"A Review on Comparison of Control Strategies Implementing Fuzzy Controller for Shunt Active Power Filters in Three-Phase Four-Wire Systems"

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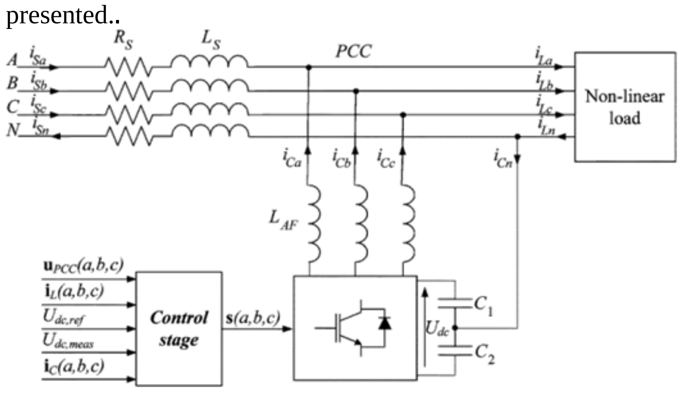
Abstract - This paper attempts to improve the dynamic performance of a shunt-type active power filter which are generally use for reducing THD in the system and hence, to improve the quality of power transmission. There number of strategies is discussed in the earlier days Strategies for extracting the three-phase reference currents for shunt active power filters are compared, evaluating their performance under different source and load conditions with the new IEEE Standard 1459 power definitions. The study was applied to a three-phase four-wire system in order to include imbalance. Under balanced and sinusoidal voltages, harmonic cancellation and reactive power compensation can be attained in all the methods. However, when the voltages are distorted and/or unbalanced, the compensation capabilities are not equivalent, with some strategies unable to yield an adequate solution when the mains voltages are not ideal. For this purpose there are some methods are discussed as earlier as iq-dq method, Instantaneous P –Q Strategy, UPF Strategy, Perfect Harmonic Cancellation (PHC) method but along these methods we are going to discuss another method for the harmonic current compensation which uses Fuzzy controllers and try to implement a hardware model for the Fuzzy controller for the harmonic current compensation and hence, to reduce the THD of the system

Key Words: Shunt active filter, Three-level (NPC) inverter, Fuzzy logic current controller,

1. INTRODUCTION

Power quality problems have been drawing more and more attentions these years, especially with the development of modern electronics industry and the continuous proliferation of nonlinear type of electric load. To solve these problems, passive power filters were used at the beginning, and the active power filter APF is now widely researched and used .Passive filters have the limitations of fixed compensation, large size, and that they can create new system resonance .That is why the solution of active power filter has been widely developed this last decade. In severe cases, the neutral currents are potentially damaging to both the neutral conductor and the transformer to which it is connected. Three phase four wire active power filters have been proposed by researchers as an effective solution to these problems .A comparative study of three phase four wire shunt active power filter is discussed. The control strategy for a shunt active power filter generates the reference current, that must be provided by the power filter to compensate reactive power and harmonic currents generated by the load.

This paper first presents a review of four control strategies (p–q method, i_d–i method, unity power factor (UPF) method, and perfect harmonic cancellation (PHC) method) with the Fuzzy Logic Controller (FLC) for the ex-traction of the reference currents for a shunt active power filter connected to a three-phase four-wire source that supplies a non-linear load (Fig. 1). Then a comparison of the methods is made by simulations under both ideal and distorted mains voltage con ditions and various load conditions. Finally experimental results are presented..



I.INSTANTANEOUS P–Q STRATEGY

Most APFs have been designed on the basis of instantaneous reactive power theory (or p–q theory) to calculate the desired compensation current. This theory was first proposed by Akagi and co-workers in 1984 [1], and has since been the subject of various interpretations and improvements In this method, a set of voltages $(u_a u_b u_c)$ and currents $(i_a i_b i_c)$ from a three-phase four-wire system are first transformed into a three-axis representation α_β_0, using the power invariant

$$\begin{bmatrix} u_0 \\ u_\alpha \\ u_\beta \end{bmatrix} = C \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}; \quad \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = C \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad C=\sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}$$

