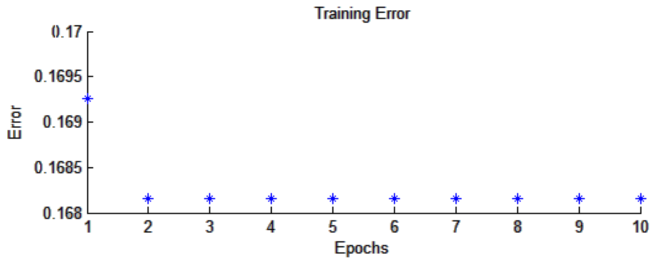

Fig. 10 (b): FIS Training error for Phase B

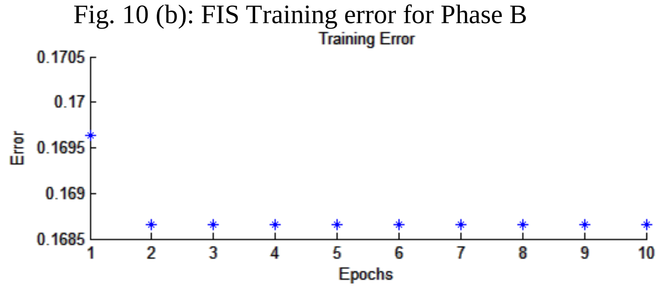

Fig. 10 (c): FIS Training error for Phase C

The surface rule for the three phases is as shown in Fig. 11 (a-c).

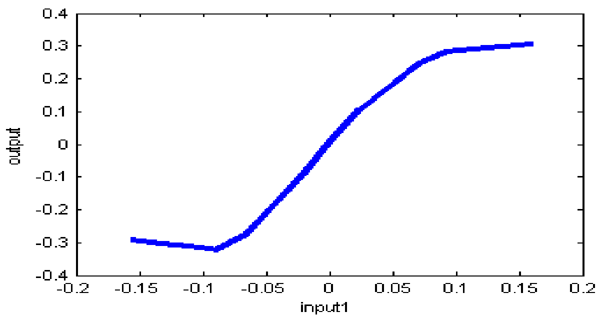

Fig. 11 (a): FIS surface for Phase A

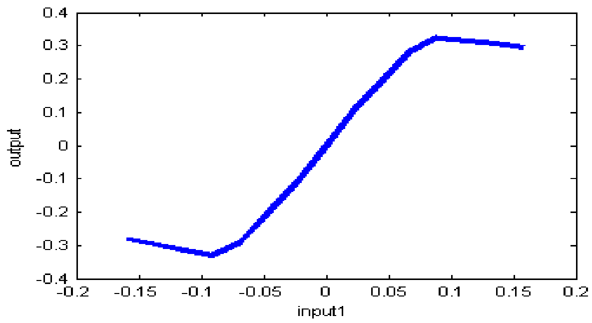

Fig. 11 (b): FIS surface for Phase B

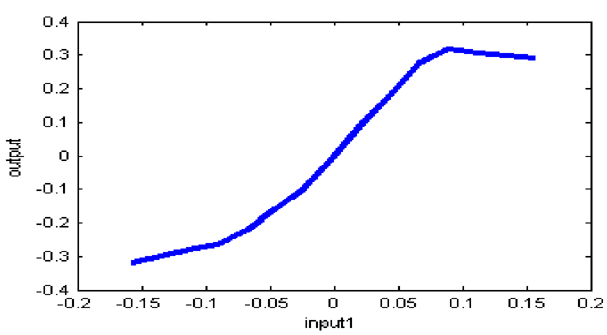

Fig. 11 (c): FIS surface for Phase C

V. SIMULATION RESULTS

In this work renewable energy sources were integrated with the grid along with a transformer and a unified power quality conditioner (UPQC). The UPQC possesses a series and shunt device that has a separate controller. The simulation results were made at PCC in different scenarios.

