UNIVERSITI PUTRA MALAYSIA

SUPPRESSION OF TOTAL HARMONIC DISTORTION USING SINGLE PHASE SHUNT ACTIVE POWER FILTER WITH FUZZY LOGIC CONTROLLER

HAMISU USMAN

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By

HAMISU USMAN

Thesis Submitted to the Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Master of Science

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DEDICATION

This thesis report is dedicated to my father Alh. Usman Mohammad Sidi and my mother Hajia Rabi Usman, for their parental guidance during my study at Universiti Putra Malaysia. Also to my wife Hadiza Mohammed, as well as my children Adamu, Hauwa,u, Usman and Aisha for their patients and support rendered to me during the period of my study.

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in Fulfillment of the requirement of the degree of Master of Science

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October 2013

Chairman: Hashim Bin Hizam, PhD

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In the previous years, electrical power system equipment and devices were designed to produce purely sinusoidal voltage and current wave forms. But nowadays, with much interest and wide spreads of power electronics equipment and devices utilized for industrial, commercials and residential consumers, these equipment and other electronics devices can no longer operate with an ideal current and voltage waveform, because of the non-linearity of the equipment and devices in nature, that draw harmonics currents and voltages from the supply. With this, traditional LC passive filters were first introduced to mitigate harmonics currents/voltages and reactive power produced by non-linear loads. But passive filters are limited in operation due to its limitations such as heavy in sizes, bulky and a tendency for parallel and series resonances with supply impedance. Due to the limitations of passive filters, active

power filters are now the dynamic and viable solution to suppress current harmonics and reactive power drawn by non-linear loads. In this thesis, the modeling and simulation of single-phase shunt active power filter to mitigate the unwanted harmonics currents/voltages and reactive power drawn by non-linear loads are proposed. Fuzzy logic controller (FLC) was used to control the active filter, because of its simplicity and does not require any accurate mathematical model. Simulations are carried out in MATLAB/SIMULINK and SIMPOWER tool box environment. In the simulation, synchronous reference frame was used to extract the harmonic reference current produced by the non-linear loads. The simulation results were validated with the experimental results of the hardware proto- type in the laboratory. Digital signal processor DSP TMS320F28335 was used in order to demonstrate the feasibility and good performance of the proposed control algorithm. The total harmonics distortions (THD %) for the simulation results are within the IEEE 519-1992 harmonic standard. While the experimental results does not comply with the recommended IEEE 519-1992 harmonic standard limits because of the real time hardware implementation and losses within the real time components.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PENGURANGAN JUMLAH HEROTAN HARMONIK MENGGUNAKAN PENURAS AKTIF SATU FASA DENGAN PENGAWAL LOGIK SAMAR

Oleh

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Pada masa dahulu, peralatan sistem kuasa elektrik dan peranti direka untuk menghasilkan gelombang voltan dan arus yang sinusoidal semata-mata. Tetapi kini, dengan peralatan elektronik kuasa dan peranti yang meluas di dalam penggunaan industri, komersil dan pengguna kediaman, peralatan ini dan alat elektronik yang lain tidak boleh lagi beroperasi dengan menggunakan gelombang arus dan voltan, yang ideal kerana sifat tidak linear peralatan dan peranti yang menyebabkan arus dan voltan harmonik dari bekalan. Dengan ini, penuras pasif LC tradisional telah mula diperkenalkan untuk mengurangkan arus/voltan harmonik dan kuasa reaktif yang

dihasilkan oleh beban tak linear. Tetapi penapis pasif adalah terhad dalam operasi kerana batasan seperti berat saizyas besar dan kecenderungan untuk resonans sesiri dan selari dengan impedan bekalan. Oleh kerana keterbatasan penapis pasif, penapis kuasa aktif kini menjadi penyelesaian yang dinamik dan berkesan untuk mengurangkan harmonik dan kuasa reaktif yang dikeluarkan oleh beban tak nonlinear.

Dalam tesis ini, pemodelan dan simulasi penapis kuasa aktif satu fasa untuk mengurangkan arus/voltan harmonik yang tidak dingini dan kuasa reaktif yang disebabkan oleh beban tak linear dicadangkan di dalam tesis ini. Pengawal logik samar (FLC) telah digunakan untuk mengawal penapis aktif, kerana ianya ringkas dan tidak memerlukan apa-apa model matematik yang tepat. Simulasi dijalankan menggunakan MATLAB/Simulink dan Simpower. Dalam simulasi, rangka rujukan segerak digunakan untuk mendapatkan rujukan harmonik yang dihasilkan oleh beban tak linear. Keputusan simulasi disahkan dengan keputusan eksperimen. Isyarat digital pemproses DSP TMS320F28335 digunakan untuk menunjukkan keupayaan dan prestasi baik daripada algoritma kawalan yang dicadangkan. Jumlah herotan harmonik (THD) bagi keputusan simulasi dan eksperimen yang diperolehi adalah dalam lingkungan yang disyorkan oleh IEEE 519-1992. Walaubagaimanapun, keputusan makmal tidak menepati piawaian harmonic IEEE 519-1992 disebabkan kekangan dalam menentusah bacaan dalam masa sebenar serta kehilangan tenaga dalam komonen yang digunakan.