(1)

where is the so called transformation matrix: $\|C\|=1$; $C^{-1}=C_T$

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The generalized instantaneous active power, p, and instanta-neous reactive power, q, defined in [2], [3] in terms of the α–β–0 components, are given by the following expressions:

$$p=u\times i=u_a i_a+u_b i_b+u_c i_c=u_0 i_0+u_\alpha i_\alpha+u_\beta i_\beta \qquad (2)$$

$$q=\begin{bmatrix} q_0 \\ q_\alpha \\ q_\beta \end{bmatrix}=u\times i=\begin{bmatrix} u_\alpha & u_\beta \\ i_\alpha & i_\beta \\ u_\beta & u_0 \\ i_\beta & i_0 \\ u_0 & u_\alpha \\ i_0 & i_\alpha \end{bmatrix} \qquad (3)$$

The instantaneous three-phase active power has two compo-nents: the instantaneous zero-sequence active power, p_0, and the instantaneous active power due to positive and negative se-quence components, $p_{\alpha\beta}$:

$$p=p_0+p_{\alpha\beta} \qquad p=u_0 i_0 \qquad p_{\alpha\beta}=u_\alpha i_\alpha+u_\beta u_\beta \qquad (4)$$

Each power component has, in turn, a mean value or dc com-ponent and an oscillating value or ac component. For the system shown in Fig. 1, the power components required by the load are:

$$p_L=\overline{p_L}+\widetilde{p_L}$$

$$q_L=\overline{q_L}+\widetilde{q_L} \qquad (5)$$

From (2) and (3), and taking into account that vectors u and q are orthogonal $(u.q=0)$, the current can be calculated by the inverse transformation

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{u_0^2+u_\alpha^2+u_\beta^2} \begin{bmatrix} u_0 & 0 & u_\beta & -u_\alpha \\ u_\alpha & -u_\beta & 0 & u_0 \\ u_\beta & u_\alpha & -u_0 & 0 \end{bmatrix} \begin{bmatrix} p \\ q_0 \\ q_\alpha \\ q_\beta \end{bmatrix} \qquad (6)$$

The objective of the p–q strategy is to get the source to give only the constant active power demanded by the load, $p_S=\overline{p}+\overline{p}$. In addition, the source must deliver no zero-se-quence 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 frame is therefore

$$\begin{bmatrix} i_{s0ref} \\ i_{s\alpha ref} \\ i_{s\beta ref} \end{bmatrix} = \frac{1}{u_\alpha^2+u_\beta^2} \begin{bmatrix} u_0 & 0 & u_\beta & -u_\alpha \\ u_\alpha & -u_\beta & 0 & u_0 \\ u_\beta & u_\alpha & -u_0 & 0 \end{bmatrix} \times \begin{bmatrix} \overline{p_{L\alpha\beta}} + \widetilde{p_0} \\ 0 \\ 0 \\ 0 \end{bmatrix} = \frac{\overline{p_{L\alpha\beta}} + \widetilde{p_0}}{+u_\alpha^2+u_\beta^2} \qquad (7)$$

This method is also known as synchronous reference frame (SRF) [6], [7]. Here, the reference frame d–q quadrature axis) is determined by the angle Here, the reference frame d-q-0. (direct axis- quadrature axis) is determined by the angle θ with respect to α-β-0 frame used in p-q theory. The transformation from d-q-0 to α-β-0 is

$$\begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix} = \begin{vmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{vmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \qquad (8)$$

If the d axis is in the direction of the voltage space vector, since the zero-sequence component is invariant, the transforma-tion is given by

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = S \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

$$S=\frac{1}{\sqrt{u_\alpha^2+u_\beta^2}} \begin{bmatrix} u_\alpha & u_\beta \\ -u_\beta & u_\alpha \end{bmatrix} \qquad (9)$$

where the transformation matrix, S , satisfies $\|S\|=1$; $S^{-1}=S^T$

Each current component(I_D, I_Q) has an average value or dc comp value or ac component.

$$i_d=\overline{i_d}+\widetilde{i_d}$$

$$i_q=\overline{i_{dL}}+\widetilde{i_d} \qquad (10)$$

The compensating strategy (for harmonic reduction and re-active power compensation) assumes that the source must only deliver the mean value of the direct-axis component of the load current. The reference source current will therefore be

$$i_{sdref}=\overline{i_{LD}} \; ; \quad i_{sqref}=i_{s0ref}=0 \qquad (11)$$

From (9), the direct-axis component of the load current is

$$i_{Ld} = \frac{u_\alpha . i_{L\alpha} + u_\beta . i_{L\beta}}{\sqrt{u_\alpha^2+u_\beta^2}} = \frac{p_{L\alpha\beta}}{\sqrt{u_\alpha^2+u_\beta^2}} = \bar{i}_{Ld} + \tilde{i}_{Ld}$$

(12)

The dc component of the above equation will be

$$\bar{i}_{Ld} = \left(\frac{p_{L\alpha\beta}}{\sqrt{u_\alpha^2+u_\beta^2}} \right)_{dc}$$

(13)

where the subscript "dc" is to be understood as the mean value of the expression within parentheses.