Scenario I: Renewable energy sources integrated with the electric grid without UPQC

The renewable energy sources (Fuel cell, Wind energy system) were integrated into an electric grid along with a non-linear load without UPQC. The voltage, current and power (Real & Reactive) were as shown in Fig. 12.(a-d)

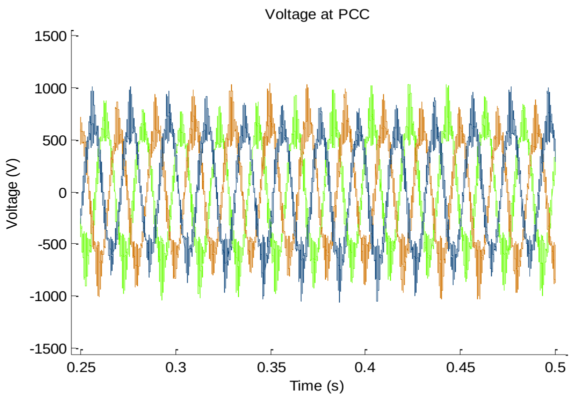

Fig. 12 (a): Voltage at Point of Common Coupling (PCC) without UPQC

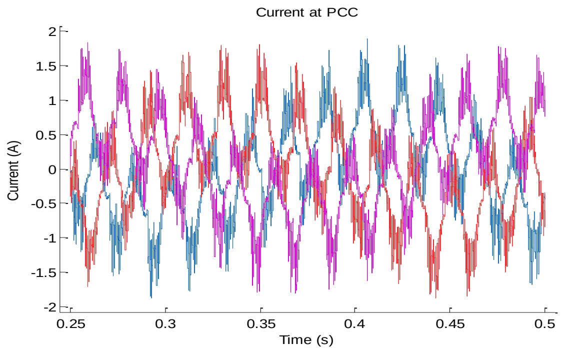

Fig. 12 (b): Current at Point of Common Coupling (PCC) without UPQC

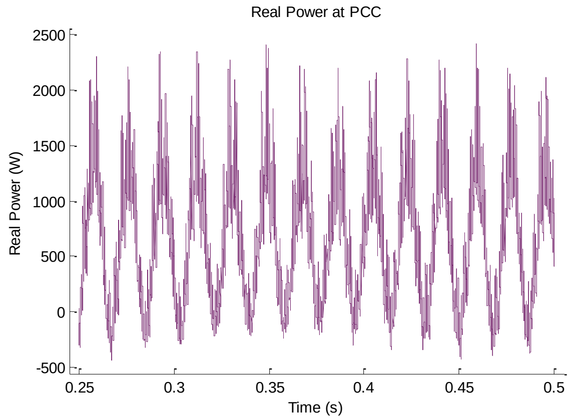

Fig. 12 (c): InstantaneousReal Power at Point of Common Coupling (PCC) without UPQC

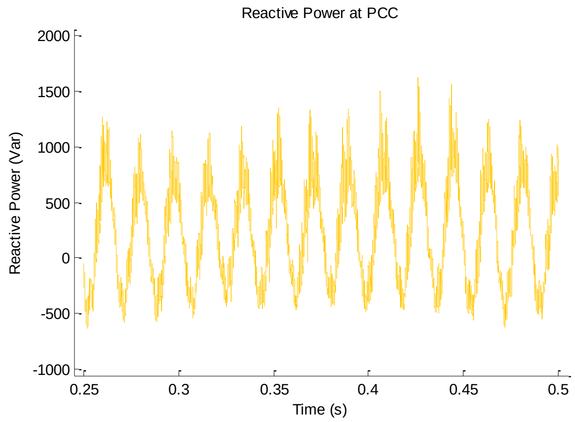

Fig. 12 (d): Instantaneous Reactive Power at Point of Common Coupling (PCC) without UPQC

Scenario II: Renewable energy sources integrated with the electric grid with PI Controlled shunt/series device (UPQC)

The renewable energy sources (Fuel cell, Wind energy system) were integrated into an electric grid along with a non-linear load with PI Controlled shunt/series device (UPQC). The voltage, current and power (Real & Reactive) were as shown in Fig. 13(a-d).

