A SINGLE-PHASE HYBRID ACTIVE POWER FILTERING USING MULTILEVEL INVERTER TOPOLOGY

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ABSTRACT

In recent years, power electronics equipments have been widely used in industry. These types of load create an intolerable power quality issues which is harmonic distortion at the main power. In order to overcome this problem, active power filtering with various topologies has been presented in previous studies. This project proposes a single-phase hybrid active power filtering using multilevel inverter topology. The proposed topology interconnects the passive filter with active power filter through point of common coupling (PCC). The topology chosen for active power filtering is the modular structured multilevel inverter which offers wide range of advantages over basic configuration of active power filter. The hybrid topology also provides advantages over non-hybrid active filter which is able to compensate both higher and lower order of harmonics. This project also proposes a nonlinear control scheme which is unified constant-frequency integration. This control scheme is able to avoid the complex calculation of current reference that is often used in most proposed hysteresis current control. Its simpler configuration utilizes one-cycle control theory which integrates the input voltage cycle-by-cycle which results in more precise current compensation. This report describes the high-pass filter design, multilevel inverter circuit topology and its control scheme. The system is verified using MATLAB/Simulink simulation package that offers wide range of application in power system. Comparison analysis shows the performance evaluation of each compensation circuit from basic H-bridge inverter circuit to non-hybrid multilevel inverter circuit and lastly the proposed hybrid configuration. Simulation results shows that the total harmonic distortion of the source current have been reduce abruptly from 124.54% to 6.61% after compensation using the proposed hybrid configuration.

ABSTRAK

Sejak kebelakangan ini, peralatan elektronik tenaga telah digunakan dengan meluas dalam industri. Ia telah mewujudkan isu kualiti tenaga iaitu distorsi harmonik pada kuasa utama. Untuk mengatasi masalah ini, penapisan kuasa aktif dengan pelbagai topologi telah banyak disampaikan dalam beberapa kajian sebelumnya. Projek ini mencadangkan penapisan fasa-tunggal penapisan kuasa aktif hibrid menggunakan topologi penyongsang pelbagai aras. Topologi yang dicadangkan ini menyambungkan penapis pasif dengan penapis kuasa aktif melalui titik gandingan sepunya (TGS). Topologi yang dipilih untuk penapisan kuasa aktif ialah penyongsang pelbagai aras struktur bermodul (PPASB) yang menawarkan pelbagai kelebihan-kelebihan atas konfigurasi asas turas kuasa aktif. Berbanding penapis kuasa tidak-hibrid, topologi ini juga menawarkan kelebihan yang mana mampu memampas kedua-dua jenis harmonik iaitu dalam harmonik pada tahap frekuensi rendah dan juga pada tahap frekuensi tinggi. Projek ini juga mencadangkan satu skim kawalan tidak linear iaitu pengamilan disatukan berfrekuensi tetap (PDBT). Skim kawalan ini mampu mengelak pengiraan kompleks arus rujukan yang sering kali digunakan dalam paling kaedah histeresis. Konfigurasinya yang lebih mudah menggunakan teori kawalan satu-kitaran yang mengintegrasikan satu persatu kitaran voltan masukan yang mengakibatkan pampasan arus yang lebih tepat. Laporan ini menerangkan tentang reka bentuk penapis pasif, topologi litar penyongsang pelbagai aras berserta sistem kawalannya. Sistem ini disimulasi menggunakan pakej MATLAB/Simulink yang menawarkan pelbagai aplikasi dalam sistem kuasa. Analisis perbandingan menunjukkan penilaian pampasan bagi setiap litar bermula dari litar asas penyongsang *H-bridge*, litar penyongsang pelbagai aras sehinggalah kepada litar yang diusulkan iaitu konfigurasi hybrid bagi penapis kuasa aktif. Keputusan simulasi menunjukkan bahawa yang distorsi harmonik berjumlah bagi arus utama telah Berjaya dikurangkan dari 124.54% kepada 6.40% selepas menggunakan konfigurasi hibrid yang diusulkan.