The reference source current must be in phase with the voltage at the PCC but with no zero-sequence component. It will therefore be obtained in the α–β–0 frame by multiplying (13) by a unit vector in the direction of the PCC voltage space

$$i_{Sref} = \bar{\bar{i}}_{Ld} \frac{1}{\sqrt{u_\alpha^2+u_\beta^2}} \begin{bmatrix} u_0 \\ u_\alpha \\ u_\beta \end{bmatrix} = \left(\frac{p_{L\alpha\beta}}{\sqrt{u_\alpha^2+u_\beta^2}} \right)_{dc} \frac{1}{\sqrt{u_\alpha^2+u_\beta^2}} \begin{bmatrix} u_0 \\ u_\alpha \\ u_\beta \end{bmatrix} \quad (14)$$

II.UPF STRATEGY

The compensating strategy known as the unity power factor (UPF) method has the objective that the load plus the compensator must be viewed by the source as a resistance [8], [9]. This method is also known as the "voltage synchronization method'' because the source current space vector is desired to be in phase with the PCC voltage space vector

$$i_{Sref} = K.u \quad (15)$$

where K is a constant whose value depends on the PCC voltage and the load. The power delivered by the source will be

$$p_s = u.\, i_S = u.K.u = K\left(u_0^2 + u_\alpha^2 + u_\beta^2\right) \quad (16)$$

The conductance K can be determined with the criterion that the power delivered by the source equals the dc component of the instantaneous active power of the load, so that

$$K = \frac{\overline{p_{L\alpha\beta}} + \overline{p_{L0}}}{u_0^2+u_\alpha^2+u_\beta^2} \quad (17)$$

Finally, the reference source current will be given by

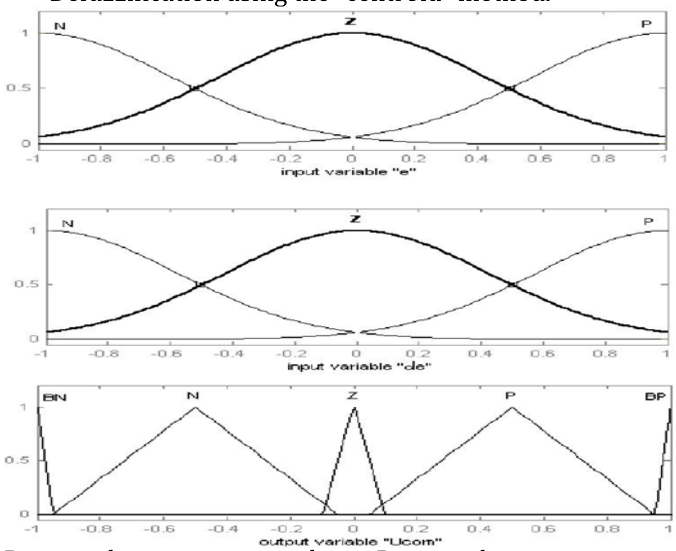
$$\begin{bmatrix} i_{s0ref} \\ i_{s\alpha ref} \\ i_{s\beta ref} \end{bmatrix} = K \begin{bmatrix} u_0 \\ u_\alpha \\ u_\beta \end{bmatrix} = \frac{\overline{p_{L\alpha\beta}} + \overline{p_{L0}}}{\left(u_0^2+u_\alpha^2+u_\beta^2\right)dc} (18)$$

III FUZZY LOGIC CONTROL

The main component of an active filter is the current controller. Recently, fuzzy logic controllers (FLCs) have been interest a good alternative in more application. The advantages of fuzzy controllers are more robust than conventional controllers, not need a mathematical model and can handle non -linearity [18],[19], and [20]. Fuzzy logic control is the evaluation of a set of simple linguistic rules to determine the control action. The desired inverter switching signals of the shunt active filter are determined according the error between the compensate currents and reference currents. A fuzzy controller is designed to improve compensation capability of APF by adjusting the current error using a fuzzy rule. In this case, the fuzzy logic current controller has two inputs, named error e and change of error de and one output s. To convert it into linguistic variable, we use three fuzzy sets: N (Negative), ZE (Zero) and P (Positive). Membership functions used for the inputs and the single output are shown is shown in Figure 4. The parameter for the fuzzy logic current controller for every phase is characterized for the following:

