A Review of Shunt Active Power Filters with Fuzzy Logic Controller

Moolchandra Patel[1] and Dr. G. P. Rathore[2]

[1] M.Tech (Power Electronics), [2]Asst.Prof.

Electrical & Electronics Department TIT-S Bhopal (M.P.)

Abstract-A review of shunt active power filter with fuzzy logic controller discuss in this paper. This is due to the increasing presence on the network of nonlinear loads; they constitute a harmonic pollution source of to the network, which generate many disturbances, and disturb the optimal operation of electrical equipments. In this work, we propose a solution to eliminate the harmonics introduced by the nonlinear loads. This paper presents the review analysis of a three-phase active power filter (APF) compensating the harmonics and reactive power created by nonlinear balanced and unbalanced low power loads in steady state and in transients.

Keywords:* *Active Power Filters, Harmonics, fuzzy logic controller.

I. INTRODUCTION

Modern electrical systems, due to wide spread of power conversion units and power electronics equipments, causes an increasing harmonics disturbance in the ac mains currents. Power Quality (PQ) is an important measure of an electrical power system. The term PQ means to maintain purely sinusoidal current wave form in phase with a purely sinusoidal voltage wave form. The power generated at the generating station is purely sinusoidal in nature. The deteriorating quality of electric power is mainly because of current and voltage harmonics due to wide spread application of the power electronics based equipments which include adjustable-speed motor drives, electronic power supplies, DC motor drives, battery chargers, electronic ballasts are responsible for the rise in power quality related problems [1] [2], [3]. These nonlinear loads absorb non-sinusoidal currents and generally consume reactive power. Harmonic currents produced by non linear loads are injected back into power distribution systems through the point of common coupling the controller is the main part of the active power filter operation and has been a subject of many researches in recent years [16–20]. Conventional PI voltage and current controllers have been used to control the harmonic current and dc voltage of the shunt

APF. However, the conventional PI controller requires precise linear mathematical model of the system, which is difficult to obtain under parameter variations, nonlinearity, and load disturbances. In recent years, fuzzy logic controllers have generated a great deal of interest in certain applications. The advantages of fuzzy logic controllers are: robustness, no need to accurate mathematical model, can work with imprecise inputs, and can handle non-linearity. In this paper, fuzzy logic control schemes are proposed for harmonic current and inverter dc voltage control to improve the performances of the three levels shunt APF. The performance of fuzzy controller is evaluated through computer simulations under steady-state conditions. The obtained results showed that, the proposed active power filter controller have provided a sinusoidal supply current with low harmonic distortion and in phase with the line voltage. The operation of APF is explained in details as well as the harmonic current (reference current) and dc voltage of the inverter control schemes. The fuzzy logic controller algorithm development and implementation is carried out in this paper.

Basic Active Power Filter

Figure 1a shows the basic compensation principle of the shunt active power filter. It is controlled to draw or supply a compensating current i_c from or to the utility, so that it cancels current harmonics on the ac side.

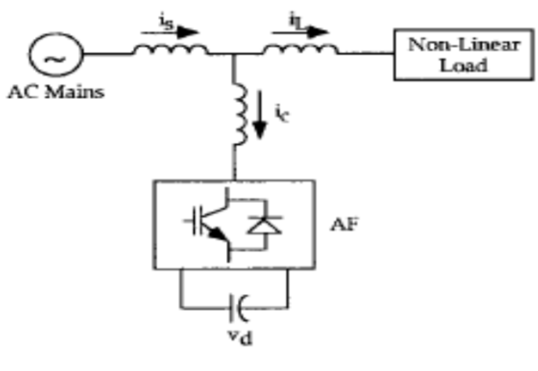

Figure 1 Block diagram of basic active power filter

Figure 2 shows the different waveforms. Curve A is the load current waveform and curve B is the desired man current. Curve C shows the compensating current injected by the active filter containing all the harmonics, to make the mains current sinusoidal. In this manner a shunt active power filter can be used to eliminate current harmonics and reactive power compensation [5]. from figure 1a the instantaneous currents can be written as;

$$i_s(t) = i_L(t) - i_c(t)$$

The source voltage is given by

$$v_s(t) = V_m \sin \omega t$$

if a nonlinear load is applied, then the load current will have a fundamental component, and the harmonic components can be represented as;

$$i_L(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \phi_n)$$

$$i_L(t) = I_1 \sin(\omega t + \phi_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n)$$

