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A Modified Control Method For A Dual Unified Power Quality Conditioner

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Abstract

This paper presents a modified control method for a dual three phase unified power quality conditioner (iUPQC). The iUPQC consists of two active filters. One is series active filters (SAF) and another one is parallel active filter (PAF). The SAF is used for voltage sag/swell compensation and PAF is used to eliminate current harmonics and unbalances. The two active filters are controlled by using sinusoidal references but in conventional UPQC two active filters are controlled by using non sinusoidal references. Therefore the iUPQC uses PWM and fuzzy logic control technologies. Fuzzy logic controller is based on fuzzy sets and fuzzy rules with their membership functions of inputs and outputs.

Key words: Active Filters, iUPQC, voltage interruption, Fuzzy logic control.

I. Introduction

With the invention of power electronic devices like thyristors, GTO`s (Gate Turn Off Thyristors) and many devices, control of electric power is simple and easy. But the power electronic devices have their non linearity characteristics, cause harmonic and draw excessive currents. The harmonics, excessive currents cause for low system efficiency. In addition to this power system is subjected to various disturbances like voltage sags and swells etc.

By using Unified power Quality Conditioner (UPQC) [1]-[10] it can supply regulated voltage for the loads, balanced and low harmonic distortion. The UPQC consists of series and shunt active power filters. Shunt active filters also provides harmonic isolation between supply system and load. The series active filter regulates the incoming voltage quality.

In the conventional UPQC both series active filters and shunt active filters are controlled by using non sinusoidal references. PAF usually acts as non sinusoidal current source used to reduce harmonic currents of the load. SAF acts non sinusoidal voltage source used to mitigate voltage disturbances. Non sinusoidal references mean combination of both fundamental and harmonic references. The extraction of harmonic contents requires complex calculations. Therefore there are so many methods to extract harmonics, but it is more complexity of reference generation [10].

Some works gives control methods for both series and shunt active filters for generation of sinusoidal references without need of harmonic extraction, in order to decrease the complexity of the reference generation for the UPQC.

This conditioner consists of two voltage source convertors. In order to generate sinusoidal reference SAF consists of three current loops and two voltage loops. PAF consists of three voltage loops. In this way both grid current and load voltage are sinusoidal and therefore their references are also sinusoidal.

The main purpose of this paper is to propose a modified control method for a dual three phase topology of a Unified Power Quality Conditioner (iupqc) [5] used in utility grid connection. ABC reference frame, classical control theory is used in this control method.

II. Dual Unified Power Quality Conditioner

Combined series and shunt active filters are known as unified power quality conditioner. These are designed to compensate voltage disturbances and to reduce current harmonics. In conventional UPQC the series active filter used as voltage source that compensates voltage interruption, sag and swell. The parallel active filer used as current source which compensates load current. Series active filter is connected in series to the line through a transformer while parallel active filter is directly connected to the load as shown in fig1.

The draw backs of unified power quality conditioner are

- More complex current and voltage reference generation.
- The leakage impedance of the transformer affects the injected voltage.
- complex calculations are required in order to extract harmonics.

To reduce the above draw backs a modified control method is used for Unified Power Quality Conditioner. The conventional UPQC is same as dual Unified Power Quality conditioner the only difference is way of controlled. The main aim of series active filter is to synchronise the current with grid voltage. The aim parallel active filter is to synchronise the load voltage with grid voltage. In this way the iUPQC [5] uses sinusoidal references for filters.

The shunt active filter of iUPQC is used as sinusoidal voltage source which provides effective synchronization of sinusoidal load voltage and grid voltage. Series active filter is used as sinusoidal current source which provides effective synchronization of input current with grid voltage. SAF transformer produces the voltages, which is same as the difference between grid voltage and load voltage. The iUPQC is shown in fig2.

