SHUNT ACTIVE POWER FILTER OPERATING WITH A MULTI-VARIABLE FILTER AND NEW REFERENCE CURRENT GENERATION FOR HARMONICS AND REACTIVE POWER COMPENSATION

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This project report is dedicated to my family for their endless support and encouragement particularly to my lovely Mum, Amina M. Mohamed and my late father, M. Dahir Haji Aweys.

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ABSTRACT

A brief overview of sources of harmonic distortion and their impact on electrical power distribution system is described in this thesis. The operation of common harmonic mitigation schemes namely passive power filters and shunt active power filter are presented and analysed. A new reference current generation scheme based on instantaneous Reactive power theory suitable for three-phase shunt active power filter control circuit under balanced and unbalanced load condition is developed. The developed control circuit is based on the Multi-Variable Filter (MVF) which is used to remove the harmonic components of the load current (Harmonic) and gives the fundamental part. The effectiveness of the proposed scheme is mathematically calculated and verified by MATLAB/Simulink simulation.

ABSTRAK

Satu gambaran ringkas mengenai sumber herotan harmonik dan kesannya terhadap sistem pengagihan kuasa electkik taleh dinyatakan di dalam tesis ini. Skim operasi yang biasa digunakan untuk mengurangkan harmonic iaitu penapis kuasa pasif dan penapis kuasa aktif pirau telah dibentangkan dan dianalisis. Skim arus janaan rujukan baru berdasarkan pada teori kuasa reaktif serta-merta yang sesuai untuk litar kawalan tiga fasa penapis kuasa aktif pirau di bawah keadaan beban yang seimbang dan tidak seimbang telah dibargunkan. Litar kawalan yang dibangunkan adalah berdasarkan pada Multi-variable Filter (MVF) yang digunakan untuk mengeluarkan komponen-komponen harmonik daripada arus beban dan memberikan arus asas. Keberkesanan skim yang taleh dicadangkan dikira menggunakan kiraan matemmatik dan disahkan menggunakan simulasi MATLAB/Simulink.

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LIST OF ABBREVIATIONS

SAPF	-	Shunt Active Power Filter
IRPT	-	Instantaneous Reactive Power Theory
SRF	-	Synchronous Reference Frame
PLL	-	Phase-Locked Loop
MVF	-	Multi-Variable Filters
IHD	-	Individual Harmonic Distortion
THD	-	Total Harmonic Distortion
TDD	-	Total Demand Distortion
HVDC	-	High Voltage Direct Current
PCC	-	Point of Common Coupling
IGBT	-	Insulated Gate Bipolar Transistor
APF	-	Active Power Filter
VSI	-	Voltage Source Inverter
CSI	-	Current Source Inverter
HPFs	-	High Pass Filters
LPFs	-	Low Pass Filters
HB	-	Hysteresis Band
TNB	-	Tenaga Nasional Berhad

LIST OF SYMBOLS

Ω	-	Ohm
mH	-	Millie Hennery
ηF	-	Micro Farad
s	-	Second
ω	-	Angular Frequency

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Power system harmonics becomes a topic of concern due to the advent of power electronics and breed of non-linear loads in residential, commercial and industrial power applications. The usage of non-linear loads on electrical power systems increases rapidly causing greater distortion for current wave form even though the supply voltage is sinusoidal which can increase the operating temperature of the equipment, increase the power losses and reduce the life expectancy of the equipment and this can lead permanent damage to the electrical power equipment such as transformers and other sensitive electronic loads.

To limit these disturbances, effective harmonic compensation technique has become essential for the utilities and the consumer end. Various topologies of harmonic filtering such as passive filters (Single Turned and Double Turned) and active filter (Shunt and Series) have been presented in [1]. The passive filters are simplest scheme to reduce the harmonic currents. Conversely they have many weaknesses such as resonance with the source inductance, fixed compensation performance and bulk in size. However the Active filter can solve the problems of harmonic currents, reactive power and excessive neutral current simultaneously, besides due their small size, flexibility and superior filtering performance provides much better solution than conventional passive filter. The active filter performance essentially depends on the reference current generation scheme. Akagi[2] introduces Instantaneous Reactive Power theory for designing and control of the shunt active power filter for three-phase balanced system. Stephan and Arede [3] developed this theory by including when the power system is unbalanced (three-phase 4-wire system) assuming AC voltage condition sinusoidal. On the other hand if the main voltages are distorted the p-q theory performance is poor for controlling shunt active filter. However to improve the SAPF performance under distorted voltages new control schemes are proposed by [4, 5].