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LIST OF SYMBOLS

C	-	Capacitor
C_d	-	DC smoothing capacitor
C_f	-	DC-bus capacitor
C_{hp}	-	High-pass filter capacitor
f_0	-	Resonant frequency of passive filter
i_{Cf}	-	Amplitude of DC-bus capacitor charging current
i_f	-	Compensation current
I_h	-	Harmonic current
i_{hp}	-	High-pass filter current
i_L	-	Load current
I_n	-	Current at n^{th} harmonic component
i_S	-	Source current
i_{sw}	-	Switching ripple of the compensation current
L_S	-	Source inductor
L_{Smooth}	-	AC smoothing inductor
R	-	Resistor
R_{hp}	-	High-pass filter resistor
R_L	-	Load resistor
R_{f1}	-	Active filter resistor 1
R_{f2}	-	Active filter resistor 2

T_s	-	Sampling period
T_{sw}	-	Switching ripple period
V_{Cf}	-	DC-bus voltage
V_f	-	Compensation voltage
v_s	-	Source voltage
V_{rms}	-	RMS value of source voltage
ω_0	-	Series resonant frequency of $Z_{hp}(s)$
ω_p	-	Pole frequency of $Z_{hp}(s)$
$Z_{hp}(s)$	-	High-pass filter impedance transfer function
Z_s	-	Source impedance
ΔI_L	-	Peak RMS value of reactive and harmonic load current
$\Delta I_{sw,p-p}$	-	Peak-to-peak switching ripple
ΔV_{Cf}	-	Maximum/minimum DC-bus capacitor voltage

LIST OF ABBREVIATIONS

AC	-	Alternating Current
APF	-	Active Power Filter
DC	-	Direct Current
FFT	-	Fast Fourier Transform
HPF	-	High-pass Filter
MLI	-	Multilevel Inverter
MSMI	-	Modular Structure Multilevel Inverter
PCC	-	Point of Common Coupling
PWM	-	Pulse Width Modulation
RMS	-	Root-Mean-Square
THD	-	Total Harmonic Distortion
VSI	-	Voltage Source Inverter

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CHAPTER 1

INTRODUCTION

1.1 Background Study

In recent years, there has been an increasing use of power electronics components in daily life which help people to improve their life quality whether in office or at home. Unfortunately, these power electronic components create a power quality issue that is harmonic distortions of the source current. Nonlinear loads such as electronic power supplies, fluorescent lamps, switching power supplies, electric furnace, high-voltage DC systems, adjustable speed drives and AC/DC converters or inverters are the primary source of these harmonic currents [1], [2]. The harmonic currents from the nonlinear loads flow from the load towards the power source through the least impedance path. The harmonic current cause additional heating in the power system components which in return cause voltage distortion and may excite resonance or cause unwanted interactions in the power system [3]. In addition, harmonic distortion also reduce system power factor. The harmonic distortion power factor cannot be compensated by simply adding power factor correction capacitors.

