IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 1 Ver. II (Jan – Feb. 2015), PP 68-74
www.iosrjournals.org

Implementation of Instantaneous Reactive Power Theory for Current Harmonic Reduction and Reactive Power Compensation in Three Phase Four Wire Power System

[1]G. Aruna Jyothi, [2]DR. P. V. R. L. Narasimham
[1]M-tech Student Scholar, Department of Electrical & Electronics Engineering, VR Siddhartha Engineering College, Kanuru; Krishna (Dt); A.P, India.
[2]Professor & H.O.D, Department of Electrical & Electronics Engineering, VR Siddhartha Engineering College, Kanuru; Krishna (Dt); A.P, India

Abstract: *Most of the pollution issues created in power systems are due to the non-linear characteristics and fast switching of power electronic equipment. Power quality issues are becoming stronger because sensitive equipment will be more sensitive for market competition reasons, equipment will continue polluting the system more and more due to cost increase caused by the built-in compensation and sometimes for the lack of enforced regulations. In this paper instantaneous reactive power theory (IRP theory) is proposed for calculating the reference compensating currents required to inject into the network at the connected point of non-linear load. Switching scheme of compensator is provided by comparing the reference compensating currents obtained from IRP theory and compensator currents. Thus IRP theory is used to identify the amount of compensating current injected into the network to compensate the reactive power required by non-linear loads and to bring the source current waveform as sinusoidal. Simulations for a three phase three wire system and three phase four wire system with a shunt active power filter have been carried out for current harmonic reduction and reactive power compensation. Thus power factor has been improved by attaining source voltage and source current in phase.***

Keywords: *IRP theory, SAPF, VSI, HBCC PWM*

I. Introduction

The problems identified with non-linear loads have considerably increased with the proliferation of power electronics equipment. The modern equipment behaves as a non-linear load drawing a considerable amount of harmonic current from the power network. Therefore, power systems in some cases have to be analyzed under non-sinusoidal conditions. This makes it very important to establish a reliable set of power definitions that are also applicable during transients and under non-sinusoidal conditions. The progress of power electronics technology has brought new limit conditions to the power theories. Precisely speaking, the new conditions have not risen up from the research of power electronics engineers. They have resulted from the proliferation of power converters using power semiconductor devices such as diodes, thyristors, insulated-gate bipolar transistors (IGBTs), gate-turn-off (GTO) thyristors, and so on. Despite the fact that these power converters have a quick response in controlling their voltages or currents, they may draw reactive power as well as harmonic current from power networks. This has made it clear that conventional power theories based on average or rms values of voltages and currents are not applicable to the analysis and design of power converters and power networks. This issue has become more serious and clear during comprehensive analysis and design of active filters intended for reactive-power compensation as well as harmonic compensation.

The shunt active power filter (SAPF) is a device that is connected in parallel to and cancels the reactive and harmonic currents from a nonlinear load . The resulting total current drawn from the ac main is sinusoidal. Ideally, the APF needs to generate just enough reactive and harmonic current to compensate the nonlinear loads in the line.

II. Instantaneous Reactive Power Theory

The IRP Theory is based on a set of instantaneous powers defined in the time domain. No restrictions are imposed on the voltage or current waveforms, and it can be applied to three-phase systems with or without a neutral wire for three-phase generic voltage and current waveforms. Thus, it is valid not only in the steady state, but also in the transient state. This theory is very efficient and flexible in designing controllers for power conditioners based on power electronics devices [1-3].

In IRP Theory three phase four wire system the Voltages and currents of a-b-c coordinates are converted into $\alpha - \beta - 0$ coordinates and then defines instantaneous power on these coordinates. Hence, this theory always considers the three-phase system as a unit, not a superposition or sum of three single-phase circuits.

III. Clarke's Transformation In Three Phase Four Wire System

In order to express instantaneous voltages and currents in three phase circuits mathematically, there is need to express voltages and currents the instantaneous space vectors.

These space vectors are transformed into $\alpha - \beta - 0$ coordinates as follows.