The fuzzy controller for every phase is characterized for the following:

- Three fuzzy sets "e" and "de" inputs,
- Five fuzzy sets for "s" output,
- Gaussian membership functions for inputs,
- Triangular and trapezoidal membership functions for output,
- Implication using the "min" operator,
- Mamdani fuzzy inference mechanism based on fuzzy implication,
- Defuzzification using the "centroid" method.



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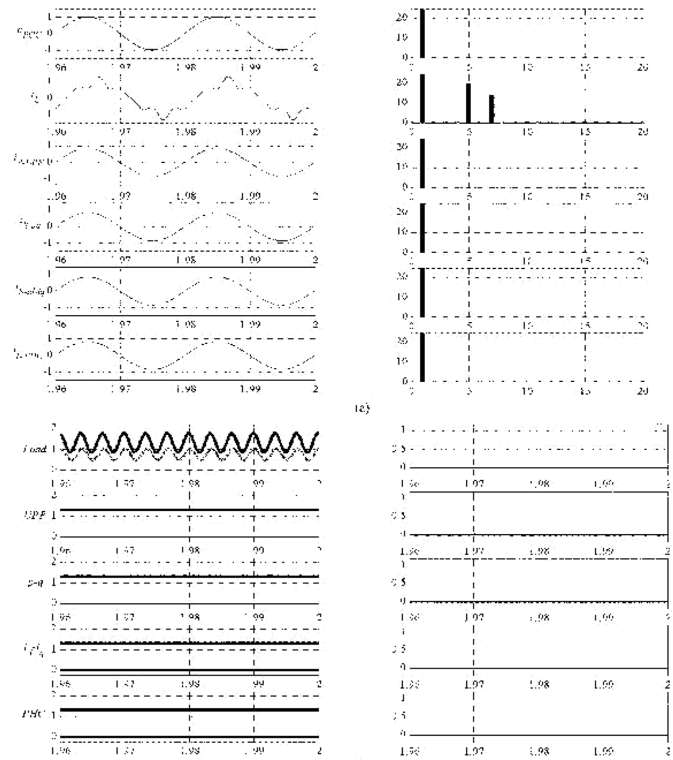

Fig. 2. Simulation results for case A.

1459 [14]. For a three-phase four-wire system, the equivalent voltage, current, and apparent power are given by

$$U_e=\sqrt{\frac{U_a^2+U_b^2+U_c^2}{3}}\ ;\ I_e=\sqrt{\frac{I_a^2+I_b^2+I_c^2+I_n^2}{3}}\ ;$$

$$S_e=3U_eI_e \qquad (17)$$

The total active power is obtained by adding the active power in each phase

$$P=\sum_k\sum_h U_{kh}I_{kh}\cos\varphi_{kh} \qquad (18)$$

where means the phase (a, b, or c), is the order of the h[th] harmonic and ϕ is the angle between the h[th] harmonic voltage and the th harmonic current for phase k. The total power factor is therefore

$$\mathrm{PF}=\frac{P}{S_e} \qquad (19)$$

A. Case A: Ideal Mains Voltage: Balanced and Distorted(Fifth and Seventh Harmonics) Load Current

Simulation results for case A are shown in Fig. 2 and summa-rized in Table II. Both source voltage and current are sinusoidal and in phase. Hence, reactive power and harmonics are fully compensated. The source supplies only the constant power de-manded by the load. With ideal mains voltage, therefore, all the strategies are equivalent.

