UNIVERSITI PUTRA MALAYSIA

HARMONIC ANALYSIS AND MITIGATION OF ELECTRONIC DEVICES USING PASSIVE FILTER

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

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DEDICATION

This thesis is dedicated to my parents

For their patience and tolerance

During my study.

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

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Chairman: **Associate Professor Nasrullah Khan, PhD**

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The objective of this present work is to investigate harmonic profiles of single and three phase non-linear loads and also performance of passive filter that has been designed. The analysis has been carried out using real time harmonic profile measurement equipment. The loads which have been measured are television, video compact disc (VCD) player, sound system, desktop and laptop personal computer (PC) , motor, uninterrupted power supply (UPS) and office automation facilities. Passive filter vis-à-vis active filter is used in the experiment because it is maintenance free and of its low cost and trouble free operation. All single phase loads, which were measured, showed that total current harmonic distortions (THDs) are above 100% because they have low fundamental current. Furthermore, most of the harmonic current especially 3^{rd}, 5^{th},7^{th}, and 9^{th} harmonic order currents were almost 90% of the fundamental current. For three phase

system, different types of non-linear loads exhibited different types of profiles. Comparatively, UPS current waveform was more distorted and its THD is higher than motor current waveform. This is because the electronic devices such as UPS, TV, PC etc. are using low current compared to other loads such as central air conditioning system which are not controlled by electronic devices but use chiller for operation. For office load automation facilities at multi storey building, new additional loads can cause the system to become imbalance due to improper wiring connection at DB. Different types of loads and modes of operations can also contribute to cancellation of total harmonic due to phase angle diversity and attenuation of system impedance. In these studies, current harmonic is more relevant than voltage harmonic because the results show that most of the THDs voltage readings are low compared with THDs current.

Results from passive filters showed that the installation of filters can reduce up between 40% ~ 50% of THD current, output current waveform is improved which is verified by simulations and all currents harmonic value is increased extensively. This shows that installation of passive filter can resonate the circuit and prevents the harmonic current from flowing back to the power source which cause only minimum problems to the voltage waveform

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

ANALISIS HARMONIK DAN PEMBAIKAN PERALATAN ELEKTRONIK MENGGUNAKAN PENURAS PASIF

Oleh

HASHBULLISHMAN BIN HASHIM

November 2005

Pengerusi: **Profesor Madya Nasrullah Khan, PhD**

Fakulti: **Kejuruteraan**

Tujuan kajian penyelidikan ini adalah untuk mengetahui perlakuan harmonik terhadap beban tidak lurus satu fasa dan tiga fasa serta hasil tindakan penapis pasif yang telah di pasang. Kajian yang dibuat adalah dengan menggunakan peralatan pengukur harmonik semasa. Beban yang telah diukur adalah telivisyen, pemain cakera padat, peralatan bunyi, komputer bimbit, komputer meja, motor, sistem bekalan kuasa tanpa gangguan (UPS) dan pengunnaan peralatan automasi pejabat di setiap tingkat. Pemilihan penuras harmonic pasif dibuat pada projek ini adalah kerana ianya tidak perlu di buat penyelenggaraan, kos pembuatannya adalah rendah dan penggendalian yang mudah berbanding dengan penuras aktif. Kesemua beban satu fasa yang telah diukur menunjukkan bacaan jumlah herotan harmonic (THD) arus adalah melebihi 100% kerana arus asasinya adalah rendah dan kebanyakan bacaan arus harmonik terutama nombor 3, 5 dan 7 adalah lebih kurang 90% daripada nilai arus asasi. Bagi beban tiga fasa, setiap

beban yang tidak lelurus yang berlainan akan menunjukkan perlakuan harmonik yang berlainan. Bacaan arus pada UPS menunjukkan gangguan yang lebih berbanding dengan arus beban motor dan nilai THDnya juga adalah tinggi. Arus pada motor adalah kecil gangguannya dan bacaan THDnya adalah rendah. Ini adalah kerana peralatan yang beroperasi dengan kawalan elektronik seperti UPS, TV, PC dan sebagainya menggunakan arus yang kecil berbanding beban lain yang mana ianya beroperasi secara konvasional seperti sistem alat penghawa dingin yang menggunakan 'chiller' dalam operasinya. Bagi beban peralatan automasi pejabat, penambahan pendawaian baru yang tidak teratur akan menyebabkan pengagihan yang tidak seimbang pada peti agihan. Kepelbagaian jenis beban juga menyumbangkan penurunan bacaan harmonik akibat sudut fasa yang berbeza dan penyusutan galangan pada sistem. Dalam kajian ini, penumpuan bacaan diutamakan terhadap nilai arus kerana kebanyakkan nilai bacaan voltan THD adalah lebih kecil jika dibandingkan dengan arus THD.