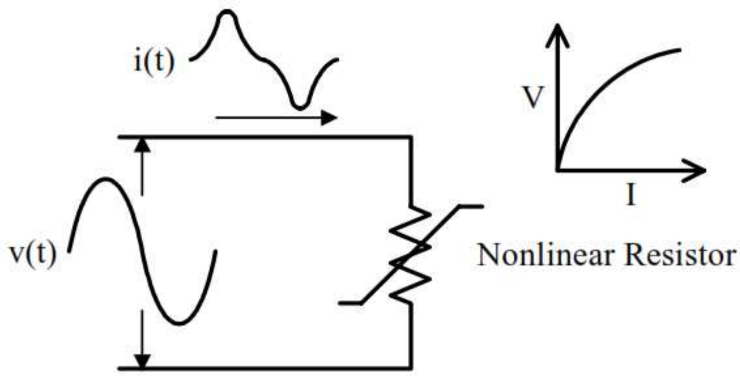

Figure 1.1 Current distortion caused by nonlinear resistance

Fig. 1.1 shows the current distortion concept. The illustration shows that the voltage source supplied sinusoidal voltage to the nonlinear resistor where the current and voltage vary according to the curve shown above. However, the resulting current is distorted instead of following the source sinusoidal wave. These distorted harmonic currents have a number of undesirable effects on the distribution system. It increased the resistive losses and voltage stresses. In addition, this harmonic current can interact adversely with power system equipment such as capacitors, transformers and motors which lead to additional losses, overheating and overloading. It can also cause interferences with telecommunication lines and errors in metering devices [4],[5].

Due to the adverse effects of harmonics current distortion in power quality, several techniques have been developed for harmonics control. It is necessary to treat harmonics in order to optimize the power quality in buildings or facilities. Harmonic treatment can be performed by two methods either by filtering or cancellation. A harmonic filter basically consists of a capacitor bank and an induction coil. The filter is designed or tuned to the predetermined non-linear load and to filter a predetermined harmonic frequency range. Usually this frequency range only accounts for one harmonic frequency [3]. The harmonic mitigation can be done by using passive or active filters. A more advance approach involves the combination of active and passive filters in order to eliminate both lower and higher order harmonics.

Passive filters consist of passive elements such as inductors, resistors and capacitors. The simple circuit makes it easier to design for harmonic filtering. However, passive filters have several drawbacks such as larger size and weight, higher cost of production, fixed compensation and resonance problems [1]. These have led to the increase use of active filters in harmonics treatment.

Active Power Filter (APF) technology is rapidly growing in the market now. APF is a viable and effective solution to compensate current harmonics and reactive power in power distribution systems. Its capability to improve power quality in wide range of frequency and voltage requirements has made it popular in the industry. APF consist of active elements such as operational amplifiers, IGBT, MOSFET, transistors, and other type of switches. Compared to the passive filter, APFs are known to be able to adapt concurrently to changing loads and can be expanded easily while not affecting the neighborhood. Generally, the APFs are smaller in size and cost effective compared to passive filters.

There are three types of active power filter which are shunt APF, series APF and hybrid APF which is the combination of active filter with passive filter. This project is focusing on the application of APF in treating the harmonics distortion in power system by determining low Total Harmonics Distortion (THD) value and improving the system's power factor.

1.2 Problem Statement

The poor quality of voltage and current of a conventional inverter is due to the presence of harmonics and significant level of energy losses. The inverters with a large number of steps can generate high quality voltage waveforms and reduce the harmonics. An active harmonic elimination method can be applied to eliminate any number of specific higher order harmonics of multilevel converters with unequal dc voltages. However, this may leave the lower order harmonics to remain in the system. The implementation of passive filter will increase the system capability to eliminate both lower and higher order of harmonics and thus, increase the power quality. The combination of active and passive filter is called Hybrid Active Power Filter. As for the APF control scheme, most existing scheme requires fast and precise calculation of the current and voltage references. A simpler control scheme is developed to overcome this problem and reduce the complexity of the circuit which is UCI control scheme.

1.3 Objectives of Research

The objectives that should be accomplished at the end of this project are:

i. To understand on the multilevel inverter as an APF and its application
ii. To design a hybrid Multilevel Inverter (MLI) by integrating aModular Structured Multilevel Inverter (MSMI) topology with passive filter.
iii. To design a control scheme for APF which is Unified Constant Frequency Integration (UCFI) control scheme.
iv. To simulate the system, verify its performance and compare with conventional non-hybrid APF method
v. To analyze the harmonic spectrum of the system and achieve low total harmonic distortion.

1.4 Scope of Project

Study in active power filtering using MLI which focus more on the proposed MSMI topology. The proposed hybrid configuration requires the design and tuning of passive filter which in this case is 2^{nd} order high pass filter. Thorough research through books and journals is done to get a system that can give optimum output with minimum losses and THD. The system is chosen, designed, constructed and simulated using Matlabsimulink. The output is then compared with the conventional non-hybrid system's output.