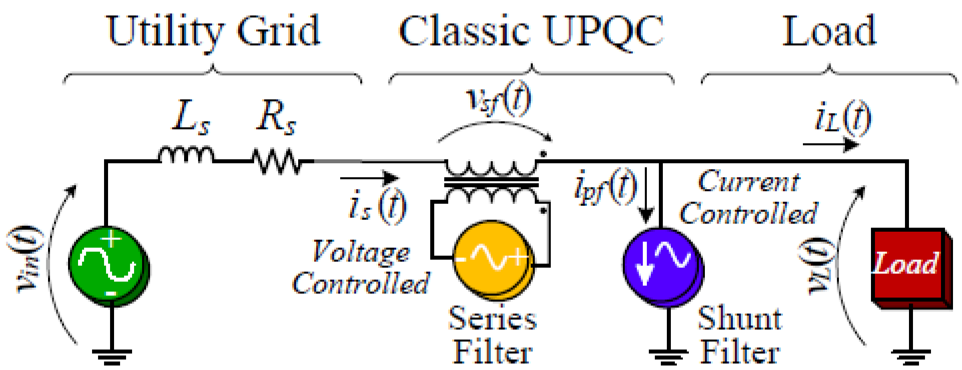

Fig. 1. Conventional UPQC

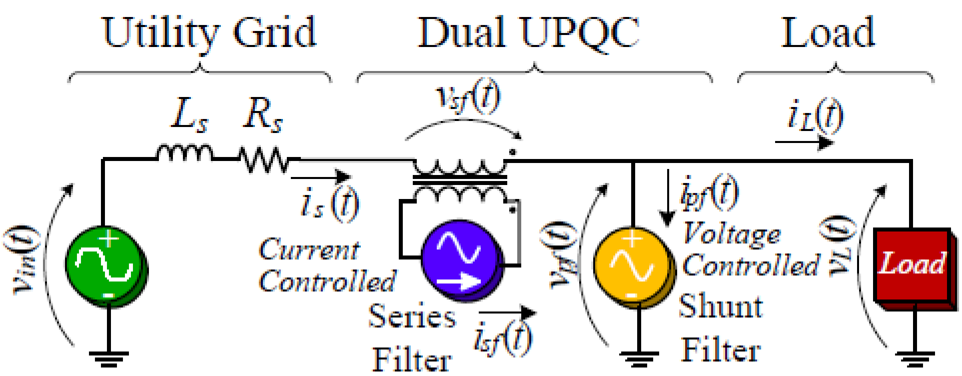

Fig. 2. Dual UPQC

The SAF acts as high impedance path for harmonic currents. So it compensates harmonics and unbalances of the voltage. The PAF acts as low impedance path for load currents. So it compensates unbalances and harmonics of the grid current. The power and design specifications are shown in table. The power circuit of iUPQC is made up of two four wire three phase converters connected back to back and their filters are shown in fig3.

TABLE I Design Specifications of the iUPQC

Input line to line Voltage	$V_{in} = 220V$
Output nominal power	$P_o = 2500VA$
DC link voltage	$V_b = 400V$
Utility grid frequency	$f_{grid} = 60Hz$
Switching frequency of series and PAFs	$f_a = 20KHZ$
Transformer ratio	n=1

TABLE II Specifications of the power modules

Leakage inductance of the SAF coupling transformers	$L_{lg} = 2.33mH$
Transformer ratio of the SAF coupling Transformers	n=1
SAF connection inductance	$L_{sf} = 650\mu H$
PAF connection inductance	$L_{Pf} = 650\mu H$
DC Link Capacitance	$C_b = 3mF$

In SAF in three phases three single phase transformers are used. The parallel active filters are directly connected to the load.

III. Control Methods

The iUPQC mainly consists of series and parallel active filer controllers. The series active filter has current loop in order to deliver a sinusoidal grid current and synchronised with grid voltage. The parallel filter consist voltage loop in order to allow a synchronised, regulated voltage to the load. These control loops are working independently in each filter. The series active filter has two another voltage loops in order to control the dc link voltage. Here voltage loop determines the current amplitude reference for the current loop.

Therefore series active filter control uses an input current and DC link voltage feedback. The parallel active filter control uses voltage feedback.

The sinusoidal references are generated by using digital signal processor (DSP). The synchronisation of input current and grid voltage are obtained through Phase Locked Loop (PLL). The control structure is in ABC reference frame. Since the power calculation and harmonic extraction are not needed.

1. SAF CONTROL

The control block diagram of the SAF is shown in fig 3. This consists of three identical current loops and two voltage loops. Each current loop is to control the input current. One voltage loop is to control DC link voltage and another voltage loop is to keep the voltage on the DC link capacitors balanced.