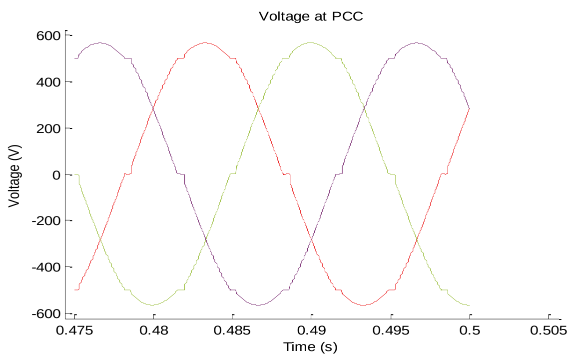

Fig. 13 (a): Voltage at Point of Common Coupling (PCC) with PI Controlled shunt/series device UPQC

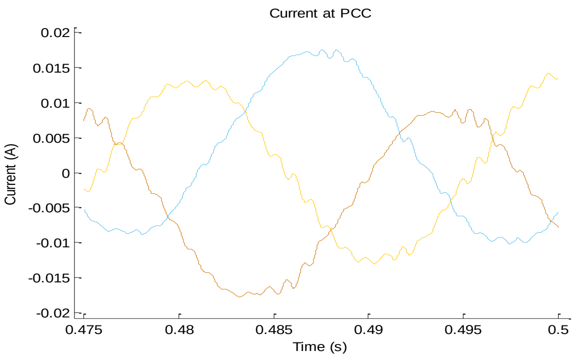

Fig. 13 (b): Current at Point of Common Coupling (PCC) with PI Controlled shunt/series device UPQC

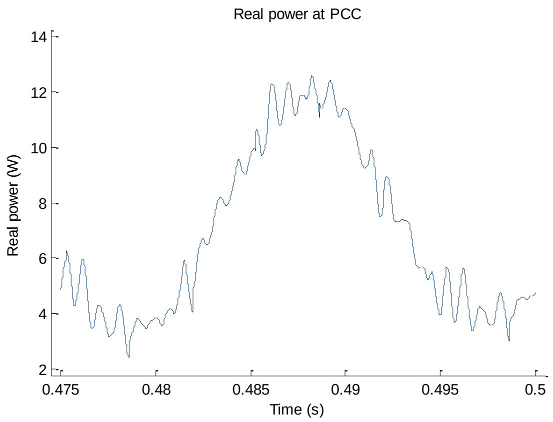

Fig. 13 (c): Instantaneous Real Power at Point of Common Coupling (PCC) with PI Controlled shunt/series device UPQC

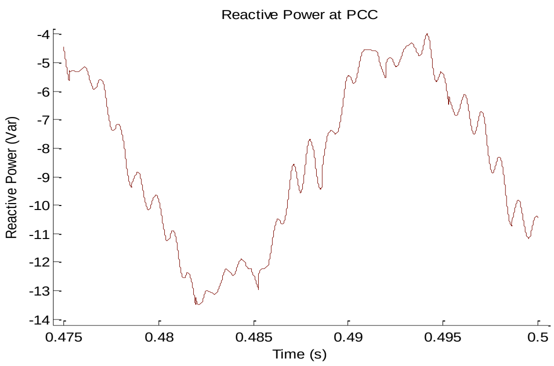

Fig. 13 (d): Instantaneous Reactive Power at Point of Common Coupling (PCC) with PI Controlled shunt/series device UPQC

Scenario III: Renewable energy sources integrated with the electric grid with ANFIS Controlled shunt/series device (UPQC)

The renewable energy sources (Fuel cell, Wind energy system) were integrated into an electric grid along with a non-linear load with ANFIS Controlled shunt/series device (UPQC). The voltage, current and power (Real & Reactive) were as shown in Fig. 14 (a-d).