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APPROVAL

I certify that a Thesis Examination Committee has met on (14/10/ 2013) to conduct the final examination of Hamisu Usman on his thesis entitled "**Suppression of Total Harmonic Distortion Using Single Phase Shunt Active Power Filter with Fuzzy Logic Controller**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

I declare that, the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

HAMISU USMAN

Date: 14 October 2013

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LIST OF ABBREVIATIONS

A	Ampere
APF	Active Power Filter
ACO	Ant Colony Optimization
ADC	Analog to Digital Converter
ANN	Artificial Neural Network
APF	Active Power Filter
AC	Alternating Current
CSI	Current Source Inverter
CCL	Current Control Loop
COA	Center of Area
COG	Center of Gravity
CCS	Code Composer Studio
DSP	Digital Signal Processor
DC	Direct Current
D-Q-O	Direct-Quadrature-Zero
DAC	Digital to Analog Converter
EMI	Electro Magnetic Induction
EPWM	Enhanced Pulse Width Modulation
e	Error
FLC	Fuzzy Logic Controller
FPGA	Field Programmable Gate Array
FFT	Fast Fourier Transform
Hz	Hertz
IEEE	Institute of Electrical and Electronics Engineers
I	Current

IGBT Insulated Gate Bipolar Transistor

IDE Integrated Design Environment

I_d Real Current

I_q Imaginary Current

I_s Source Current

I_c Compensation Current

I_f Filter Current

I_m Maximum Current

KCL Kirchhoff Current Law

K_i Integral Constant

K_p Proportional Constant

LMI Linear Matrix Inequality

LC Inductive Capacitive

MOSFET Metal Oxide Semi Conductor Field Effect Transistor

MVA Mega Volt Ampere

PWM Pulse Width Modulation

PLL Phase Locked Loop

PF Power Factor

PS Positive Small

PL Positive Large

PM Positive Medium

PCC Point of Common Coupling

P-Q Real and Reactive Power

PI Proportional Integral

PID Proportional Integral Derivative

REF Reference

SCR Silicon Control Rectifier

SRF Synchronous Reference Frame

SMPS	Switch Mode Power Supply
SAPF	Shunt Active Power Filter
THD	Total Harmonic Distortion
TDD	Total Demand Distortion
TI	Texas Instrument
TV	Television
TIF	Telephone Influence Factor
UPS	Uninterruptable Power Supply
V_{dc}	DC Voltage
VA	Volt Ampere
VCL	Voltage Control Loop
V_s	Supply Voltage
V_m	Maximum Voltage
V	Voltage
Z	Zero

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Most of electrical equipment and devices used to be operated on purely sinusoidal current and voltage waveforms. However nowadays, with the introduction and proliferation of modern power electronics devices like adjustable speed drives, uninterrupted power supply, cyclo converters switch mode power supplies, fluorescent lamps, television set, fax machines, photocopy machines, personal computers printers and many more non-linear devices used in industrial, commercial and consumers applications, current and voltage requirements are no longer sinusoidal, solely based waveforms. This is due to their non-linearity in nature. The non-linearity of the devices draws and injects harmonics current to the supply system which affects the performance efficiencies of the equipment and devices. These harmonics injection leads to power quality degradation of the supply system which causes adverse devastating effects like overheating in cables, power losses, interference to nearby communication facilities, electromagnetic induction (EMI) and pre matured failure of equipment etc. Harmonics produced by non-linear loads in power system draw current in unexpected pulses than in a smooth way [1]. For the past decades and up till now, power quality issues have been a concern to utilities, consumers, researchers and power quality system engineers.

With this, efforts have been made in order to remedy these harmonics problems, so that the compensated results of the THD meet the IEEE 519-1992 standard norms on the minimum THD of current within the supply system. Various solutions to overcome these harmonics problems are traditional passive filters, active filters, and magnetic wave shaping and network reconfiguration to mention a few [2], [3], [4]. The most popular devices among the harmonic cancellations techniques are passive and active filters. Traditionally, passive filters were first introduced for the harmonic current compensation, but due to their drawbacks, such as series and parallel resonances, tuning problem, large in size and weight, their operation becomes very limited nowadays. With the introduction and advancement of superior filters to the passive filters in our today's markets, active power filters are now the dynamic and viable solution for simultaneously compensating harmonics current and reactive power drawn by non-linear loads. In addition, shunt active filters have the advantages of power factor correction, cancellation of harmonics induced in the neutral conductor of three-phase four-wire system, and balancing of voltage levels in three-phase three-wire system.