Instantaneous load power can be given as

$$p_L(t) = v_s(t) * i_L(t)$$

$$p_L(t) = V_m I_1 \sin^2 \omega t * \cos\phi_1 + V_m I_1 \sin\omega t * \cos\omega t * \sin\phi_1$$
$$+ V_m \sin\omega t * \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n)$$
$$p_L(t) = p_f(t) + p_r(t) + p_h(t)$$

From equation (4) real (Fundamental) power is drawn by the load

$$p_f(t) = V_m I_1 \sin^2 \omega t * \cos\phi_1 = v_s(t) * i_s(t)$$

From equation (6) the source current supplied by the source, after compensation

$$i_s(t) = \frac{p_f(t)}{v_s(t)} = I_1 \cos\phi_1 \sin\omega t = I_{sm} \sin\omega t$$

Also there are some switching losses in the PWM converter. Hence, the utility must supply a small overhead for the capacitor leaking and converter switching losses in addition to the real power of the load.

Hence, total peak current supplied by the source

$$I_{sp} = I_{sm} + I_{sL}$$

If the active filter provides the total reactive and harmonic power then i_s (t) will be in phase with the utility voltage and pure sinusoidal. At this time the active filter must provide the following compensation current:

$$i_c(t) = i_L(t) - i_s(t)$$

Hence for the accurate and instantaneous compensation of reactive and harmonic power, it is necessary to calculate is (t), the fundamental component of load current, as the reference current

Estimation of Reference source current

The peak value of the reference current I_{sp} can be estimated by controlling the dc side capacitor voltage. The ideal compensation requires the main current to be sinusoidal and in phase with the source voltage irrespective of the load's current nature. The desired source currents after compensation can be given as

$$i_{sa}^* = I_{sp} \sin\omega t,$$
$$i_{sb}^* = I_{sp} \sin(\omega t - 120^o),$$
$$i_{cb}^* = I_{sp} \sin(\omega t + 120^o),$$

Where $I_{sp} = I_1 \cos\phi_1 + I_{sL}$ is the amplitude of the desired source current, while the phase angles can be obtained from the source voltages? Hence, the waveform and phases of the source currents are known only the magnitude of the source currents needs to be determined.

The peak value of the reference current has been estimated by regulating the dc side capacitor voltage of the PWM converter. This capacitor voltage is compared by a reference value and the error is processed in a PI controller. The output of the PI controller has been considered as t_e amplitude of the desired source current, and the reference currents are estimated by multiplying this peak value with the unit sine vectors in phase with the source voltage.

Role of DC side Capacitor

The dc side capacitor serves two main purposes (1) it maintains a dc voltage with a small ripple in steady state, and (2) it serves as an energy storage element to supply the real power difference between load and source during the transient period. In the steady state the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate for the losses in the active filter. Thus dc capacitor voltage can be maintained at a reference value. However, when the load condition changes, the real power balance between the source and the load will be disturbed. This real power difference is to be compensated for by the dc capacitor. This changes the dc capacitor voltage away from the reference voltage. In order to keep the satisfactory operation of the active filter, the peak value of the reference current must be adjusted to change proportionally the real power drawn from the source. This real power charged or discharged by the capacitor compensates for the real power consumed by the load. If the dc capacitor voltage is recovered and attains the reference voltage, the real power supplied by the source is supposed to equal that consumed by the load again.

Thus, in this fashion the peak value of the reference source current can be obtained by regulating the average voltage3 of the dc capacitor. A smaller dc capacitor voltage than the reference voltage means that the real power supplied by the source is not enough to supply load demand. Therefore, the source current (i.e. the real power drawn from the source) needs to e increased; while a larger dc capacitor voltage than the reference voltage tries to decrease the reference source current. This change in capacitor voltage has been verified from the simulation results shown in figure 10.The real reactive power injection may result in the ripple voltage of the dc capacitor. A low pass filter is generally used to filter these ripples which introduce a finite delay. To avoid the use of this low pass filter the capacitor voltage is sampled at the zero crossing of the source voltage. A continuously changing reference current makes the compensation non instantaneous during transient. Hence this voltage is sampled at the zero crossing of one of the phase voltage. This makes the compensation instantaneous. Sampling only twice in a cycle as compared to six times in a cycle give a little higher dc capacitor voltage rise or drip during transients, but the settling time is less. Here it is shown how harmonic elimination is done in Inverter by Pulse Width Modulation technique by solving the non linear equations. Equations are used to determine switching angles of an Inverter. Switching angles play an important role to produce the desired output by eliminating selected harmonics.