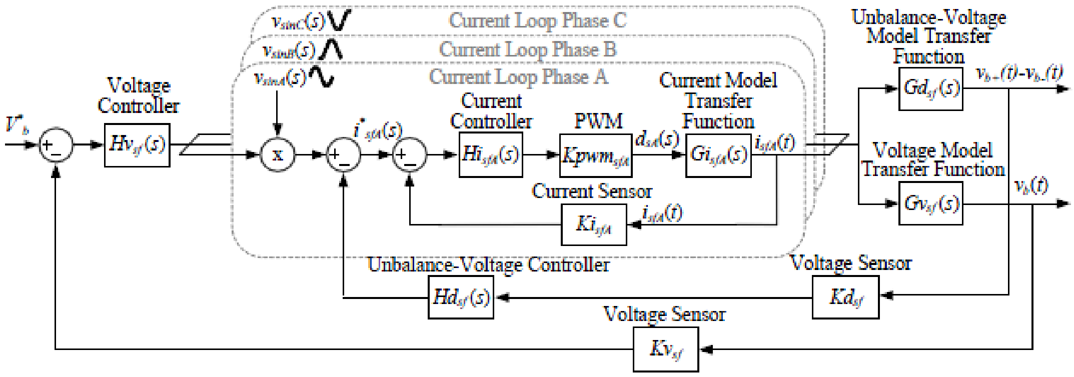

Fig. 3. Control block diagram of SAF

The amplitude current reference for current controller is determined from the voltage control loop, because the voltage control loop has low frequency response. When load increases the controllers will supply the additional power. So the active power consumption from dc storage. This makes dc link voltage imbalance. The voltage unbalanced loop generates the average dc reference voltage and maintain the two capacitor voltage equal.

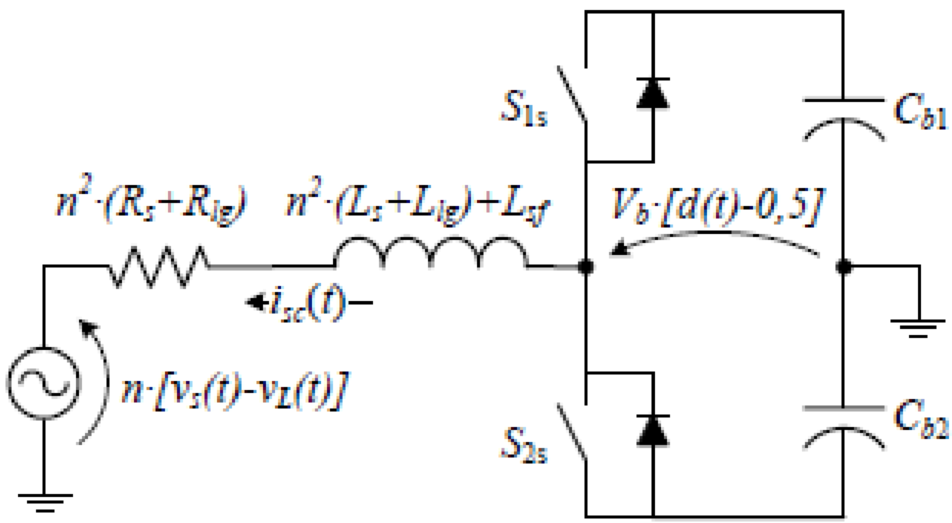

Fig. 4: Single Phase equivalent circuit of SAF.

To control the dc link voltage fuzzy logic and pole controllers are used. All the controls have phase margin between 30° and 90°. The current control consists of three identical loops, except for 120° phase displacement from each other. When voltage imbalance occur the unbalanced voltage control loop changes current reference, to equalise the capacitor voltages.

The voltage loop transfer function is represented as

$$GV_{sf}(S) = \frac{3}{2}.\frac{m_a}{C_b.s}\frac{HV_{sf}.KV_{sf}.K_m}{Hi_{sf}} \quad (1)$$

The Unbalance Voltage loop transfer function is represented as

$$Gd_{sf}(S) = \frac{3}{2.C_b.S}.\frac{Hd_{sf}.Kd_{sf}}{Hi_{sf}} \quad (2)$$

The Current loop transfer function is represented as

$$Gi_{sf}(S) = \frac{V_b}{L_{sf}.S}.\frac{Hi_{sf}.Ki_{sf}}{V_{msf}} \quad (3)$$

Where

C_b -DC Link Capacitance;
Hd_{sf} -Unbalance Voltage Sensor Gain;
Hi_{sf} -Current Sensor Gain;
HV_{sf} -Voltage Sensor Gain;
Kd_{sf} -Unbalance Voltage Control attenuation;
Ki_{sf} -Current Control Attenuation;
KV_{sf} -Voltage Control Attenuation;
Km -Multiplier Gain;
L_{sf} -Series Filter Inductance;
m_a -Modulation Ratio;
V_b -DC Link Voltage;
Vm_{sf} - Pulse Width Modulator Gain.

