UNIVERSITI PUTRA MALAYSIA

DESIGN OF SINGLE· PHASE ACTIVE POWER FILTER FOR HARMONIC MITIGATION IN DISTRIBUTION POWER LINE

MOHAMED S. A. DAHIDAH

DESIGN OF SINGLE-PHASE ACTIVE POWER FILTER FOR HARMONIC MITIGATION IN DISTRIBUTION POWER LINE

By

MOHAMED S. A. DAHIDAH

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Dedicated to

My parents,

And lovely brothers,

Khaled and Mustafa

Abstract of thesis presented to the senate of Universiti Putra Malaysia in partial fulfilment of requirement for the degree of Master of Science

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Chairman: Norman Mariun, Ph.D.

Faculty: Engineering

Recently, the wide use of power electronic components in various applications has affected the quality of the power. One of the most serious problems is that of the harmonic, which is generated from the nonlinear loads such as variable frequency AC motor drives, uninterruptible power supplies (UPSs), personal computers, laser printers, and many more [1-4], is has harmful effect on the electrical equipment.

Several techniques have been carried out over the year to prevent the effects of the harmonic [3], [7], The active power filter is the most efficient method, which has been developed in different configurations to meet the different demands [9]. This thesis presents the design and development of a single-phase shunt active power filter that is suitable for commercial or educational buildings with computer loads [9]. The proposed filter is designed to mitigate the third and fifth order harmonics for two main reasons. Firstly, because of using large number of relatively small single-phase loads that may produce excessive total amount of the third harmonic fifth and seventh harmonic [3]. Secondly because of the active power filter rating could be

highly reduced when the suppression of one or two special harmonics is effected by the active filter [20].

Full-bridge single-phase inverter is designed as active power filter to cancel the harmonics generated from the nonlinear load. We preferred the voltage-fed PWM inverter to the current-fed PWM inverter because the voltage-fed PWM inverter is higher in efficiency and lower in initial costs than the second one [16], [20]. IGBT was chosen as power switches for the inverter due to its simplicity of controlling the gate as well as lower cost as compared to the thyristors [6]. Sinusoidal pulse width modulation (SPWM) was introduced as a technique to control the output of the inverter due to its ability to control the frequency and the phase angle of the inverter output. The control of active filter is accomplished by monitoring the current to the nonlinear load and then generating gate signals for the inverter to create a current waveform that will cancel the harmonics in the load current. FFT method [31] is chosen to compensate for individual harmonic components in the load current by performing a rolling FFT on the sampled load current waveform and then reproducing a current waveform that has the same harmonic components with the opposite phase angle.

The design of the active power filter is verified by doing the simulation using the capabilities of PSPICE. The result shows that the THD is reduced from 41.1% to 5%, which is acceptable with referring to IEEE-519 limits. The inverter circuit has been successfully implemented in the laboratory as the active power filter and it is capable to generate variable frequencies (i.e. generating the third and fifth harmonic).

Finally, the experimental results are compared and they agree with the simulation study as given in chapter 4 of this thesis.

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

REKABENTUK PENAPIS KUASA AKTIF SATU FASA UNTUK MENGURANGKAN HARMONIK DALAM TALIAN PENGAGIHAN KUASA

Oleh

MOHAMED S. A. DAHIDAH

Januari 2002

Pengerusi: **Norman Mariun, Ph.D.**

Fakulti: **Kejuruteraan**

Pada masa kini, penggunaan komponen-komponen elektronik kuasa yang meluas dalam pelbagai penggunaan telah memberi kesan kepada kualiti kuasa. Salah satu daripada masalah yang paling besar ialah harmonik, yang terjanakan daripada beban-beban tidak linear seperti pemacu frekuensi bolehubah motor AU, bekalan kuasa tanpa gangguan, komputer peribadi, pencetak laser, dan banyak lagi[1-4]. Ia boleh memberikan banyak kesan buruk kepada alat-alat tersebut.