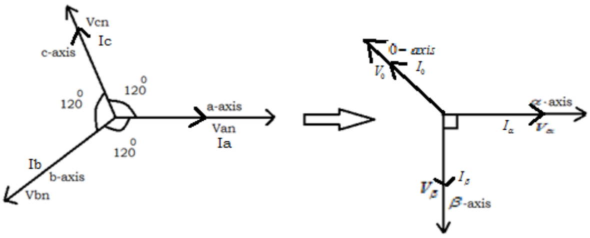


Fig.1 a-b-c to $\alpha - \beta - 0$ transformation in currents and voltages

In order to get the expressions for p, q and p_0 first phase voltages and currents are converted into $\alpha - \beta - 0$ coordinate system using Clarke's transformation.

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} p_0 \\ p \\ p \end{bmatrix} = \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_0({v_\alpha}^2 + {v_\beta}^2)} \begin{bmatrix} ({v_\alpha}^2 + {v_\beta}^2) & 0 & 0 \\ 0 & v_0 v_\alpha & v_0 v_\beta \\ 0 & v_0 v_\beta & -v_0 v_\alpha \end{bmatrix} \begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} \tag{4}$$

. The difference is the additional definition of the zero-sequence power. Before explaining it, the three-phase instantaneous active power should be re-written in terms of the $\alpha - \beta - 0$ components.

$$\begin{aligned} p_{3\phi} &= v_\alpha i_\alpha + v_\beta i_\beta + v_0 i_0 \\ &= p + p_0 \end{aligned} \tag{5}$$

Which is equal to the conventional three phase power

$$P_{3\phi} = v_a i_a + v_b i_b + v_c i_c \tag{6}$$

This equation shows that the three-phase instantaneous active power $P_{3\emptyset}$ is equal to the sum of the real power p and the zero-sequence powerp_0. In the case of a three phase, three-wire circuit, the power p_0 does not exist, and so is $P_{3\emptyset}$ equal to p [4].

The relation between the conventional concepts of powers and the new powers defined in the p-q Theory is better visualized if the powers p, q, and p_0 are separated in their average values $\bar{p}$, $\bar{q}$ and $\overline{p_0}$, and their oscillating parts $\tilde{p}$, $\tilde{q}$ and $\widetilde{p_0}$.

Zero-sequence power: $p_0 = \overline{p_0} + \widetilde{p_0}$ (7)
Real power: $p = \bar{p} + \tilde{p}$ (8)
Imaginary power: $q = \bar{q} + \tilde{q}$ (9)

IV. Selection Of Power Components To Be Compensated

The idea is to compensate all undesirable power components generated by nonlinear loads that can damage or make the power system overloaded or stressed by harmonic pollution. In this way, it would be desirable for a three-phase balanced power-generating system to supply only the average real power $\bar{p}$ of the load. Thus, all other power components required by the nonlinear load, that is, $\tilde{q}$, $\tilde{p}$, $\widetilde{p_0}$, $\bar{q}$ and $\overline{p_0}$, should be compensated by a shunt compensator connected as close as possible to this load.

The compensation algorithm based on the IRP Theory is very flexible[5]. The undesirable powers to be compensated can be conveniently selected.

$$\begin{bmatrix} i_0^* \\ i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_0(v_\alpha{}^2+v_\beta{}^2)} \begin{bmatrix} (v_\alpha{}^2+v_\beta{}^2) & 0 & 0 \\ 0 & v_0 v_\alpha & v_0 v_\beta \\ 0 & v_0 v_\beta & -v_0 v_\alpha \end{bmatrix} \begin{bmatrix} -p_0 \\ -\tilde{p} \\ -q \end{bmatrix} \tag{10}$$

$$i_0{}^* = -\frac{p_0}{v_0} \tag{11}$$

$$i_\alpha{}^* = -\frac{v_\alpha}{v_\alpha{}^2+v_\beta{}^2}(-\tilde{p}) + \frac{v_\beta}{v_\alpha{}^2+v_\beta{}^2}(-q) \tag{12}$$

$$i_\beta{}^* = \frac{v_\beta}{v_\alpha{}^2+v_\beta{}^2}(-\tilde{p}) - \frac{v_\alpha}{v_\alpha{}^2+v_\beta{}^2}(-q) \tag{13}$$

Powers to be compensated are $\tilde{p}$ and q. This means that all the undesirable current components of the load are being eliminated. The compensated current is sinusoidal, produces a constant real power, and does not generate any imaginary power. The nonlinear load and the compensator form an ideal, linear, purely resistive load. The source current has a minimum rms value that transfers the same energy as the original load current that produce the average real power $\bar{p}$. This is the best compensation that can be made from the power-flow point of view, because it smoothes the power drawn from the generator system. Besides, it eliminates all the harmonic currents.