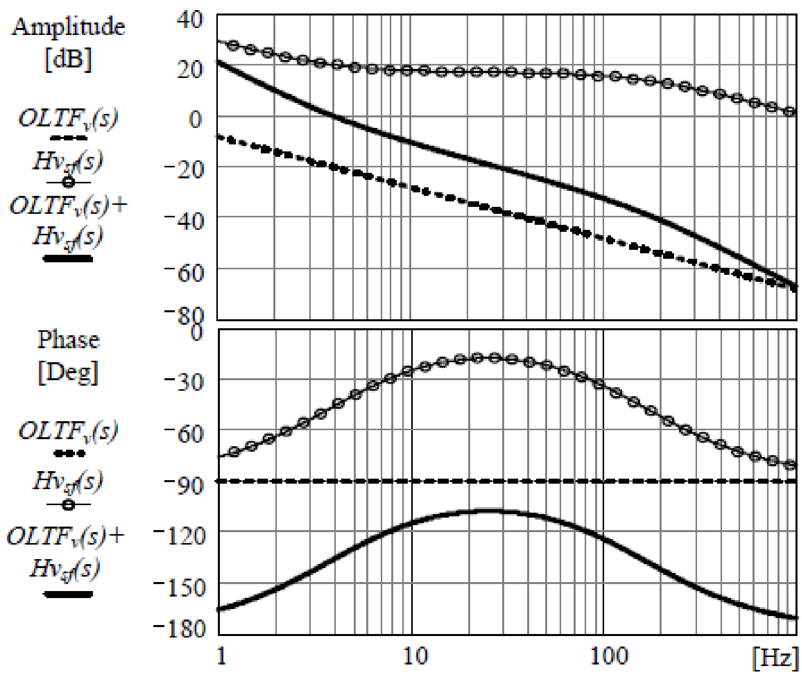

Fig. 4: Voltage loop frequency response of the SAF.

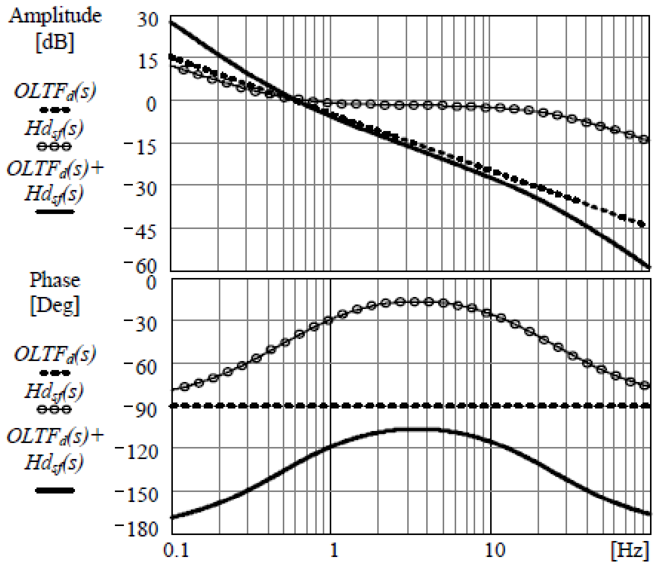

Fig. 5: Unbalance Voltage loop frequency response of SAF.

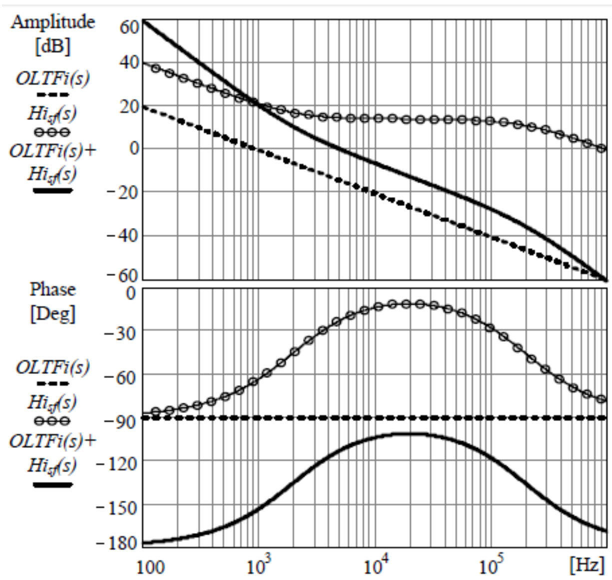

Fig. 6: Current loop frequency response of the SAF.