Beberapa kaedah telah digunakan dalam beberapa tahun kebelakangan ini untuk menghindar kesan harmonik [3],[7]. Penapis aktif adalah kaedah yang paling berkesan, di mana ia telah dibina dalam pelbagai tatarajah untuk memenuhi pelbagai keperluan [9]. Tesis ini mengemukakan rekabentuk and pembinaan penapis kuasa aktif pirau satu fasa yang sesuai untuk bangunan komersial atau bangunan pendidikan yang mempunyai komputer sebagai beban [9].Terdapat dua sebab utama mengapa penapis ini dikemukakan bagi mengurangkan harmonik tertib ketiga dan kelima. Pertama, apabila menggunakan banyak bilangan beban fasa tunggal yang rendah, jumlah harmonik tertib ketiga, kelima dan ketujuh akan wujud dengan kadar yang melampau [3]. Kedua, kadar penapis kuasa aktif akan menurun dengan

banyaknya apabila berlaku pengurangan satu atau dua harmonik tertentu yang dipengaruhi oleh panapis aktif [20].

Penyongsang satu fasa titi penuh, direka sebagai penapis kuasa aktif untuk membatalkan harmonik yang dijana oleh beban tidak linear. Kami memilih kaedah penyongsang PWM jenis suap-voltan daripada jenis suap-arus kerana jenis suap-voltan mempunyai keberkesanan yang lebih tinggi dan kos permulaan yang lebih rendah [16],[20]. IGBT telah dipilih sebagai suis-suis kuasa untuk penyongsang kerana ia lebih mudah dikawal dan harganya lebih murah berbanding tiristor [6]. Pemodulatan lebar dedenyut bentuk sinus diperkenalkan sebagai teknik untuk mengawal penyongsang kerana ia berupaya mengawal frekuensi dan sudut fasa keluaran daripada penyongsang tersebut. Pengawalan penapis kuasa aktif diperolehi dengan pengawasan arus yang memasuki beban tidak linear dan kemudiannya menjana isyarat get untuk penyongsang agar sebuah gelombang arus terbentuk yang akan membatalkan harmonik tersebut. Kaedah FFT [31] ialah cara yang dipilih untuk mengseimbangkan komponen harmonik individu di dalam arus beban dengan melakukan gulungan FFT ke atas sampel arus beban dan kemudiannya mengeluarkan sebuah gelombang arus yang mempunyai kandungan harmonik yang sama tetapi berlawanan sudut fasa.

Rekabentuk penapis kuasa aktif ini diverifikasi dengan penggunaan simulasi program Pspice. Keputusan menunjukkan jumlah erotan harmonik (THD) berjaya dikurangkan daripada 41.1% kepada 5%, iaitu di dalam lingkungan had yang ditentukan oleh peraturan IEEE-519. Litar penyongsang berkenaan telah berjaya diimplementasi di makmal sebagai penapis kuasa aktif dan berupaya menjana

frekuensi bolehubah (iaitu bagi harmonik tertib ketiga dan kelima). Akhir sekali, hasil-hasil ujian telah dibandingkan dengan hasil simulasi dan mereka mempunyai persamaan yang rapat ; sepertimana dibentangkan di bab keempat daripada tesis ini.

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LIST OF ABBREVIATIONS

AC	Alternating Current
ANSI	American National Standard Institute
BW	Band Width
C	Capacitor
DC	Direct Current
DSP	Digital Signal Processor
EMC	Electromagnetic Compatibility
f	Frequency
FACTS	Flexible AC Transmission Systems
FET	Field Effect Transistor
FFT	Fast Fourier Transformer
Hz	Hertz
I	DC Current
i	AC current
I_{CBS}	Bootstrap Capacitor Leakage Current
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers.
I_F	Forward Current
IGBT	Isolated-Gate Bipolar Transistor
I_L	Load Current
I_{SC}	Short Circuit Current
k	Kilo
P	Power
PCC	Point of Common Coupling
PWM	Pulse Width Modulation
Q_g	Total Gate Charge
Q_{LS}	Level shift charge required per cycle
R	Resistance
RMS	Root Mean Square
RSS	Root of the Sum of the Squares
SCR	Short Circuit Ratio