1.5 Methodology of Research

In analyzing the research, a harmonic spectrum analysis of the source current distortion is carried out. It features a nonlinear full-bridge diode rectifier RC load with DC smoothing capacitor as the harmonic current source. The MATLAB/Simulink simulation package is utilized to perform the analysis using time domain. Afterwards, an extensive simulation involving basic H-bridge APF, multilevel inverter and hybrid multilevel inverter configuration is performed to obtain the comparison of each compensation circuit. In the meantime, the UCI controller is integrated with the APFs configuration. Each harmonic spectrum is analyzed and listed in a table to compare the performance of each circuit. A conclusion is then made accordingly.

1.6 Thesis Organization

This thesis consists of this introductory chapter and five other chapters arranged as follows:

Chapter 2 consists of literature review on harmonics, passive filtering, active power filtering and multilevel inverter. Theadvantages and advantages of APFs configuration is studied and the integration of passive filter and multilevel inverter as a hybrid APF is revised. The proposed control technique for APF which is UCI control scheme that utilizes one-cycle control theory is also explained in this chapter.

Chapter 3 is the methodology part where the development phase of the project is described. The proposed circuitry is also included and its operating principle is described in detail.

Chapter 4 describes the configuration of the proposed system in MATLAB/Simulink. The calculation of several important components of the circuit is also included.

Chapter 5 shows the results and analysis of the systems performances. The waveforms for the proposed circuitry obtained from the simulation is discussed and compared with conventional APF results.

Chapter 6 provides conclusion for all the results and analysis of the project. Recommendation for future works is also included in this chapter.

REFERENCES

[1] P. Martins "The Use of an Active Power Filter for Harmonic Elimination and Power Quality Improvement in a Nonlinear Loaded Electrical Installation" *Proceedings of the International Conference on Renewable Energies and Power Quality,* pp. 1-6, 2003

[2] A. M. Mohammed, "Analysis and Simulation of Shunt Active Power Filter for Harmonic Cancellation of Nonlinear Loads", *Engineering and Technical Journal,* Vol. 28, No. 16, 2010

[3] Z. Salam, T.P. Cheng and A. Jusoh, "Harmonics Mitigation Using Active Power Filter: A Technological Review", *ELEKTRIKA,* Vol. 8, No. 2, pp. 17-26, 2006

[4] K. Hur and S. Santoso, " Analysis and Modeling of Dynamic Overvoltage Phenomena Due to Overvoltage Energizing" *Power Engineering Society General Meeting,* Vol. 2, pp. 1126 – 1130, June 2005

[5] N. Gupta, S.P Singh and S.P Dubey, "Neural Network Based Shunt Active Filter For Harmonic and Reactive Power Compensation Under Non-ideal Mains Voltage", *The 5th IEEE Conference on Industrial Electronics and Applications (ICIEA),* pp. 370-375, June 2010

[6] L. A. Moran, J.W. Dixon, J.R. Espinoza, R.R. Wallace, "Using Active Power Filters to Improve Power Quality", *5thBrasilian Power Electronics Conference (COBEP '99),* 1999

[7] “-“, ”Power Quality Analysis”, *ECS International Inc.,* Jan 2010

[8] T. Wood, “Frequency Variations Measurement Techniques in Power Quality Monitoring”, May 2008

[9] D. Chapman, “Introduction to Power Quality”, *Copper Development Association,* Nov. 2001

[10] Akagi, “New Trends in Active Filters for Power Conditioning,” *IEEE Trans. on Industry Applications*, vol. 32, no. 6, pp. 1312-1322, 1996.