In order to form the equation set, fundamental component is given desired output value and all other harmonics are equated to zero. In my simulation I find the switching angles for the 5th, 7th and 11th harmonics.

The equation which is derived for Total Harmonic distortation of the output voltage and current of an inverter is used in order to reduce the harmonics that are produced in the inverter. The percentage of the Total Harmonic Distortion is given by the following formula [15].

$$\%THD = \left[\frac{1}{a^2{}_1} \sum_{n=5}^{\infty} (a^2{}_n \right] \times 100$$

Where n = 6i ± 1(i = 1, 2, 3….)

Fuzzy logic controller

Over the past few decades, the use of fuzzy set theory, or fuzzy logic, in control systems has gained widespread popularity, especially in Japan. From as early as themid-1970s, Japanese scientists have been instrumental in transforming the theory of fuzzy logic into a technological realization. Today, fuzzy logic-based control systems, or simply fuzzy logic controllers (FLCs), can be found in a growing number of products, from washing machines to speedboats, from air condition units to handheld auto focus cameras. The inference engine is the heart of a fuzzy controller (and any fuzzy rules system) operation. Its actual operation can be divided into three steps (Figure 1):

i) Fuzzification – actual inputs are fuzzified and fuzzy inputs are obtained.

ii) Fuzzy processing – processing fuzzy inputs according to the rules set and producing fuzzy outputs.

iii) Defuzzification – producing a crisp real value for a fuzzy output.

A Review

Unified power quality conditioners (UPQC's), which aim at the integration of series-active and shunt-active filters. The main purpose of a UPQC is to compensate for voltage flicker/imbalance, reactive power, negative sequence current, and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. This paper discusses the control strategy of the UPQC, with a focus on the flow of instantaneous active and reactive powers inside the UPQC. Experimental results obtained from a laboratory model of 20 kVA, along with a theoretical analysis, are shown to verify the viability and effectiveness of the UPQC.[1]

Shunt active power filters are used to eliminate the current harmonics and to improve the power factor in systems with non-linear loads. At the present time, different methods exist to control active power filters. Some of them are based on instantaneous reactive power theory [I] and others are based on the synchronous reference frame using Park's transformation [2j. The purpose of this paper is to present a new control method of shunt active power filters in unbalanced systems, both in load currents, and in AC supply voltage, with a high contents of harmonics. The method is based on the time domain analysis carried out by P. Filipski. With this control method one can make that the set formed by the nonlinear load and the shunt power filter behaves every time like a resistance, UPF (with unity power factor), or that the current absorbed by the set is perfectly sinusoidal, by simply acting on a switch. The system has been simulated for different load and line conditions. Waveforms of the line currents are shown, with their harmonic distortion contents.[2]

A capacity-limitation technique to enlarge the power capacity that can be handled by the shunt active power filters (APFs). The capacity limited includes the reactive power as well as the amplitude of the distortion current supplied by the APFs. Under capacity-limitation control m+1 APFs supply the load reactive power with m APFs supplying their rated power and one APF supplies a fraction of its rated value. Similarly, n+1 APFs supply the load current harmonic with n APFs supplying the distortion current limited in amplitude and one APF supplying a fraction of its limited amplitude. Advantages of the proposed approach include high flexibility for extending system capacity, high reliability due to no control interconnection, reducing power capacity demand of APF, high modularity due to identical APFs, stable reactive power and harmonic current sharing and its performance is insensitive to parameters mismatch of APFs, cost-effective due to modularization, and so on. Three single-phase 1KVA APFs are designed and implemented. The effectiveness is demonstrated by some experimental results.[3]

A comparison of three different techniques used for the generation of the current reference signal in shunt active power filters. The three different techniques are evaluated and compared in terms of compensation performance under steady state and transient operating conditions, implementations requirements, and compensation in four wire power distribution systems, with unbalanced single phase nonlinear loads. The three techniques analyzed are the Instantaneous Reactive Power Theory (PQ Theory), the Synchronous Reference Frame Theory (SRF) and Peak Detection Method (PDM). The technical evaluation is done by considering the robustness for the operation with unbalanced and distorted supply voltages, unbalanced load currents, control signals conditioning and processing delays introduced by the

The comparison is based on theoretical analysis and simulated results obtained with Matlab. The principal conclusion is that the compensation performance of the different techniques is similar under ideal conditions, but under the presence of unbalanced and voltage distortion, the compensation performance is quite different, and not all the reference methods allows full compensation. The Synchronous Reference Frame algorithm presents the best performance for different operating conditions.[4]