Keputusan daripada penapis pasif menunjukkan pemasangan sesetengah penapis tersebut dapat mengurangkan sehingga 40% hingga 50% daripada nilai arus THD. Bentuk gelombang arus yang dikeluarkan juga menunjukkan hasil perubahan yang baik di mana ianya menghampiri kepada bentuk sinus dan disahkan oleh simulasi. Semua bacaan arus yang telah ditapis adalah tinggi. Ini menunjukkan pemasangan penapis pasif akan membuat arus itu mengampul dan mengelakkan arus harmonik daripada kembali ke punca bekalan yang menjejaskan bentuk gelombang voltan secara minima.

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LIST OF ABBREVIATIONS

A	Ampere
AC	Alternating current
ANSI	American National Standard Institute
APF	Active Power Filter
C	Capacitor
CSI	Current source inverter
DB	Distribution board
DC	Direct current
f	Frequency
HMTs	Harmonic Mitigation Techniques
Hz	Hertz
IEC	International Electromechanical Commission
IEEE	Institute of Electrical and Electronic Engineers
IGBT	Insulated Gate Bipolar Transistor
KVA	Kilo volt ampere
KVAR	Kilo volt ampere reactive
MCCB	Moulded case circuit breaker
MSB	Main switch board
P	Power
PCC	Point of common coupling
PWM	Pulse Width Modulation
R	Resistance
RMS	Root mean square
SMPS	Switch mode power supply
SPWM	Sinusoidal Pulse Width Modulation
TDD	Total demand distortion
THD	Total harmonic distortion
THID	Total current harmonic distortion
TNB	Tenaga National Berhad
UPS	Uninterruptible power supply
VAC	Voltage alternating current
VDC	Voltage direct current
VFD	Variable frequency drive
VSI	Voltage source inverter
W	Watt

CHAPTER 1

INTRODUCTION

1.1 Background

Electrical engineers responsible for design and maintenance of industrial networks or extensive facilities are facing increased problems caused by harmonic pollution. Due to recent developments in the power electronics field, a range of new energy efficient devices such as DC rectifiers, frequency converters, soft starter, etc. have been introduced in the market. By means of these devices the manufacturing processes can be run more efficiently and more economically [1].

However, power electronic devices are by nature not compatible with AC power systems. Rectifiers and converters constitute non-linear loads that draw non-sinusoidal currents. A typical harmonic source is a phase-controlled thyristor rectifier having a sufficient DC inductance to produce a non-pulsating DC current.

Accordingly, parallel passive and parallel active filters are commonly applied to non-linear loads to mitigate harmonics. The principle of parallel passive filter is to provide a low impedance shunt branch to the load's harmonic current, thus reducing harmonic current flowing back into the source. The principle of parallel active filter is to inject harmonic current with the same amplitude and opposite phase of the load harmonics current into the line, thus eliminating harmonic current flowing back into the source.

1.2 Problem Statement

This research is to identify selective domestic electronic equipments which produce harmonic with live measurement. There was a similar work done by Chang Chee Meng during last Master Thesis and Table 1.1 shows the works comparison between previous and current thesis.