V. Shunt Active Power Filter

In this paper shunt active filters, applied to three-phase three wire systems and three phase four wire systems. The shunt active filters described have controllers based on the instantaneous reactive power theory (i.e., IRP Theory) Most applications of shunt active filters are intended to compensate for the source current harmonics produced by a specific load. Another interesting compensation function that a shunt active filter can realize is to provide harmonic damping in power lines, in order to avoid harmonic propagation resulting from harmonic resonances between the series inductances and shunt capacitors[6].

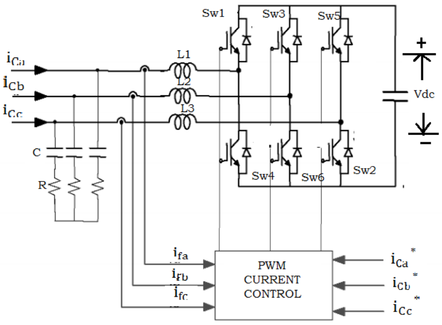


Fig.2 PWM converter for shunt active filter

Shunt active filters generally consist of two distinct main blocks:
1. The PWM converter (power processing)
2. The active filter controller (signal processing)

VI. Active Filter Controllers

The control algorithm implemented in the controller of the shunt active filter determines the compensation characteristics of the shunt active filter. There are many ways to design a control algorithm for active filtering. Certainly, the p-q Theory forms a very efficient basis for designing active filter controllers.

According to the p-qTheory, to draw constant instantaneous active power from the source means that the shunt active filter must compensate for the oscillating real power ($\tilde{p}$). Additionally, the rms value of the compensated current is minimized by the compensation of the total imaginary power $q = \bar{q} + \tilde{q}$ of the load. There is no zero-sequence power because a three-phase, three-wire system is being considered. If the system voltage contains harmonics and/or imbalance at the fundamental frequency, the compensated current cannot be sinusoidal to guarantee constant real power, p, that is drawn from the source[7]. From the above analysis, we can see that harmonic compensation can have different functionalities.

PWM converters generate undesirable current harmonics around the switching frequency and its multiples. If the switching frequency of the PWM converter is sufficiently high, these undesirable current harmonics can be easily filtered out by using small, passive high-pass filters represented by R and C. Ideally, the switching-frequency current harmonics are fully cut out, and the compensating currents i_{Ck} correctly track its references $i_{Ck}{}^{*}$(k= a, b, c)[8].

VII. Hysteresis Current Control For Active Power Filter With Constant Frequency

The hysteresis band current control for active power filter that the current can carried out to generate the switching pattern of the inverter. The various current control methods proposed for such active power filter configuration but the hysteresis band current control method has the highest rate among other control methods, because quick current controllability, easy to implement. Hysteresis band current control is robust provides excellent dynamics and fast control with minimum hardware [9].

Conventional hysteresis current control operates the PWM VSI by comparing the current error against fixed hysteresis band. This current error is the difference between $i_C{}^{*}$ (which is calculated from p-q theory) and filter current i_f. Fig.3 Hysteresis-band PWM current control[10].

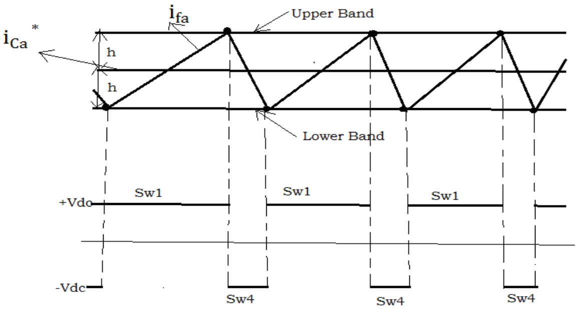


Fig.3 Hysteresis-band PWM current control

we have instantaneous value equation as:

$$V_{dc} - L\frac{di_a}{dt} - v_{an} = 0 \tag{14}$$

$$L\frac{di_a}{dt} = V_{dc} - v_{an} \tag{15}$$

When the active power filter output current is equal to reference current i^{*} , the corresponding equation will be