[11] W. E. Kazibwe and M. H. Sendaula. *Electric Power Quality Control Techniques*, Van Nostrand Reinhold, 1993, New York, USA

[12] J. C. W. Lam and P.K. Jain, “A High-Power-Factor Single Stage Single-Switch Electronics Ballast for Compact Fluorescent Lamps”, *IEEE Transactions on Power Electronics,* Vol. 25, No. 8, pp. 2045-2058, August 2010

[13] “-“, “Power System Harmonics: Causes and Effects of Variable Frequency Drives Relative to the IEEE 519-1992 Standard”, *Square D, Product Data Bulletin, Raleigh, NC, U.S.A,* No. 8803PD9402, August 1994

[14] P.C. Tan, Z. Salam and A. Jusoh, “A Single-Phase Hybrid Active Power Filter Using Extension p-q Theorem for Photovoltaic Application”, *International Conference on Power Electronics and Drive Systems (PED 2005),* pp. 1250-1255, 2005

[15] A. Emadi, A. N. Nasiri and S. B. Bekiarov, “Uninterruptible Power Supplies and Active Filters” *CRC Press 2005,* pp. 63-115

[16] S. Thota, “Harmonic Filters Overview – Part One”, *Frost & Sullivan,* April 2003

[17] G. Tsengenes and G. Adamidis, “An Improved Current Control Technique For an Investigation of a Power System with a Shunt Active Filter”, *International Symposium on Power Electronics Electrical Drives Automation and Motion (SPEEDAM),* pp. 239-244, June 2010

[18] M. Routimo, M. Salo and H. Tuusa, “A Novel Control Method for Wideband Harmonic Compensation,” *Proceedings of the IEEEInternational Conference on Power Electronics and Drive Systems (PEDS)*, pp. 799-804, 2003

[19] R. C. Dugan, M. F. McGranaghan, S. Santoso and H. W. Beaty, *Electrical Power Systems Quality* 2nd. Edition, McGraw-Hill, 2002, USA.

[20] W. M. Grady and S. Santoso, “Understanding Power System Harmonics,” *IEEE Power Engineering Review*, vol. 21, no. 11, pp. 8-11, 2001.

[21] Institute of Electrical and Electronics Engineers, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, IEEE Standard 519, 1993, USA.

[22] D. A. Gonzalez and J. C. McCall, “Design of Filters to Reduce Harmonic Distortion in Industrial Power Systems,” *IEEE Trans. on Industry Applications*, vol. PCC IA-23,pp. 504-512, 1987.]

[23] A. Ludbrook, “Harmonic Filters for Notch Reduction,” *IEEE Trans. on Industry Applications*, vol. 24, pp. 947-954, 1988.

[24] J. K. Phipps, “A Transfer Function Approach to Harmonic Filter Design,” *IEEE Industry Applications Magazine*, vol. 3, no. 2, pp. 68-82, 1997

[25] J. C. Das, “Passive Filters – Potentialities and Limitations,” *IEEE Trans. on Industry Applications*, vol. 40, no. 1, pp. 232-241, 2004

[26] M. Kesler and E. Ozdemir, “Simplified Control Method for Unified Power Quality Conditioner (UPQC)”, *International Conference on Renewable Energies and Power Quality (ICREPQ’09), Spain,* April 2009

[27] W. M. Grady, M. J. Samotyj, and A. H. Noyola, “Survey of Active Power Line Conditioning Methodologies,” *IEEE Trans. Power Delivery*, vol. 5, pp. 1536–1542, July 1990.

[28] G. Sandoval and J. Houdek, “A Review of Harmonic Mitigation Techniques”, 2005

[29] M. Hacil, A. Khezzar, A.L. Nemmour and L. Louze, “Harmonic Current Cancellation and Control of a Grid-Connected Synchronous Generator Entrained by a Wind Turbine”, *Review of Renewable Energy,* Vol. 12, pp. 405-418, 2009

[30] J.K. Steike, “Use of an LC Filter to Achieve a Motor-friendly Performance of the PWM Voltage Source Inverter”, *IEEE Transactions on Energy Conversion*, Vol. 14, N°3, September 1999

[31] M.A. Chaudhari and H.M. Suryawanshi, ‘High-Power-Factor Operation of Three-Phase AC-to-DC Resonant Converter’, *IEEE Proceedings on-Line*, 2005