1.2 Motivation of the Project Work

The SAPF performance mostly depends on the reference current generation scheme. Under three-phase balanced loads, Instantaneous Reactive Power Theory (IRPT) and Synchronous Reference Frame (SRF) strategies offer similar filtering performances. Differences arise when worked under unbalanced condition. In this case IRPT performances are poor while the best results are obtained with SRF. However a phase-locked loop (PLL) for each phase must be used in SRF theory that makes the control system more complex. In addition IRPT control strategies conventionally use HPF for extracting the harmonic components of the voltage and the current signals. But this method is not satisfactory due to high error in phase and magnitude of the harmonics. These difficulties of IRPT can be overcome by adopting modified version of IRPT using Multi-Variable Filters (MVF) to extract DC components of voltage and current signals.

1.3 Objectives of the project

The objective of this study is as follows:

1. To demonstrate the concept of harmonics, investigate the sources and effect of harmonics.

2. To propose a improved version of instantaneous Reactive power theory using Multi-variable filter.
3. To Model and simulate SAPF using MATLAB/Simulink for the minimization of the harmonics and the compensation of reactive power generated by non-linear loads

1.4 Scope of the Work

This project investigates and analyzes the SAPF with digital reference current generation for harmonic mitigation and power factor correction in a three-phase four-wire power system that is feeding a non-linear load. The non-linear load is represented by a three-phase rectifier that is connected to a load of either a balanced or unbalanced. SAPF with Multi-variable filter, fixed reference current generation with hysteresis controller are proposed as part of its control system.

1.5 Methodology

The work has started with the discussion of project title, objective and scope followed by collecting the information for literature review and the time schedule arrangement. The simulation of shunt active filter is done using MATLAB/Simulink.

The time schedule is arranged based on the number of weeks for two semesters. For the first semester, the project has focused on understanding the literature review and run the initial simulation of shunt active filter. In the second semester, the work has continued with the simulation and to develop a new reference current generation that is applicable for controlling of SAPF by using MVF for the reference current generation and improved form of the conventional IRPT. Simulation results were analyzed and discussed. Finally, suggestions for further work and improvement were made.

1.6 Thesis Organization

Chapter 1: This chapter labels the introduction about sources, effects and harmonic filtering with their historical background. It also provides exploratory details about motivation of the work, project objectives, scope and methodology.

Chapter 2: A review of the topic literature in the previous researches is explained in this chapter that includes harmonic definitions, harmonic standards, sources and effects of harmonic in the power system. The conventional harmonic elimination approaches using PF are explained, and then the improved mitigation approaches using SAPF are presented. It followed by the reviewing different types of reference signal approximation methods. An overview of the control strategies for SAPF is finally presented.

Chapter 3: This chapter describes the modeling process of each subsystem and how the various components of the system will be connected to form the overall Modelling of SAPF.

Chapter 4: This chapter discusses the results that have been achieved from MATLAB/Simulink that includes results filtering of harmonic current; reactive power compensation and elimination of the neutral current.

Chapter 5: This chapter gives the conclusion of the whole work, and some additional work has been suggested for future development.

REFERENCES

[1] H. Akagi, "Modern active filters and traditional passive filters," *Bulletin of the Polish Academy of sciences, Technical sciences,* vol. 54, 2006.

[2] H. Akagi, Y. Kanazawa, and A. Nabae, "Instantaneous Reactive Power Compensators Comprising Switching Devices without Energy Storage Components," *Industry Applications, IEEE Transactions on,* vol. IA-20, pp. 625-630, 1984.

[3] M. Aredes, J. Hafner, and K. Heumann, "Three-phase four-wire shunt active filter control strategies," *Power Electronics, IEEE Transactions on,* vol. 12, pp. 311-318, 1997.