1.2 Problem Statement

In previous years, currents and voltages waveforms in power system network are purely sinusoidal in nature. But nowadays, with the proliferation and wide spread of modern power electronics equipment and devices the supply current and voltages are no longer sinusoidal. These equipment and devices inherits nonlinearities in them [4]. Nonlinear loads such as personal computers, TV sets, switch mode power supply, at

their inputs add up o a large increase in the amount of harmonic currents injections at the point of common coupling (PCC). For large nonlinear industrial loads, such as adjustable speed drive, motors, generators arc furnaces, welding machines etc are considered to be large source of harmonics injection for medium voltage supply. These harmonics due to industrial loads when added up caused desirable effects such as additional losses, overheating and overloading in the supply system. However, another harmful effects of harmonics problems are electromagnetic interference to the nearby communication facilities, premature ageing of equipment, nuisance tripping of circuit breakers and fuses [4]. The problem of power quality due to harmonics produced by nonlinear loads has necessitate power quality engineers, researchers, power system analyst etc to mitigate the harmonic pollution effects in power supply system network. Traditional passive filter were the earliest mitigation technique for harmonic current mitigation produced by nonlinear loads. But passive filter have draws back, such as series and parallel resonance with the supply impedance, heavy in size, and problem of detuning. With these limitations of passive filter, it forced researchers to look for another alternative solution to mitigate the current harmonic produced by nonlinear loads. The advancement in technology has leads to superior technique to overcome the difficulties of passive filter. Shunt active power filter a family of active power filter had been tested and proven to be a viable solution to mitigate the undesirable harmful effect of harmonics produced by nonlinear loads.

1.3 Objectives of the study

The main objectives of this research work are as follows:

1. To model and simulate single phase shunt active power filter using fuzzy logic controller for the controlling of current harmonics.

2. To fabricate prototype hardware of a single phase shunt active power filter using fuzzy logic controller via DSP TMS320F28335 controller.

3. To minimize THD produced by non-linear loads based on IEEE 519-1992 Harmonics Standard limit.

1.4 Scope of the work

In this thesis the scope of work to be carried includes: modeling and simulation of single phase shunt active power filter in order to mitigate the burden caused by non-linear loads in power system. The work also includes the design of an appropriate mamdani approach fuzzy logic controller to control the active power filter. Also included in this thesis, is the implementation of the hardware prototype single phase shunt active power filter in laboratory with the DSP TMS320F28335 controller.

1.5 Thesis Contribution

The contribution of this thesis work will be the design of the fuzzy logic controller membership's function. Based on the selected fuzzy logic controller, Mamdani inference system was chosen due to its simplicity in implementation, which does not also require an accurate mathematical modeling of the inputs and output variables. Triangular membership functions were also used rather than other membership

functions because of easy identification of their point of intersections. Moreover, the design memberships are overlapped to each other which give certain robustness to the fuzzy logic controller and possibility in observing two memberships to be active at a time. In the same vein, a greater resolution is also achieved with higher number of membership functions. The fuzzy inference system was firstly designed based on the MATLAB fuzzy toolbox in the simulation study, but the whole fuzzy inference system from tool box was converted to SIMULINK modeling all the fuzzy process up to the deffuziffication stages as the real time hardware does not accept fuzzy toolbox rather than fixed discrete approach. Another contribution made in this thesis, is the generation of the shunt active power filter harmonic current reference signal. In this work, three phase synchronous reference frame was modeled under balanced condition. One phase was selected for the use of the single phase shunt active power filter.

1.6 Thesis organization

This thesis work is organized into five chapters. Chapter 1, the general background introduction of the aim of the research work, in which the power quality issues militating power supply system due to non-linear loads, are discussed. The causes and the effect of power quality are also highlighted in this chapter. Chapter 2 discusses the literature reviewed of the previous similar work carried out by many researches, with modeling and simulations of shunt active power filters for both three-phase and single-phase controlled with different algorithms and techniques. Also, different

topologies and control techniques for the active filter and hard ware real time implementations are reviewed in this chapter.

Chapter three explains the methodology adopted in carrying out this research work. In this chapter, the steps involved in carrying out the modeling and simulation of the proposed single-phase shunt active power filter design methodology are also included. Chapter four includes the simulation and hardware results analysis of the fuzzy logic controller algorithm. Lastly, chapter five contains the conclusion and recommendations for future work.

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