Table 1.1 Thesis comparison

Previous Thesis	Current Thesis
1. Simulation a. Single phase Half wave rectifier b. Three phase half wave rectifier c. Harmonics in the neutral conductor d. light dimmer e .parallel loads f. parallel resonance circuit	1. Experiments and Simulations a. Single tuned 3 rd filter b. Double tuned 3rd and 5th filter c. Series filter d. Low pass filter e. AC line reactor f. Single phase motor
2. Real time measurement a. light dimmer b. 166MMX IBM PC c. Television, video player d. AC-AC Drive machine	2. Real time measurement a. Office and home appliances – TV, VCD Player, PC, laptop PC b. Main Switch Board and Sub Switch Board – Chiller Plant Room and UPS
3. Harmonic monitoring- Computer Center UPM	3. One week measurement – UPM Engineering Administration Building.
4. Experiment – light dimmer	4. Experiment – single phase motor

1.3 Research Objectives

This research has two objectives which are to analyze load harmonic profiles and harmonic filters performance. To achieve these objectives, the following steps were carried out:-

1. To study various harmonic problems and comprehend the different techniques used to solve the problem
2. To measure harmonic profiles on a single and three phase loads and analyze the results.
3. To design and enhance a single phase passive harmonic filter which can eliminate or reduce the selected harmonics and verify the improvement waveform by simulations.

1.4 Scope of Work

The scope of work is to do measurement with selective electronic equipments and propose passive filter to improve the distorted waveform.

1.5 Thesis Organization

This thesis is divided into five chapters.

Chapter 1 (Introduction) is an introduction to the purpose of the thesis including its aim and objectives.

Chapter 2 (Literature Review) contains a comprehensives literature review of the perspectives and problems of harmonics including it's effect on electrical power system and highly sensitive equipments. Several techniques that were developed to mitigate harmonics are also being elaborated and discussed in this chapter.

Chapter 3 (Methodology) deals with methods used to measure real time harmonic profiles on single and three phase loads. Single and three phase loads refer to home appliances and commercial or industrial instruments respectively. The schematic and block diagram of passive harmonic filters will also be discussed in this chapter.

Chapter 4 (Results and Discussions) presents the results from real time measurement of harmonic profiles and single phase passive harmonic filters. The real time measurement results will include current and voltage waveforms, harmonic spectrum, current and THDs voltage, power factor and power consumptions. For passive filters, only current measurement will be analyzed to determine whether such filter can improve or repair the THD currents and waveform.

Chapter 5 (Conclusions and Suggestions) expounds on the conclusions of the results and suggestions for future development of this research.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

As a result of the growth in non-linear loads, such as switch mode power supplies (SMPS) and computers used in the utility facilities, serious power pollution is produced and reflected in the distribution and transmission networks. High current harmonics, low power factor and high pulsating current generated from the diodes rectifiers (non-linear loads) are the main sources of power pollution. Power pollution results in an increase in losses and interference for power equipment. One of the most important issues for power electronic designers is the reduction of current or voltage harmonics created by the converters [2].

In three phase AC circuits which contain balanced linear loads, the sinusoidal waveforms for voltage, current and power remain proportionally related as well, and there is no net current flowing in the neutral. The situation changes when non-linear loads are imposed on one or more phases. Non-linear load is a steady-state electrical load that draws current discontinuously or whose impedance varies throughout the cycle of the input AC voltage or current waveform.

Harmonic current flows at multiples of fundamental frequency. In a 50 Hz system, the 2^{nd} and 3^{rd} harmonics appear at 100 Hz, 150 Hz. In a balanced three phase circuit, even numbered harmonic currents cancel out on the neutral; whereas odd numbered harmonics do not. Instead, they add up algebraically, sometimes to rather high levels. Worst of all are the so-called triplen harmonics 3, 9, 15... which can produce neutral currents that can be up to as high as 173% of the individual phase currents. Most of the three phase branch circuits contain a single neutral conductor for all three phase conductors. This is a safe arrangement when the neutral current is zero, or at worst, equal to the current in any single phase. When the neutral current is higher than the phase current, the solitary neutral conductor is in danger of overheating.

In a power circuit that contains non-linear devices, it is almost certain that harmonic distortions can be found. The irony is that computers and communications equipment, which generates harmonics and other non-linear voltage currents, are also highly sensitive to such perturbations or waveform distortions. There are some basic concepts about waves that will make it easier to understand what is common among all these definitions.

2.2 Categories of Waveform Distortion

Harmonics is a part of waveform distortion. Waveform distortion is a steady state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation. Table 2.1[3] shows more detailed for each of the waveform distortion.