[4] Y. Komatsu and T. Kawabata, "A control method for the active power filter in unsymmetrical voltage systems," *International journal of electronics,* vol. 86, pp. 1249-1260, 1999.

[5] C.-C. Chen and Y.-Y. Hsu, "A novel approach to the design of a shunt active filter for an unbalanced three-phase four-wire system under nonsinusoidal conditions," *Power Delivery, IEEE Transactions on,* vol. 15, pp. 1258-1264, 2000.

[6] L. B. Neto, J. C. C. B. S. de Mello, E. G. Gomes ,and L. A. Meza, "Data Envelopment Analysis and Fourier Series Integrated Use: The Case of The Harmonic Distortion Evaluation," *Latin America Transactions, IEEE (Revista IEEE America Latina),* vol. 9, pp. 810-816, 2011.

[7] "IEEE Recommended Practice for Power System Analysis (IEEE Brown Book)," *ANSI/IEEE Std 399-1980,* pp. 1-223, 1980.

[8] "IEEE Recommended Practice for Establishing Transformer Capability When Supplying Non-sinusoidal Load Currents," *ANSI/IEEE Std C57.110-1986,* p. 0_1, 1988.

[9] G. W. Massey, "Estimation methods for power system harmonic effects on power distribution transformers," in *Rural Electric Power Conference, 1993. Papers Presented at the 37th Annual Conference*, 1993, pp. B4/1-B4/5.

[10] H. Fujita and H. Akagi, "A practical approach to harmonic compensation in power systems-series connection of passive and active filters," in *Industry Applications Society Annual Meeting, 1990., Conference Record of the 1990 IEEE,* 1990, pp. 1107-1112 vol.2.

[11] C. K. Duffey and R. P. Stratford, "Update of harmonic standard IEEE-519: IEEE recommended practices and requirements for harmonic control in electric power systems," *Industry Applications, IEEE Transactions on,* vol. 25, pp. 1025-1034, 1989.

[12] J. K. Phipps, J. P. Nelson, and P. K. Sen, "Power quality and harmonic distortion on distribution systems," *Industry Applications, IEEE Transactions on,* vol. 30, pp. 476-484, 1994.

[13] J. S. Subjak, Jr. and J. S. McQuilkin, "Harmonics-causes, effects, measurements, and analysis: an update," *Industry Applications, IEEE Transactions on,* vol. 26, pp. 1034-1042, 1990.

[14] H. Akagi, "Active Harmonic Filters," *Proceedings of the IEEE,* vol. 93, pp. 2128-2141, 2005.

[15] H. Fujita and H. Akagi, "A practical approach to harmonic compensation in power systems-series connection of passive and active filters," *Industry Applications, IEEE Transactions on*, vol. 27, pp. 1020-1025, 1991.

[16] J. Hurng-Liahng, W. Jinn-Chang, C. Yao-Jen, and F. Ya-Tsung, "A novel active power filter for harmonic suppression," *Power Delivery, IEEE Transactions on,* vol. 20, pp. 1507-1513, 2005.

[17] Z. Salam, P. C. Tan, and A. Jusoh, "Harmonics mitigation using active power filter: A technological review," *Elektrika,* vol. 8, pp. 17-26, 2006.

[18] U. Khruathep, S. Premrudeepreechacharn ,and Y. Kumsuwan, "Implementation of shunt active power filter using source voltage and source current detection," in *Industrial Electronics and Applications, 2008. ICIEA 2008. 3rd IEEE Conference on*, 2008, pp. 2346-2351.

[19] W. Jidong, "Simulation of Three-Phase Four-Wire Shunt Active Power Filter," in *Power and Energy Engineering Conference, 2009. APPEEC 2009. Asia-Pacific*, 2009, pp. 1-4.

[20] C. A. Quinn, N. Mohan, and H. Mehta, "A four-wire, current-controlled converter provides harmonic neutralization in three-phase, four-wire systems," in *Applied Power Electronics Conference and Exposition, 1993. APEC'93. Conference Proceedings 1993., Eighth Annual*, 1993, pp. 841-846.

[21] W. Diyun, C. Wang, and K. W. E. Cheng, "Design and performance of a shunt active power filter for three-phase four-wire system," in *Power Electronics Systems and Applications, 2009. PESA 2009. 3rd International Conference on*, 2009, pp. 1-4.