[32] B. Singh, K. Al-Haddad and A. Chandra, “A Review of Active Filters for Power Quality Improvement”, *IEEE Trans. On Industrial Electronics,* Vol. 46, No. 5, pp. 219-224, 1996

[33] M. Ehsani and K. R. Ramani, “ Recent Advances in Power Electronics and Application”, *Southcon Conference Record,* pp. 8-13, March 1994

[34] P. Karuppana and K. K. Mahapatra, “PLL with Fuzzy Logic Controller Based Shunt

[35] Active Power Filter For Harmonic and Reactive Power Compensation”, *International Conference on Power Electronics (IICPE),* pp. 1-6, Jan. 2011

[36] P. Wei, H. Chen and D. Chen, “Harmonic Suppression and Reactive Power Compensation of Shunt Active Power Filter”, *Third International Conference on Intelligent Information Technology Application (IITA),* pp. 386-390, Nov. 2009

[37] M. Kale and E. Ozdemir, “Harmonic and Reactive Power Compensation With Shunt Active Power Filter Under Non-Ideal Mains Voltage”, *Electrics Power Systems Research,* Vol. 74, No. 3, pp. 363-370, June 2005

[38] H. Fujita, “A Single-Phase Active Filter Using an H-Bridge PWM Converter with a Sampling Frequency Quadruple of the Switching Frequency”, *IEEE Power Electronics Specialists Conference,* pp. 2882-2888, June 2008

[39] S. Sladic, B. Barisic and N. Ungureanu, “Adoption of Active Power H-Bridge Filter to Vibration Compensator for Machining Processes”, *II Journal Manufacturing Engineering,* pp. 80-86, 2008

[40] L. P. Yi and N. A. Azli, “Comparison of Inverters’ Performance as Active Power Filters With Unified Constant-Frequency Integration Control”, *Journal of Technology,* pp. 121-134, June 2007

[41] O.S. Senturk, S. Munk-Nielsen, R. Teodorescu, L. Helle and P. Rodriguez, “A Single Leg Switched PWM Method for Three-Phase H-Bridge Voltage Sourve Converters” *IEEE Energy Conversion Congress and Exposition,* pp. 3137-3142, Sept 2009

[42] J. Doucet, D. Eggleston and J. Shaw “DC/AC Pure Sine Wave Inverter” 2007

[43] C. Ridrigues and A.R. Silva, “A Bipolar DC Power Supply Using Full-Bridge Topology as Active Shunt for Magnets”, *Brazilian Power Electronics Conference*, pp. 693-697, 2009

[44] S. Zabihi and F. Zare, “Active Power Filters with Unipolar Pulse Width Modulation to Reduce Switching Losses”, *International Conference on Power System Technology,* pp. 1, Oct. 2006

[45] M. D. Manjrekar, P. K. Steimer and T. A. Lipo, “Hybrid Multilevel Power Conversion System: A Competitive Solution for High-Power Applications”, *IEEE Transactions on Industry Applications,* Vol. 36, No. 3, June 2000

[46] “-“, “Design and Implementation of a Pulse-Width Modulation (PWM) For modular Structured Multilevel Inverter” Nov. 2005

[47] P. Karuppanan and K.K. Mahapatra, “Cascaded Multilevel Inverter based Active Filter for Power Line Conditioners using Instantaneous Real-Power Theory” *IEEE-IICPE 2010 Indian International Conference on Power Electronics, NIST-New Delhi,* Jan. 2011

[48] R. Gupta, A. Ghosh and A. Joshi, “ Switching Characterization of Cascaded Multilevel-Inverter-Controlled Systems” *IEEE Trans on Industry Electronics,* Vol. 55, No. 3, pp. 1047-1058, March 2008

[49] M. Malinowkski, K. Gopakumar, J. Rodriguez and M. A. Perez, “A Survey on Cascaded Multilevel Inverters” *IEEE Trans on Industrial Electronic,* Vol. 57, No. 7, pp. 2197-2205, July 2010