$$V_{dc}{}^{*} - L\frac{di_a{}^{*}}{dt} - v_{an} = 0 \tag{16}$$

$$L\frac{di_a{}^{*}}{dt} = V_{dc}{}^{*} - v_{an} \tag{17}$$

Where $V_{dc}{}^{*}$is the reference VSI terminal voltage corresponding to$I_a{}^{*}$. if we define APF current tracking error $\Delta i = i_a - i_a{}^{*}$

$$L\frac{d\Delta i}{dt} = V_{dc} - V_{dc}{}^{*} \tag{18}$$

Where VSI terminal voltage V_{dc} and for s=1 $V_{dc} = +V_{dc}$

And for s=0 $V_{dc} = -V_{dc}$

If the error current exceeds the upper limit of the hysteresis band, the upper switch of the inverter arm is turned OFF and the lower switch is turned ON. If the error current crosses lower limit of the hysteresis band the lower switch of the inverter arm is turned OFF and the upper switch is turned ON.

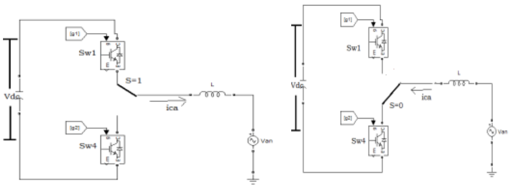


Fig.4 single phase VSI

VIII. Matlab/Simulink Results

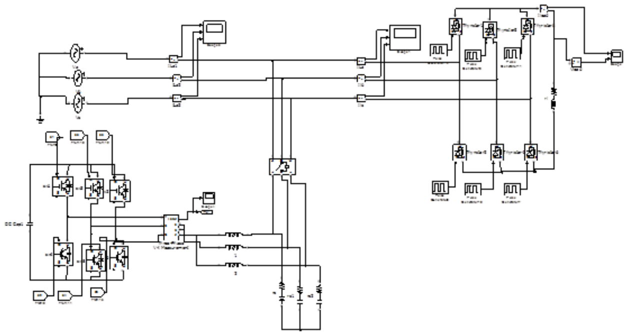


Fig.5 implementation of SAPF for thyrister based non-linear load

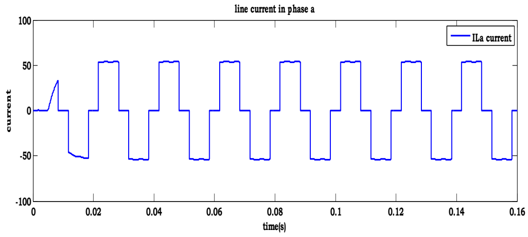


Fig.6 source currents in phase a

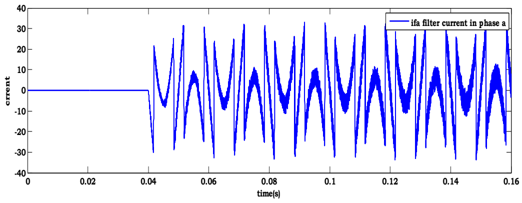


Fig.7 filter currents in phase a

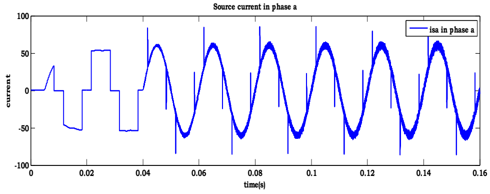