Table 2.1 Categories and typical characteristics of waveform phenomena

Categories	Typical spectral content	Typical duration	Typical voltage magnitude
1. DC offset		Steady state	0 – 0.1%
2. Harmonic	0 – 100^{th} Hz	Steady state	0 – 20%
3. Interharmonics	0 – 6kHz	Steady state	0 – 2%
4. Notching		Steady state	
5. Noise	broad band	Steady state	0 – 1%

There are five primary types of waveform distortion as follows :-

2.2.1 DC offset – the present of a DC voltage or current in an AC power system.

2.2.2 Harmonics – are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is design to operate termed the fundamental frequency; usually 50 Hz or 60 Hz.

2.2.3 Interharmonics – can be found in networks of all voltages classes. They can appear as discrete frequencies or as wide band spectrum. The main sources of interharmonics waveform distortion are static frequency converters, cyclo converter, induction motors and arcing devices.

2.2.4 Notching – is a periodic voltage disturbance caused by the normal operation of power electronics devices when current is commutated from one phase to another (Figure 2.1)

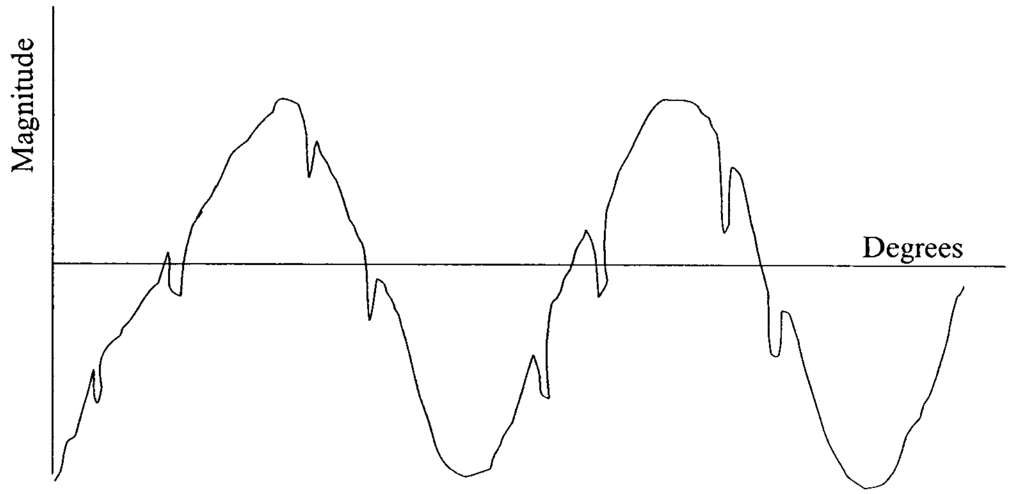

Figure 2.1 Notching

2.2.5 Noise – is unwanted electrical signals with broadband spectral content lower than 200 kHz superimposed upon the power system voltage or current in phase conductors, or found on neutral conductors or signal lines. Noise problems are often exacerbated by improper grounding (Figure 2.2)

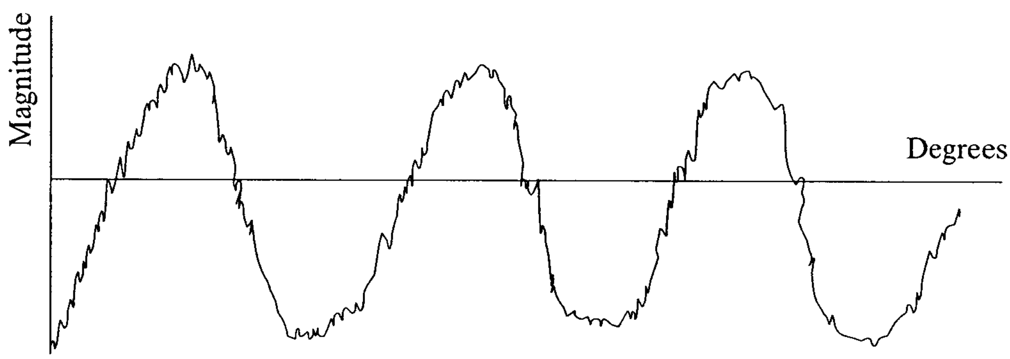

Figure 2.2 Noise