A novel control method for shunt active power filters using SVPWM is presented. In the proposed control method, The APF reference voltage vector is generated to instead of the reference current, and the desired APF output voltage is generated by space vector modulation. The control algorithm is simple and can be realized by a low cost controller. The active power filter based on the proposed method can eliminate harmonics, compensate reactive power and balance load asymmetry. A 10kVA laboratory prototype of APF is designed. This prototype adopts the voltage source inverter as the main power circuit and low cost DSP ADMC326 as control core. Simulation and experimental results proves the validity of the analysis and the feasibility of the APF with the proposed control method.[5]

A novel current detection algorithm based on time domain approach for three-phase shunt Active Power Filters (APF) to eliminate harmonics, and/or correct power factor, And/or balance asymmetrical loads is analyzed in this paper. First, a basic overview and evaluation of the performance of three existing current detection algorithms for active power filters is presented. According to different complicated power quality issues and various compensation purposes, a novel current detection algorithm is then proposed. Comparing with existing algorithms, this algorithm has shorter time delay and clearer physical meaning. Different compensating current references can thus be accurately and easily obtained by adopting the proposed algorithm. It ensures that a shunt APF can very well achieve different compensation purposes. Moreover, it is very easy to implement this algorithm in a Digital Signal Processor (DSP). Simulation results obtained with Matlab and testing results on an experimental shunt APF are presented to validate the proposed algorithm.[6] modern navy electric ship, the application of multiple shunt active power filters (SAPF) has become an attractive choice to mitigate the current distortion of the nonlinear loads. Multiple SAPF has the advantage of high power capacity andhigh reliability. Based on the introduction of SAPF, this paper analyzes the importance of paralleling SAPF in electric ship systems. A new paralleling approach is proposed and compared with several known paralleling cascading methods. The proposed method separates the tasks of compensating for reactive power and harmonic currents. It has fast response and is suitable for redundancy design. Simulation results verify the analyses.[7]

Shunt Active Power Filters (Shunt APFs) represent the most important and most widely used filters in industrial purposes, this is due not only to the fact that they eliminate the Harmonic current with a neglected amount of active fundamental current supplied to compensate system losses, but also they are suitable for a wide range of power ratings. Modern power electronic devices such as IGBTs allowed to configure non harmonic generating shunt APFs, this paper focuses on this type of configuration namely the voltage source inverter based three phase shunt active power filters aiming to present an overview on the mater.[8]

Shunt active power filters (APF) are commonly used for the reduction of current harmonics and improvement of the power factor in power systems with nonlinear loads, such as diode rectifiers. A pulse width modulation (PWM) power converter constitutes the main component of the APF. The low-order harmonics of the line current are attenuated, but the switch-mode operation of the converter results in electromagnetic interference (EMI) spreading to the grid. Specifically, clusters of harmonics appear in the frequency spectra of voltages and currents of the converter at multiples of the switching frequency. In this paper, transferring the discrete spectral power of those harmonics to the continuous spectral power density is proposed as means for mitigation of the EMI. It is accomplished by randomization of the switching periods using a novel random PWM method (RPWM II). In contrast to the existing random PWM methods, in RPWM II the sampling frequency of the digital modulator is constant and equal to the average switching frequency. Computer simulations and experimental investigation of an APF designed for shipboard power systems are described, and the results are presented. They demonstrate significant reduction of the EMI, a feat achieved at practically no expense.[9]

These methods incorporate possible frequency deviation of the fundamental grid frequency. The proposed methods are an extension of a recently proposed synchronization method named Kalman Filter-PLL (KF-PLL). In this paper it is shown that the KF-PLL can also be used to provide the current references for shunt active power filters. It is considered references generation for the following cases: harmonics cancelation, harmonics and displacement power factor correction, harmonics and unbalance compensation and harmonics with unbalance and displacement power factor correction.[10]

The most important part of the active power filters is generating of gate signal for inverters. This paper presents Single Phase Application of Space Vector Pulse Width Modulation for shunt active power filters. In conventional SVPWM, all of the phase's currents are controlled together, but in this method each of phase currents is controlled independently from the measured currents of other phases. In another word, this method prevents from influence of other phase’s errors in the control of considered phase. In this method, the implementation of control logic will be simpler than the conventional SVPWM. For showing the performance of proposed method a typical system has been simulated by MATLAB/SIMULINK. At last, the results of proposed method are compared with the conventional SVPWM. The results show that proposed method have better performance in generating of the compensation current in active power filter.[11]