SPWM	Sinusoidal Pulse Width Modulation
SVC	Static VAR Compensator
T	Temperature
TDD	Total Demand Distortion
t_f	Fall time
THD	Total Harmonic Distortion
t_r	Rise time
t_{rr}	Reverse Recovery Time
UPS	Uninterruptible Power Supply
V	DC Voltage
v	AC voltage
VAR	Volt Ampere Reactive
VDE	Verband Deutscher Electrotechiker
V_F	Forward voltage drop across the bootstrap diode
V_{LS}	Voltage drop across the low side FET
V_{RRM}	Repetitive reverse voltage
W	Watt

CHAPTER 1

INTRODUCTION

1.1 Importance of the Study

There are problems of growing proportions in the nation's utility distribution system. The problem is harmonics, a problem that started with the emergence of modern electronic processing equipment, and then increased as the world's demand for electronic power began to exceed the supply. The natural growth of population and industry – rating form the burgeoning personal computer industry to the growing maze of industrial complexes and high-rise office structures – has exceed the ability of utilities to provide a corresponding growth in electricity. Energy supply is limited.

Utilities are offering a variety of incentives, including restrictions, for the use of innovative power-saving techniques, such as variable frequency drives that control large motor. These enable motors to operate in manner that saves up to 60% of the previously required electrical power. But the increased use of variable frequency drives, combined with considerable growth of energy-efficient lighting and electronic data processing equipment, has resulted harmonics problem, which is as serious as the energy shortage itself.

Recently, the harmonic aspect is the most serious problem that is faced by industries, therefore many researches have been figured to overcome its influence. Several techniques are investigated for different tasks in this field; active power filter is one of them. The development of active power filter has given more attention from many researchers eventually due to its high ability of reducing the harmonic effects over

other techniques such as passive filters. There are numbers of criterion that limit the design of desired filter such as the ratings, the location of installation, single-phase or three-phase.

1.2 Aim of Work

The aim of this work is to design a single-phase active power filter to provide an acceptable suppression of 3^{rd} and 5^{th} order of harmonics, which are generated from the nonlinear load. Proposed circuit of active filter has been fabricated of inverter-based IGBTs switches power devices, and the control of the inverter is provided by using sinusoidal pulse-width-modulation (SPWM) technique. Moreover the hardware of the DC-to-AC inverter, which is the heart of the filter, is constructed in order to achieve the proposed task for the active filter. Capabilities of PSPICE software have been used to develop the active power filter. The comparison between experimental results and simulation studies are to be done.

1.3 Objectives

To achieve the stated aim the following five objectives need to be taken into account:

1- Study the influences of the harmonic on the power systems and knowing the different techniques, which have been developed to avoid its effects.
2- Study the different types of harmonic filters.
3- View previous implementations of active filter design and compare their performance.
4- Come-up with a suitable design of proper active filter, which can eliminate the third and fifth harmonic satisfactorily.

1.4 Thesis Organization

This thesis is organized into five chapters. Chapter I gives an introduction to the project. The objectives and scope of the study is also presented.

Chapter II contains a critical literature review of power quality problems and its causes. Special attention is given to harmonic effects. And several techniques that were developed to mitigate its effects are also presented. General descriptions of active power filters are given at the end of this chapter.

Chapter III deals with the main design of the filter and the circuits design that are related to the design is discussed. Different components such as power switches, diodes, waveform generators and heat sink are chosen in order to construct the circuit according to the proposed ratings.

Chapter IV presents the result obtained at different points in the circuit. The comparison between simulation and experimental results are discussed.

Chapter V Conclusion of the present research work and suggestions for the future research and development of the active power filter are given.