TABLE I: SIMULATION RESULTS OF CASE A

	i_L	$i_{S\text{-}UPF}$	$i_{S\text{-}p\text{-}q}$	$i_{S\text{-}id\text{-}iq}$	$i_{S\text{-}PHC}$
THD	24.46%	0.041%	0.041%	0.041%	0.044%
I_1	0.707	0.612	0.612	0.612	0.612
I	0.728	0.612	0.612	0.612	0.612
dPF	0.866	1	1	1	1
P	1.299	1.299	1.299	1.299	1.299
S_e	1.544	1.299	1.299	1.299	1.299
PF	0.841	1	1	1	1

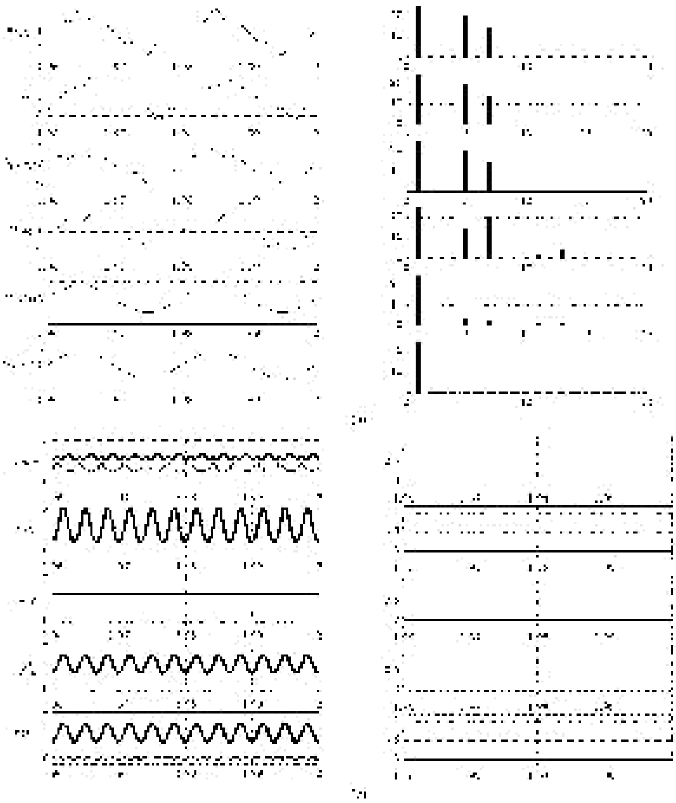

Fig. 3. Simulation results for case *B*.

TABLE II: SIMULATION RESULTS OF CASE

	i_L	$i_{S\text{-}UPF}$	$i_{S\text{-}p\text{-}q}$	$i_{S\text{-}id\text{-}iq}$
THD	24.46%	24.66%	25.79%	4.23%
I_1	0.707	0.543	0.611	0.610
I	0.728	0.559	0.631	0.611
dPF	0.866	1	1	1
P	1.221	1.221	1.221	1.221
S_e	1.590	1.221	1.379	1.256
PF	0.768	1	0.885	0.972

Simulation results for case B are presented in Fig. 3 and Table III. Comparing the frequency spectra, one observes that only the PHC strategy cancels all the harmonics in the source current. The UPF strategy maintains the source voltage total harmonic distortion (THD), whereas the p–q strategy even in-creases this ratio because it contains new harmonics at frequen-cies not present in the load currents. One could conclude from Table III that i_d–i are able to satisfy the IEEE-519 Standard harmonic current limits [15].