PWM inverters, a time delay between consecutive semiconductor switching is introduced to prevent a short-circuit in the DC link. This action causes the dead-time effect, which is detrimental to the performance of inverters. This paper deals with a new technique that speedup the feedback loop in Shunt Active Power Filter, in order to compensate the dead-time effect. A simple method based on an average value theory can be used to compensate this effect. For Shunt Active Power Filters (SAPF), the compensation can be done in two different ways, one for the feed forward configuration and the other for the feedback one. This paper presents both techniques and discusses the details, advantage of the feedback implementation with a new fast feedback loop that guaranties the dead-time compensation and the overall stability. Experimental results are presented showing the effectiveness of the proposed technique[12] the analysis and the application of a current controller in an active power filter (APF) based on a PWM voltage-source electronic converter with three legs and four wires. The neutral wire is connected to the middle point of the DC-capacitor voltage. The controller proposed here is an extension of the one proposed for a three-wire Shunt Active Power Filter. The controller is a two-level nested controller. The outer loop generates the reference current for the inner-loop. The latter, is a state-feedback current controller with integral action. The former consists of (i) a selective harmonic elimination technique and (ii) a DC capacitor-voltage controller. This paper will focus on the neutral-wire current control and on the balance control of the DC-capacitor voltage. The performance of the control algorithm has been demonstrated using a test-rig with balanced and non-balanced non-linear loads.[13]

In recent years, the increase of non-linear loads in electrical power system has sparked the research in power,quality issue. The shunt active power filter (SAPF) is a power electronic device which has been developed to improve power quality. The current control of shunt power filters is critical since poor control can reinforce existing harmonic problems. Various control strategies have been proposed by many researchers. In this paper, a comparative evaluation of the performance of two current control techniques, resonant and predictive controller, is presented with identical system specification. The design procedure and principle of both current control methods are also presented in detail. Simulation results show the comparison of transient response, steady state control and performance in the presence of variation of supply impedance between two control techniques.[14]

II. CONCLUSION

The power electronic equipment lead to an increasing harmonic contamination in power transmission or distribution systems. Review of Many researchers from the field of the power systems and automation have searched for different approaches to solve the problem. One way was open by introducing the harmonic compensation by using Shunt active filters. In this thesis we explain harmonics of power system, inverter circuit and shunt active filter for the three-phase circuit is simulated and the THD measured verifies the reduction of harmonics based shunt active filter. The Shunt AF is able to compensate balanced and unbalanced nonlinear load currents of a four-wire system with the neutral wire connected to the capacitor midpoint.

REFERENCES

[1] Hideaki Fujitaand Hirofumi Akagi, "The Unified Power Quality *Conditioner*: The Integration of Series- and Shunt-Active Filters," *IEEE Transaction on Power Electronics*, vol.13, pp . 315-322 , 1998.

[2] Antonio Abellan, Gabriel Garcera, Jose M. Benavent, " A New Control Method for Obtaining Reference Currents of Shunt Active Power Filters in Unbalanced and Non Sinusoidal Conditions," *IEEE ISIE'99 - Bled, Slovenia*,pp.831-836,1999.

[3] S. J. CHIANG and J. M. CHANG National Lien Ho Institute of Technology Taiwan, "Parallel Operation of Shunt Active Power Filters with Capacity Limitation Control,"*IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS*,VOL. 37, NO. 4, pp.1312-1320,2001.

[4] Victor Ciirdenas, Luis Moriin, Arturo Bahamonded, Juan Dion, "Comparative Analysis of Real Time Reference Generation Techniques for Four-Wire Shunt Active Power Filters,"*IEEE*, pp.791-796,2003.

[5] Wang Jianze, PengFenghua, Wu Qitao, JiYanchao, Member, and Yaping Du, " A Novel Control Method for Shunt Active Power Filters Using SVPWM," *IAS*,IEEE, pp.129-134, 2004

[6] Hongyu Li, Fang Zhuo, LonghuiWu,Wanjun Lei, Jinjun Liu, Zhaoan Wang, " A Novel Current Detection Algorithm for Shunt Active Power Filters in Harmonic Elimination, Reactive Power Compensation and Three-phase Balancing, " *IEEE Power Electronics Specinlisrs Conference* ,pp.1017-1023,2004.