[50] R.A. Ahmed, S. Mekhilef and H.W. Ping, “New Multilevel Inverter Topology with Reduced Number of Switches”, *Proceedings of the 14th International Middle East Power Systems Conference (MEPCON),* pp. 565-570, Dec. 2010

[51] K. Corzine, Y.A. Familiant, “New Cascaded Multilevel H-bridge Drive”, *IEEE Transactions on Power Electronics*, Vol. 17, No. 1, pp. 125-131, Jan. 2002

[52] M. Fracchia, T. Ghiara, M. Marchesoni, and M. Mazzucchelli, “Optimized modulation techniques for the generalized N-level converter,” *Proc. IEEE Power Electron. Spec. Conf., Madrid, Spain,* pp. 1205–1213, 1992

[53] K. A. Corzine and S. D. Sudhoff, “High state count power converters: An alternate direction in power electronics technology,” *SAE Trans., J. Aerosp*., pp. 124–135, 1998.

[54] K. A. Corzine and S. K. Majeethia, “Analysis of a novel four-level DC/DC boost converter,” *IEEE Trans. Ind. Applicat*., vol. 36, pp. 1342–1350, Sept./Oct. 2000.

[55] K. A. Corzine, S. D. Sudhoff, E. A. Lewis, D. H. Schmucker, R. A. Youngs, and H. J. Hegner, “Use of multilevel converters in ship propulsion drives,” in Proc. All Electric Ship Conf., London, U.K., Sept. 1998, pp. 155–163.

[56] M. El-Habrouk, M. K. Darwish and P. Mehta, “Active Power Filters: A Review,” *Proc. IEE Electric Power Applications*, vol. 147, no. 5, pp. 403-413, 2000

[57] S. Buso, L. Malesani, P. Mattavelli and R. Veronese, “Design and Fully Digital Control of Parallel Active Power Filters for Thyristor Rectifiers to Comply with IEC-1000-3-2 Standards,” *IEEE Trans. on Industry Applications*, vol. 34, no. 3, pp. 508-517, 1998.

[58] P. Jintakosonwit, H. Fujita and H. Akagi, “Control and Performance of a Fully-Digital-Controlled Shunt Active Filter for Installation on Power Distribution System,” *IEEE Trans. on Power Electronics*, vol. 17, no. 1, pp. 132-140, 2002.

[59] S. Fukuda and T. Endoh, “Control Method for a Combined Active Filter System Employing a Current Source Converter and a High Pass Filter,” *IEEE Trans. on Industry Applications*, vol. 31, no. 3, pp. 590-597, 1995.

[60] Y.H.Kim, S.H. Kim, K.H. Lee, "A New Hybrid Power Filter Using Multi-Level Inverters", *The 4th International Power Electronics and Motion Control Conference,* Vol.1, pp. 210-214, 14-16 Aug. 2004

[61] S. Khositkasame and S. Sangwongwanich, "Design of Harmonic Current Detector and Stability Analysis of a Hybrid Parallel Active Filter," *Proceedings of the Power Conversion Conference (PCC),* Nagaoka, Japan, 1997 pp. 181-186.

[62] K.M. Smedley, L. Zhou, C. Qiao, "Unified Constant-Frequency Integration Control of Active Power Filters", *IEEE Transactions On Power Electronics,* Vol. 8, No. 3, pp. 428-436, May 2001

[63] M. Ruzbehani, L. Zhou and N. Mirzaei, "Improvement of One-cycle Controller Response with a Current Mode Controller" *Journal of Power Electronics,* Vol. 10, No. 1, Jan. 2010

[64] K. M. Smedley and S. Cuk, "One-cycle control of switching converters," *IEEE Transactions on Power Electronics,* pp. 625-633, 1995

[65] R. brown and M. Soldano, "PFC Converter Design with IR1150 One Cycle Control IC" *International Rectifier Application Note*, AN-1077