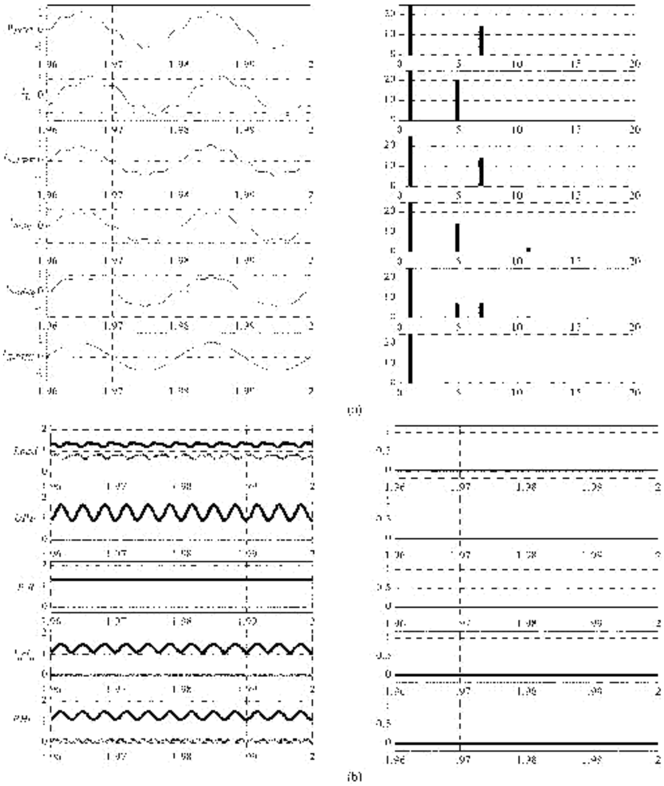

Fig. 4. Simulation results for case C

TABLE III: SIMULATION RESULTS OF CASE

	i_L	$i_{S\text{-}UPF}$	$i_{S\text{-}p\text{-}q}$	$i_{S\text{-}id\text{-}iq}$
THD	19.887%	14.317%	14.429%	10.160%
I_1	0.707	0.600	0.612	0.606
I	0.721	0.606	0.619	0.609
dPF	0.866	1	1	1
P	1.299	1.299	1.299	1.299
S_e	1.545	1.299	1.326	1.306
PF	0.841	1	0.980	0.995

E. Case E: Unbalanced and Undistorted Source Voltages ($U^{-}_{\mathrm{PCCe1}}/U^{+}_{\mathrm{PCCe1}} = U^{0}_{\mathrm{PCCe1}}/U^{+}_{\mathrm{PCCe1}}$ =52%); Unbalanced and Undistorted Load Currents ($I^{-}_{Le1}/I^{+}_{Le1} = I^{0}_{Le1}/I^{+}_{Le1}$ = 52%)

Simulation results for case E are presented in Fig. 6 and Table VI. The frequency spectra of phase c are shown since this is the least favourable phase. Here, in contrast to case D, there is zero-sequence instantaneous active power demanded by the load. Only the p–q and PHC strategies can eliminate this power term, while UPF maintains the zero-sequence component of the voltage in the current (yielding a PF <1), and i_d–i is unable to compensate this term, as can be concluded from Table I (the term p_{L0} is not taken into account for extracting the reference current, but $i_{S0\_id\_i}$=0, so $p_{S0\_id\_i}$=0) and the active power data in Table VI (P_L^q= 1.28 W while P_S^q= 1.05 W because the dc zero-sequence active power demanded by the load is not delivered by the source, what implies the need of an external source to provide this power). In terms of the distortion and imbalance, the results are similar to case D.

F. Analysis of the Simulation Results

From the above figures and tables, one may draw the fol-lowing conclusions:

UPF: The source current waveforms will be identical to the voltage waveforms and can thus not comply with the IEEE Standard 519 limits, or will be unbalanced depending on the voltage. The instantaneous reactive power demanded by the load is fully eliminated [q_S calculated from (3) and (15) is null in all cases, as is seen in Figs. 2(b) –6(b)]. In three-phase four-wire systems with zero-sequence compo-nents in the voltage at the PCC (cases D and E), the energy transfer is not maximal, yielding a power factor less than unity and source currents with greater RMS values. Fur-thermore, in these situations the source delivers zero-se-quence power—Figs. 5(b) and 6(b)—even though the load does not demand this power term (case D).

p–q: The instantaneous active power delivered by the source equals the constant active load power $(p_S = p_{S\alpha\beta} = \overline{p}_{L\alpha\beta} + \overline{p}_{L0})$, as can be observed in Figs. 2(b) –6(b). The generalized p q– strategy has dis-advantages when the voltage at the PCC has harmonics and/or is unbalanced. In these situations the modulus of the instantaneous vector of the PCC voltage with no zero-sequence component, $u_{\alpha\beta}$, is not constant, so that, as follows from Table I, the reference current is obtained by multiplying a time-varying term by the vector, $u_{\alpha\beta}$. This could even include harmonics of orders not contained in the load current [8], as is seen in the frequency spectra of Figs. 3(a) –6(a).

Although the original and modified p–q theories have been the most extensively used strategies for conditioner con-trol, and have been a benchmark in the development of to harmonics and imbalance in the mains voltages. In the present simulations, this method gave the poorest results in terms of THD and PF, and worked adequately only in the case of ideal mains voltages.

i_d–i_q: In this method, the source delivers the dc direct load current component. However, this technique introduces many errors when the PCC voltage contains harmonics or imbalance due to negative-sequence components because the unit vector in the direction of the vector $u_{\alpha\beta}$ is not calculated correctly—see (14). This is the reason for the harmonics in the source current in cases B–E. Another drawback, as was mentioned above, is that the method is