[7] TingQian, Brad Lehman, Anindita Bhattacharya, Herb Ginn, Marshall Molen, "Parallel Operation of Shunt Active Power Filters for Damping of Harmonic Propagation in Electric Shipboard Power Systems," *IEEE Electric Ship Technologies Symposium*, pp. 248-254,2005.

[8] Abdelaziz Zouidi , Farhat Fnaiechand Kamal AL-Haddad, "Voltage source Inverter Based three-phase shunt active Power Filter: Topology, Modeling and Control Strategies," *IEEE ISIE , Montreal, Quebec, Canada*, PP.785-790,2006.

[9] Konstantin Borisov, Herbert L. Ginn III and Andrzej M. Trzynadlowski, "Attenuation of Electromagnetic Interference in a Shunt Active Power Filter, *IEEE TRANSACTIONS ON POWER ELECTRONICS*,VOL. 22, NO 5, pp.1912-1918, SEPTEMBER 2007.

[10] Rafael Cardosoand Joao Marcos Kanieski and Humberto Pinheiroand Hilton Abılio Grundling, "Reference Generation for Shunt Active Power Filters Based on Optimum Filtering Theory" *IEEE* , pp. 1621-1627, 2007.

[11] A. Koochaki ,S.H. Fathi, and M.Divandari, "Single Phase Application of Space Vector Pulse Width Modulation for Shunt Active Power Filters,"*IEEE*, pp. 611-616, 2007.

[12] Carlos Henrique da Silva1, Rondineli R. Pereira1, Luiz Eduardo Borges da Silva1, GermanoLambert-TorresJoao Onofre Pereira Pinto, and Se Un Ahn, "Dead-Time Compensation in Shunt Active Power Filters Using Fast Feedback Loop," *IEEE* ,2008.

[13] P. García-González, A. García-Cerrada and O. Pinzón-Ardila, "Control of a shunt active power filter based on a three-leg four-wire electronic converter,"*COMPATIBILITY AND POWER ELECTRONICS CPE2009 6TH INTERNATIONAL CONFERENCE-WORKSHOP*, pp.292-297, 2009.

[14] WanchakLenwari and MilijanaOdavic, "A Comparative Study of Two High Performance Current Control Techniques for Three-Phase Shunt Active Power Filters," *PEDS*, pp.962-966, 2009.

[15] A. Dell'Aquila, G. Delvino, M. Liserre, P. Zanchetta, A new fuzzy logic strategy for active power filter, in: Proc. Eighth Int. Conf. on Power Electronics and Variable Speed Drives, September 2000, pp. 392–397 (IEEConf. Publ. No. 475).

[16] S. Fan, Y.Wang, Fuzzy model predictive control for active power filter, in:Proc. IEEE Int. Conf. on Electric Utility Deregulation, Restructuring and Power Technologies (DRPT 2004), vol. 1, April 2004, pp. 295–300.

[17] S.K. Jain, P. Agrawal, H.O. Gupta, Fuzzy logic controlled shunt active power filter for power quality improvement, IEE Proc. Electr. Power Appl.149 (September (5)) (2002) 317–328.

[18] D. Chen, S. Xie, Review of the control strategies applied to active power filters, in: Proc. IEEE Int. Conf. on Electric Utility Deregulation, Restructuring and Power Technologies (DRPT-2004), Hong Kong, April, 2004,pp. 666–670.

[19] A.M. Massoud, S.J. Finney, B.W.Williams, Practical issues of three-phase, three-wire, voltage source inverter-based shunt active power filters, in: Proc.11th Int. Conf. on Harmonics and Quality of Power, 2004, pp. 436–441.

[20] R.M. Duke, S.D. Round, The steady state performance of a controlledcurrent active, IEEE Trans. Power Electr. 8 (April (3)) (1993) 140–146.

[21] K. Chatterjee, B.G. Fernandes, G.K. Dubey, An instantaneous reactive voltam perecompensator and harmonic suppressor system, IEEE Trans. Power Electr. 14 (March (2)) (1999) 381–392.

[22] B. Singh, A. Chandra, K. Al-Haddad, Computer aided modeling and simulationof active power filters, Electr. Mach. Power Syst. 27 (11) (1999)1227–1241.

[23] S.-J. Huang, J.-C. Wu, A control algorithm for three-phase three wiredactive power filter under non-ideal mains voltages, IEEE Trans. Power Electr. 14 (July (4)) (1999) 753–760.