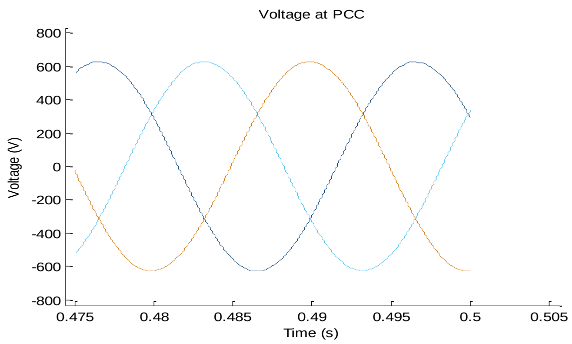

Fig. 14 (a): Voltage at Point of Common Coupling (PCC) with ANFIS Controlled shunt/series device UPQC

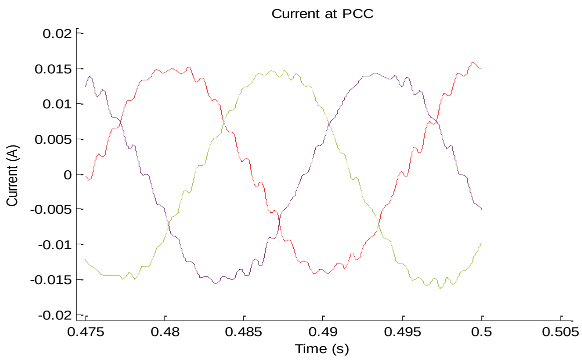

Fig. 14 (b): Current at Point of Common Coupling (PCC) with ANFIS Controlled shunt/series device UPQC

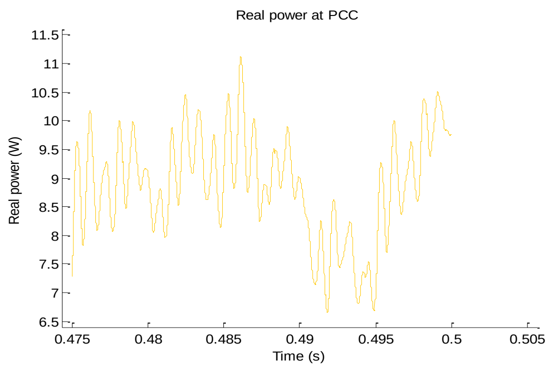

Fig. 14 (c): Instantaneous Real Power at Point of Common Coupling (PCC) with ANFIS Controlled shunt/series device UPQC

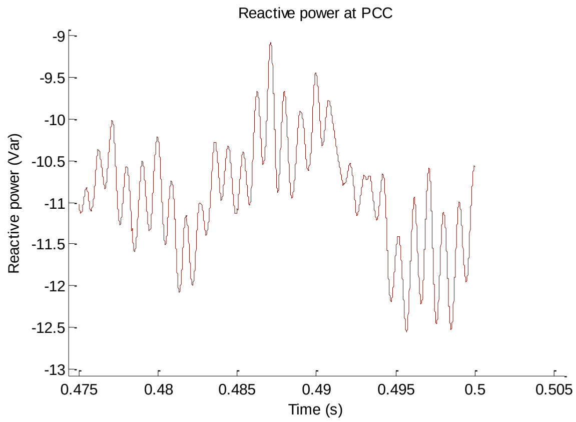

Fig. 14 (d): Instantaneous Reactive Power at Point of Common Coupling (PCC) with ANFIS Controlled shunt/series device UPQC

VI Total Harmonic Distortion

Using Fourier analysis the Total harmonic distortion of the voltage at the PCC is calculated in three different scenarios for one complete cycle at 0.48s. The values were shown in Table.1

Table 1: THD in Voltage across PCC (%)

Phases	Total Harmonic Distortion (%)		
	System without UPQC	System with PI Controlled shunt/series device (UPQC)	System with ANFIS Controlled Series/shunt controlled device (UPQC)
A	17.58	5.96	0.24
B	17.43	5.95	0.21
C	16.92	5.93	0.26

Conclusion

The ANFIS controller of a unified power quality conditioner is a proficient stand for mitigating the power quality problems that may arise due to the loads and renewable energy systems. This scheme offers a solution to power quality problems like voltage unbalances and reduces the total harmonic distortion at the point of common coupling. It helps to integrate the renewable energy sources effectively with power quality impact. The proposed control strategies for the UPQC minimize the power quality impact introduced by the renewable energy sources and the non linear load hence several solutions was offered to reduce the impact on power quality issues due to loads however it offers the solution to the both problems that may produce by the renewable power and the loads it is also observed that the effectiveness of the ANFIS controller used in the UPQC reduces the power quality issues more at the point of common coupling hence it is validated and compared with a conventional PI controller.

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