Fig.8 source current after compensation

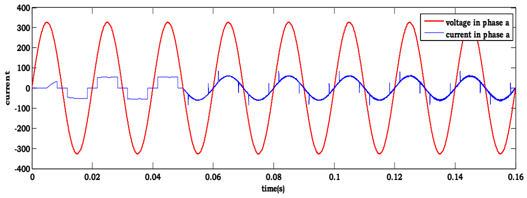


Fig.9 source voltage and source current after compensation

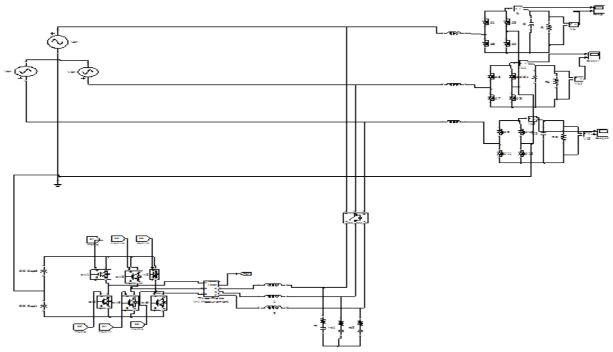


Fig.10 implementation of SAPF for three phase four wire non-linear load

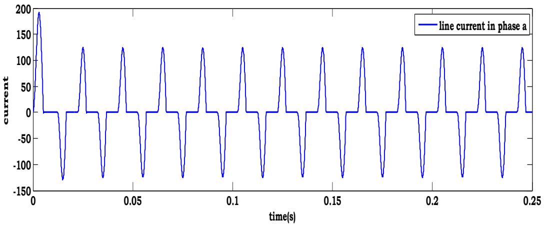


Fig.11 source current in phase a before compensation

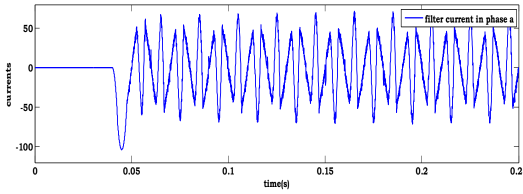


Fig.12 filter current in phase a

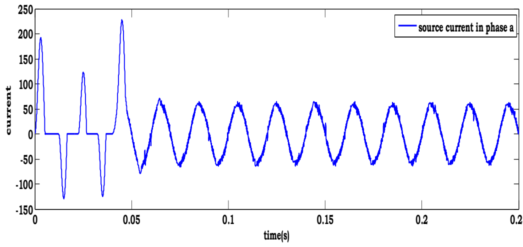


Fig.13 source current in phase a after compensation

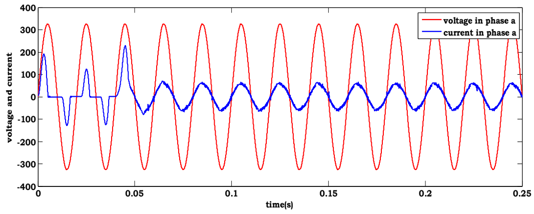


Fig.14 source voltage and source current after compensation

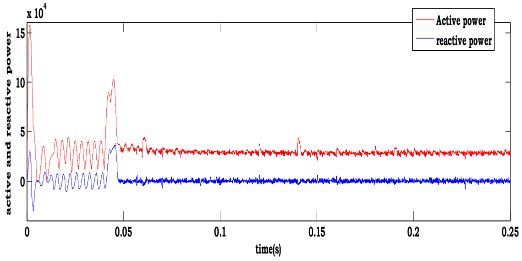
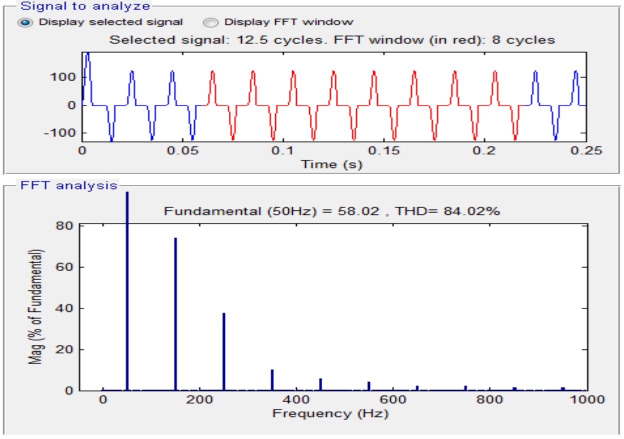


Fig.15 Source side active power and reactive power



Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 12.5 cycles. FFT window (in red): 8 cycles

FFT analysis

Fundamental (50Hz) = 58.02 , THD= 84.02%

Fig.16 THD analysis for source currents before compensation for three phase four wire system

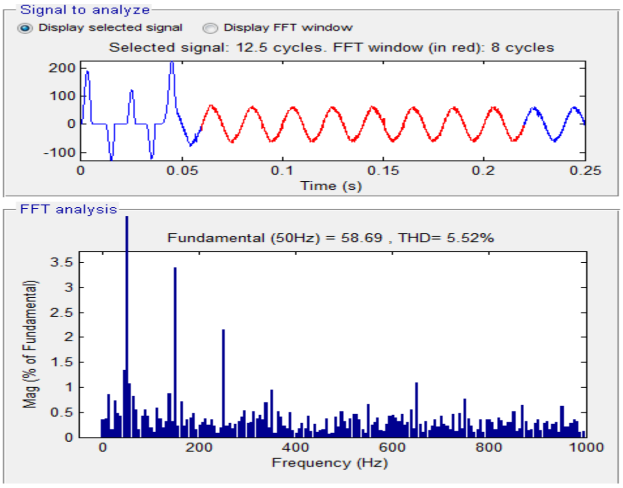


Fig.17 THD analysis for source currents before compensation for three phase four wire system.