2. PAF CONTROL

The Parallel active filter scheme consists of three identical voltage feedback loops. Each loop is used for each phase, in order to compare the load voltage signal and sinusoidal reference. These loops are except for 120 degree phase displacements from references of each other. Fig. 7 shows the control block diagram of the parallel active filter.

The voltage loop transfer function is obtained by the analysis of single phase equivalent circuit shown in fig. 8. For circuit analysis average values related to switching period are used. By using small signal analysis and Laplace the voltage loop transfer function is given by

$$Gv_{pf}(S) = \frac{V_b}{L_{pf}C_{pf}} \cdot \frac{1}{S^2 + S\left(\frac{1}{C_{pf}R_L}\right) + \frac{1}{L_{pf}C_{pf}}} \quad (4)$$

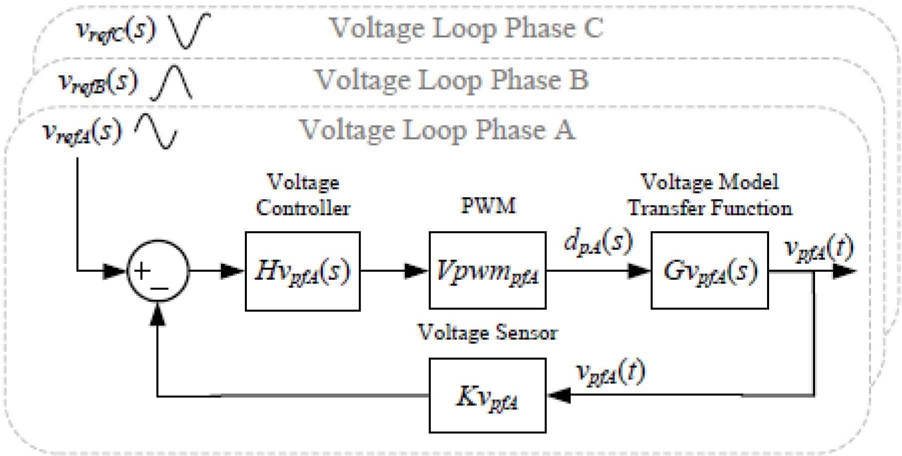

Fig. 7: Control block diagram of the PAF.