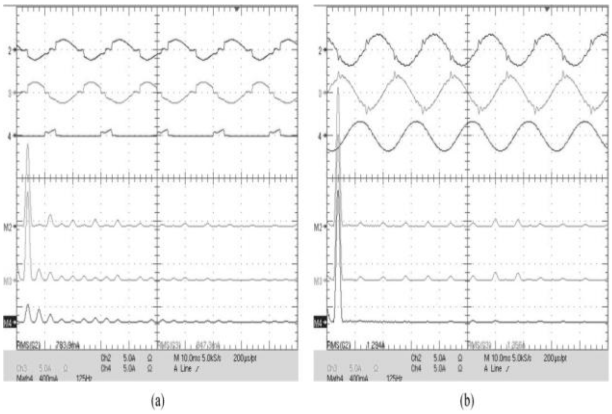

Fig. 8. Experimental results under conditions of unbalanced source voltage with zero-sequence component. Waveforms (5 A/division) and frequency spectra (400 mA/division) for phases a, b, and c: (a) load currents and (b) source currents after compensation.

unable to compensate the dc zero-sequence active power demanded by the load, so that an external source would be needed in such situations. This problem could be obviated if (14) were replaced by

$$\begin{bmatrix} i_{s0ref} \\ i_{S\alpha ref} \\ i_{s\beta ref} \end{bmatrix} = \left(\frac{p_{L\alpha\beta}}{\sqrt{u_\alpha^2 + u_\beta^2}} \right)_{dc} \frac{1}{\sqrt{u_\alpha^2 + u_\beta^2}} \begin{bmatrix} u_0 \\ u_\alpha \\ u_\beta \end{bmatrix} \quad (20)$$

EXPERIMENTAL RESULTS:

The simulation analysis showed the least favorable situation to correspond to the case of a three-phase four-wire system with zero-sequence components in the voltage imbalance condition at the PCC. The above mention methods are not fit in this situation so here we can propose Fuzzy Logic Controller strategy which is having capability to eliminate imbalance in the source currents. The working of this strategy is as discussed in the section

CONCLUSION:

This paper has provided a comparative analysis of four con-trol strategies for shunt APFs installed in three-phase four-wire systems with harmonic distortion and/or imbalance. It was shown that the p–q strategy (maybe the most widely used) and the i_d–i_q strategy are the most sensitive to distortion and imbalance in the voltages at the PCC.

Although the objective of UPF is to attain unity PF and to minimize the source current RMS values, with the new power definitions of IEEE Standard 1459 these goals are not achieved in the case of three-phase four-wire systems with zero-sequence components in the voltage.

The simulations showed that, if one seeks compliance with harmonics standards, imbalance elimination, and reactive power compensation, FLC is the only strategy which is capable of cor-rect action under any conditions of use. This was confirmed by experiment in the case of the least favourable situation

REFERENCES

[1] Chennai Salim1 and Benchouia Mohamed Toufik2 1Electrical Engineering Department, Birine Nuclear Research Center, Algeria,2Laboratory L.G.E.B., Biskra University, Algeria" Three-level (NPC) Shunt Active Power Filter Performances based on Fuzzy Controller for Harmonic Currents Compensation under Non-Ideal Voltage Conditions", International Journal on Electrical Engineering and Informatics - Volume 6, Number 2, June 2014

[2] Chennai Salim1 and Benchouia Mohamed Toufik2 1Department of Electrical Engineering, Research Center of Birine, Algeria,2Laboratory L.G.E.B., University of Biskra, Algeria" Intelligent Controllers for Shunt Active Filter to Compensate Current Harmonics Based on SRF and SCR Control Strategies" International Journal on Electrical Engineering and Informatics - Volume 3, Number 3, 2011

[3] E.Latha Mercy,1el.Gr.Lecturer/EEE Government College of Technology, Coimbatore-641 013R.Karthick,2, Lecturer/Electrical Dept., CSI College of Engg., Ketti, OotyS.Arumugam,3 Chief Executive Officer, Nandha Engineering Col., Erode Dist Tamil Nadu, India" A Comparative Performance Analysis of Four Control Algorithms for a Three Phase Shunt Active Power Filter" IJCSNS International Journal of Computer Science and Network Security, VOL.10 No.6, June 2010.

[4] María Isabel Milanés Montero, *Member, IEEE, Enrique Romero Cadaval, Member, IEEE, and* Fermín Barrero González, *Member, IEEE"* Comparison of Control Strategies for Shunt Active Power Filters in Three-Phase Four-Wire Systems" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 22, NO. 1, JANUARY 2007.