Table 1: Three Phase Three Wire System Parameters

AC Voltage Source	Vs	230.9 Vrms value
Fundamental frequency	F	50 Hz
Load	RL	10 Ohm and 35 mH
DC bus capacitor	Cdc	5 uF
Filter inductor	Lf	1.5 mH

Table 2: Three Phase Four Wire System Parameters

AC Voltage Source	Vs	230.9 Vrms value
Fundamental frequency	F	50 Hz
Load	RL	10 Ohm and 1mH
DC bus capacitor	Cdc1 and Cdc2	1100 uF and 1100uF
Filter inductor	Lf	6 mH

IX. Conclusion

Proposed IRP theory is used to identify the amount of compensating current injected into the network to compensate the reactive power required by non-linear loads and to bring the source current waveform as sinusoidal. A shunt active power filter has been investigated for power quality improvement. The MATLAB simulation results shown that the harmonic currents drawn by non-linear load are compensated and source currents are appeared as sinusoidal. Also power factor is improved by reactive power compensation, so that source voltage and source current are in phase. The THD of line currents has been reduced by implementing shunt active power filter.

References

[1]. H. Akagi, Y. Kanazawa, and A. Nabae, “Instantaneous reactive power compensators comprising switching devices without energy storage components,” IEEE Transactions on Industry Applications, vol. IA-20, no. 3, May/Jun. 1984, pp. 625–630.

[2]. Reyes S. Herrera and Patricio Salmerón, “Instantaneous Reactive Power Theory: A Reference in the Nonlinear Loads Compensation,” IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 56, NO. 6, JUNE 2009

[3]. Reyes S. Herrera, Patricio Salmerón, and Hyosung Kim,“Instantaneous Reactive Power Theory Applied to Active Power Filter Compensation: Different Approaches, Assessment, and Experimental Results,” IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 55, NO. 1, JANUARY 2008

[4]. Leszek S. Czarnecki, “Instantaneous Reactive Power p-q Theory and Power Properties of Three-Phase Systems ,” IEEE Transactions on Power Delivery, Vol. 21, No.1, Jan. 2006, pp. 362-367.

[5]. P. Salmerón, R.S. Herrera, “Instantaneous reactive power theory—A general approach to poly-phase systems,” Electric Power Systems Research 79 (2009) 1263–1270

[6]. João Afonso, Maurício Aredes, Edson Watanabe, Júlio Martins, “shunt active filter for power quality improvement,” International Conference UIE 2000 – “Electricity for a Sustainable Urban Development” Lisboa, Portugal, 1-4 Novembro 2000, pp. 683-691.

[7]. João L. Afonso, M. J. Sepúlveda Freitas, and Júlio S. Martins, “p-q Theory Power Components Calculations,” ISIE’2003 - IEEE International Symposium on Industrial Electronics Rio de Janeiro, Brasil, 9-11 Junho de 2003.

[8]. Sangu Ravindra, Dr.V.C.Veera Reddy, Dr.S.Sivanagaraju, “Design of Shunt Active Power Filter to eliminate the harmonic currents and to compensate the reactive power under distorted and or imbalanced source voltages in steady state,” International Journal of Engineering Trends and Technology- Volume2 Issue3- 2011.

[9]. DAVID M.BROD, and DOMALD W.NOVOTNY, “current control of VSI-PWM inverter,” IEEE Transactions on Industry Applications, vol.1A-2. no. 4, May/Jun. 1985.

[10]. Jian Zeng,Chan Tu,Qingru Qi, Zheng Yan, Yixin Ni,B.L.Zhang,Shousum Chen ,Felinx, “A novel hysteresis current control for active power filter with constant frequency,”electrical power systems research 68(2004)75-82.