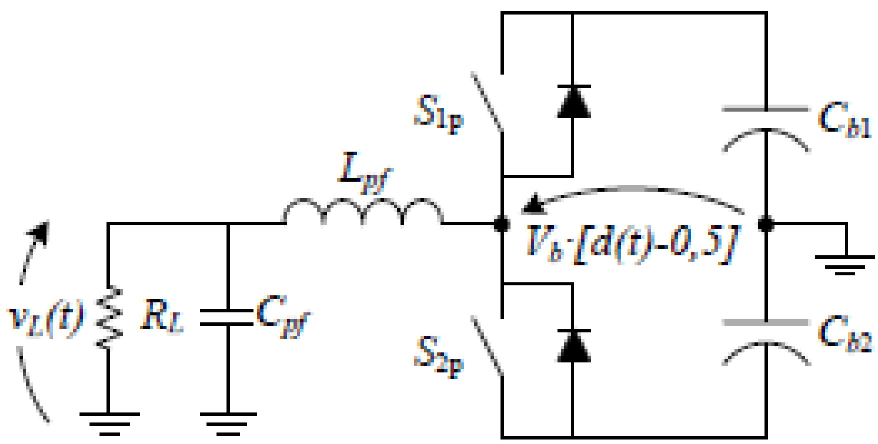

Fig. 8: Single phase equivalent circuit of PAF

The open loop transfer function is given by

$$OLTFv(S) = Gv_{pf}(S).Kpwm_{pf}.Kv_{pf} \quad (5)$$

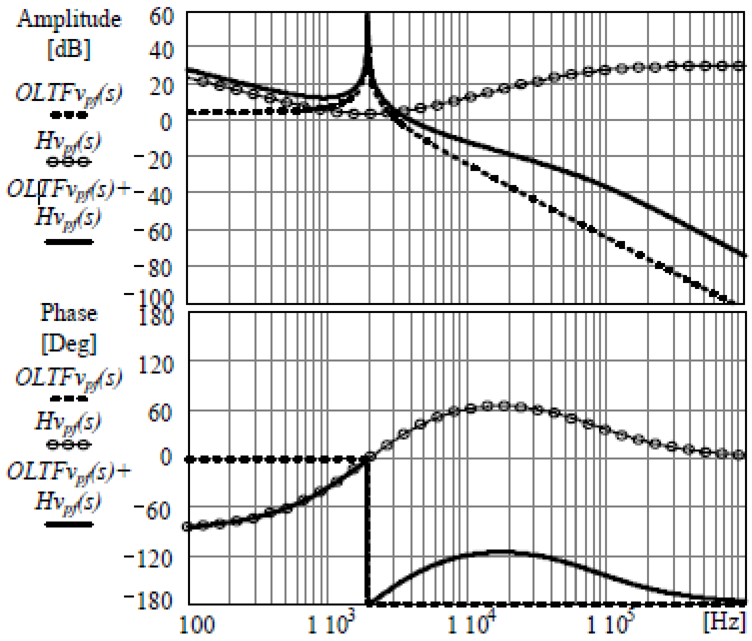

Fig. 9: Voltage loop frequency response of the PAF.

$Kpwm_{pf}$ - Shunt filter PWM modulator gain

The voltage loop frequency response is shown in fig. 9, including the open loop transfer function, controller transfer function and the compensated loop transfer function.

3. FUZZY LOGIC CONTROL

The Fuzzy logic control consists of set of linguistic variables. The mathematical modelling is not required in FLC. FLC [9] consists of

1. Fuzzification

Membership function values are assigned to linguistic variables. In this the scaling factor is between 1 and -1.

2. Inference Method

There are several composition methods such as Max-Min and Max-Dot have been proposed and Min method is used.

3. Defuzzificaion

A plant requires non fuzzy values to control, so defuzzification is used. The output of FLC controls the switch in the inverter. To control these parameters they are sensed and compared with the reference values. To obtain this the membership functions of fuzzy controller are shown in fig (10).

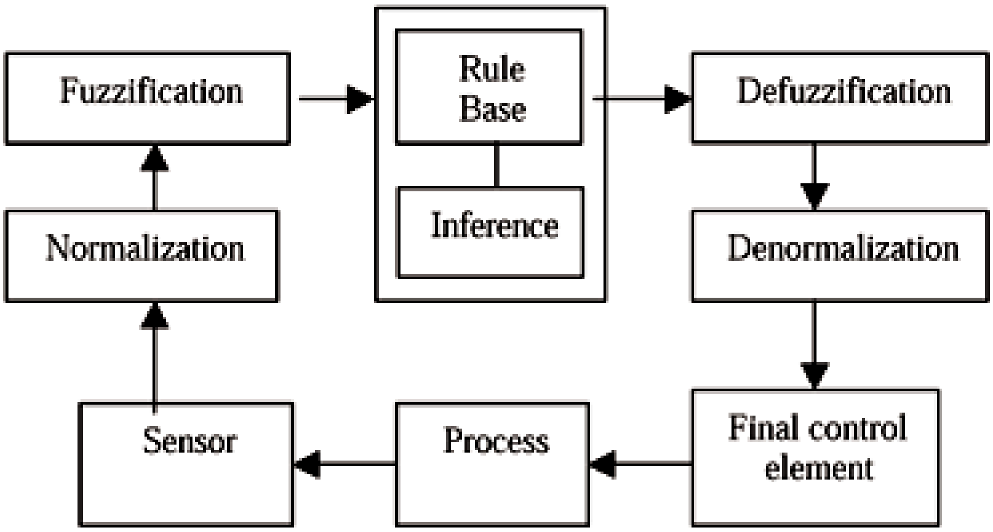

Fig. 10: Fuzzy logic Controller

IV. Power Flow

The active power flow of the iUPQC is shown in fig. 10. In fig. 10(a) the grid voltage Vs has lower amplitude than the load voltage V_L. So the PAF delivers active power to the load. In fig. 10(b) the grid voltage Vs has higher amplitude than the load voltage V_L. In this case SAF delivers active power to the load. Therefore voltage imbalance occurs at the dc link. This voltage imbalance can be compensated by unbalance voltage loop transfer function. When Vs is equal to V_L the power drained from the electrical grid equals the sum of the load power and the iUPQC power losses.