[22] M. Pakdel and H. Farzaneh-fard, "A Control Strategy for Load Balancing and Power Factor Correction in Three-Phase Four-Wire Systems Using a Shunt Active Power Filter," in *Industrial Technology, 2006. ICIT 2006. IEEE International Conference on*, 2006, pp. 579-584.

[23] M. K. Mishra and K. Karthikeyan, "A Study on Design and Dynamics of Voltage Source Inverter in Current Control Mode to Compensate Unbalanced and Non-linear Loads," in *Power Electronics, Drives and Energy Systems, 2006. PEDES '06. International Conference on*, 2006, pp. 1-8.

[24] L. A. Morán, J. W. Dixon, J. R. Espinoza, and R .R. Wallace, "Using active power filters to improve power quality," in *5th Brazilian Power Electronics Conference*, 1999, pp. 501-511.

[25] S. Chiang, W. Ai, and F. Lin, "Parallel operation of capacity-limited three-phase four-wire active power filters ",*IEE Proceedings-Electric Power Applications*, vol. 149, pp. 329-336, 2002.

[26] Z. Fang, Y. Jun, W. Zhaoan, and H. Junfei, "Active power filter for three-phase four-wire system," *JOURNAL-XIAN JIAOTONG UNIVERSITY*, vol. 34, pp. 87-90, 2000.

[27] J. C. M. Asquerino and P. S. Revuelta, "Strategies of instantaneous compensation for three-phase four-wire circuits," *Power Delivery, IEEE Transactions on,* vol. 17, pp. 1079-1084, 2002.

[28] Y. Komatsu and T. Kawabata, "Characteristics of three phase active power filter using extension pq theory," in *Industrial Electronics, 1997. ISIE'97., Proceedings of the IEEE International Symposium on,* 1997, pp. 302-307.

[29] L. P. Ling and N. A. Azli, "SVM based hysteresis current controller for a three phase active power filter," in *Power and Energy Conference, 2004. PECon 2004. Proceedings. National*, 2004, pp. 132-136.

[30] C. L. Chen, C. E. Lin, and C. Huang, "An active filter for unbalanced three-phase system using synchronous detection method," in *Power Electronics Specialists Conference, PESC'94 Record., 25th Annual IEEE*, 1994, pp. 1451-1455.

[31] B. Singh, K. Al-Haddad, and A. Chandra, "A new control approach to three-phase active filter for harmonics and reactive power compensation," *Power Systems, IEEE Transactions on* ,vol. 13, pp. 133-138, 1998.

[32] C. Donghua and X. Shaojun, "Review of the control strategies applied to active power filters," in *Electric Utility Deregulation, Restructuring and Power Technologies, 2004. (DRPT 2004). Proceedings of the 2004 IEEE International Conference on*, 2004, pp. 666-670 Vol.2.

[33] M. El-Habrouk, M. Darwish, and P. Mehta, "Active power filters: a review," *IEE Proceedings-Electric Power Applications,* vol. 147, pp. 403-413, 2000.

[34] W. M. Grady, M. J. Samotyj, and A. H. Noyola, "Survey of active power line conditioning methodologies," *Power Delivery, IEEE Transactions on*, vol. 5, pp. 1536-1542, 1990.

[35] S. Hong-Seok, P. Hyun-Gyu, and N. Kwanghee, "An instantaneous phase angle detection algorithm under unbalanced line voltage condition," in *Power Electronics Specialists Conference, 1999. PESC 99. 30th Annual IEEE*, 1999, pp. 533-537 vol.1.

[36] S. Hong-Seok and N. Kwanghee, "Dual current control scheme for PWM converter under unbalanced input voltage conditions," *Industrial Electronics, IEEE Transactions on*, vol. 46, pp. 953-959, 1999.

[37] E. Clarke, *Circuit Analysis of A-C Power system* vol. Vol 1, 1943.

[38] J. L. Afonso, M. J. S. Freitas, and J. S. Martins, "p-q Theory power components calculations," in *Industrial Electronics* .2003 ,*ISIE '03. 2003 IEEE International Symposium on,* 2003, pp. 385-390 vol. 1.