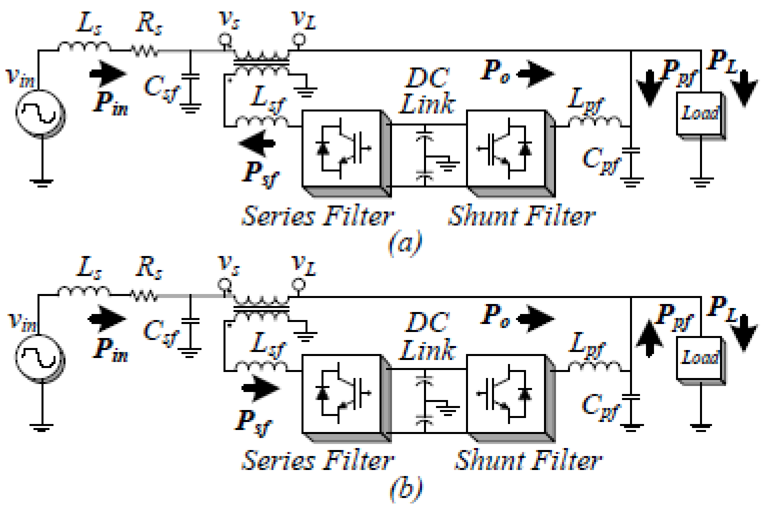

Fig. 10: Power flow of iUPQC; (a) Vs<V_L (b) Vs>V_L

V. Simulation Results

The simulation results of the Dual Unified Power Quality Conditioner using fuzzy logic controller are shown in fig. 11. Here we are creating voltage dip and load changing. Therefore the voltage unbalance and harmonics are controlled by using series active filter, parallel active filter and fuzzy logic controllers. The injected voltage to compensate the voltage can be suppled by using DC Link voltage.

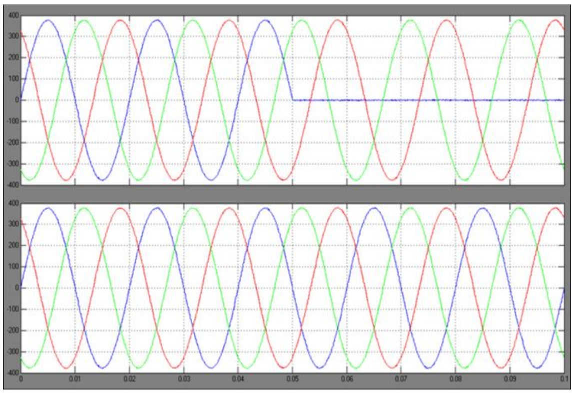

Fig. 11 (a):Source voltage and load voltage during a voltage dip in phase in A

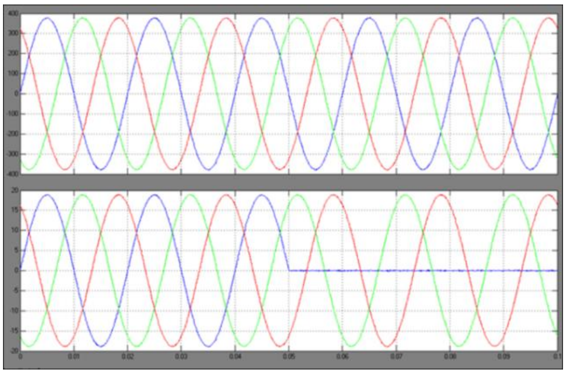

Fig. 11(b): Load voltages and source currents

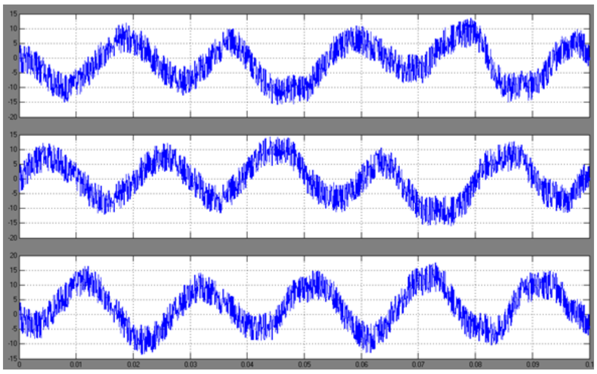

Fig. 11(c): Parallel active filter currents

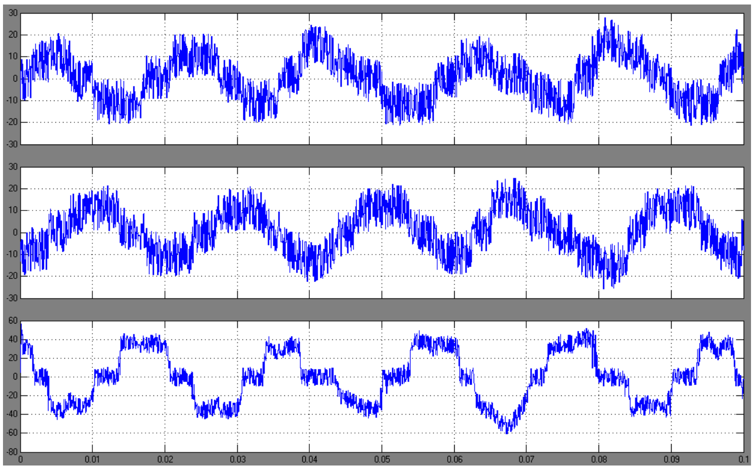

Fig. 11(d): Series active filter voltages

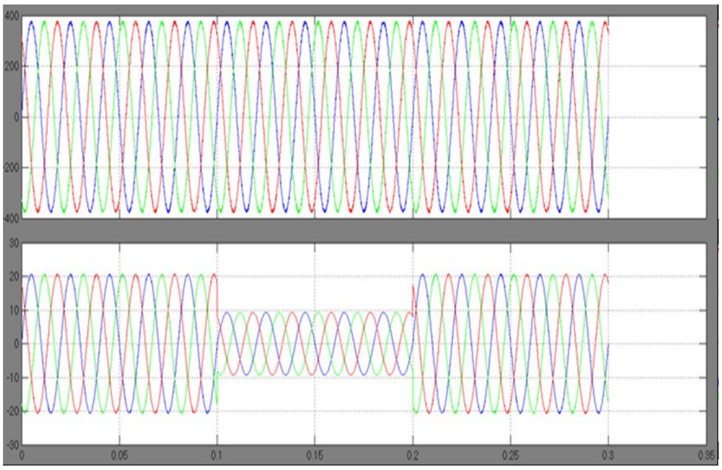

Fig. 11(e): Load voltages and load currents during load change

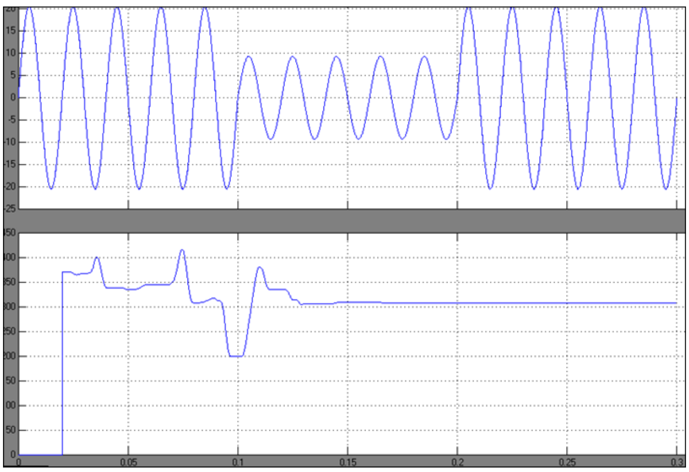

Fig. 11(f): DC link voltage and load current

VII. Conclusion

The results obtained with iUPQC using fuzzy logic controller and ABC reference frame were able to compensate the non linear load currents and also to provide the sinusoidal load voltages. The main advantage of the proposed scheme is to provide sinusoidal references which reduce complexity of harmonic extraction.

The proposed scheme of iUPQC using fuzzy logic controller in ABC reference frame of both SAF and PAF control loops are generated by a digital signal processor. This control loops and its utilisation of sinusoidal references eliminates the harmonics between grid and load. The results show the proposed iUPQC control scheme providing power quality improvement.

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