“ I hereby declare that I have read through this report entitle “Design and Development of A Three Phase Shunt Active Filter Based on P-Q Theory” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

Signature : ....

Supervisor’s Name : ....

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DESIGN AND DEVELOPMENT OF A THREE PHASE SHUNT ACTIVE FILTER BASED ON P-Q THEORY

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A report submitted in partial fulfillment of the requirements for the degree of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2013

I declare that this report entitle “*Design and Development of A Three Phase Shunt Active Filter Based on P-Q Theory*” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	………………………………………
Name	:	………………………………………
Date	:	………………………………………

To my beloved mother and father

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ABSTRACT

Power quality is one of the most important aspects at both transmission and distribution levels. Power quality can be defined as the delivery of sufficiently high-grade electrical services to the consumer or customer. Power quality (PQ) studies are principally concerned with the deviation of the supply voltage and load current from their ideal shapes (sinusoidal). Power quality can be defined as "any power problem due to distort in voltage, current, or frequency deviations that result the customer equipment may cause malfunction or shutdown". Harmonic is one of the interference that which caused poor power quality. Harmonic disturbance causes electric equipment that used will be heated and cannot function properly. Thereby, the aim of this project is to design and development of a three phase shunt active filter based on P-Q theory in order to mitigate current harmonics in the low voltage distribution system. A circuit design and its parameters of a three phase shunt active filter will be simulated using MATLAB/SIMULINK. The performance of shunt active based on simulation using P-Q theory for harmonic compensation will be analysed. There are four steps involved in developing a harmonic reduction to ensure the project is achieved. Firstly, the requirements for the information and references related of the project are discussed. Second, determine the appropriate circuit design to create a three phase shunt active filter. The third phase is a simulation of a circuit design using MATLAB/Simulink software. The final phase is involves final results and analyse the outcome of experiment results. From the simulations carried out, the design and development of a three phase shunt active filter based on P-Q theory can filter and reduce the harmonics distortion in the power system.

ABSTRAK

Kualiti kuasa adalah salah satu aspek yang paling penting pada peringkat penghantaran dan pengagihan. Kualiti kuasa boleh ditakrifkan sebagai penyampaian perkhidmatan elektrik gred tinggi yang mencukupi kepada pengguna atau pelanggan. Kajian kuasa kualiti (PQ) terutamanya berkenaan dengan penyelewengan voltan bekalan dan beban semasa dari bentuk ideal (sinus). Kualiti kuasa boleh ditakrifkan sebagai "apa-apa masalah kuasa disebabkan oleh gangguan pada voltan, arus, atau perubahan frekuensi yang menyebabkan peralatan pelanggan mengalami kerosakan atau penutupan". Harmonik adalah salah satu daripada gangguan yang disebabkan kelemahan kualiti kuasa. Gangguan harmonik menyebabkan peralatan elektrik yang digunakan akan panas dan tidak boleh berfungsi dengan betul. Dengan itu, tujuan projek ini adalah untuk rekabentuk dan pembangunan tiga fasa penapis pirau aktif berdasarkan teori P-Q untuk mengurangkan arus harmonik dalam sistem pengagihan voltan rendah. Satu rekabentuk litar dan parameter tiga fasa penapis pirau aktif akan menggunakan simulasi MATLAB / SIMULINK. Pencapaian penapis aktif berdasarkan simulasi menggunakan teori P-Q untuk pengurangan harmonik akan dianalisis. Terdapat empat langkah-langkah yang terlibat dalam membangunkan pengurangan harmonik untuk memastikan projek itu dicapai. Pertama, keperluan untuk maklumat dan rujukan yang berkaitan projek dibincangkan. Kedua, menentukan reka bentuk litar yang sesuai untuk menghasilkan tiga fasa penapis pirau aktif. Fasa ketiga adalah simulasi reka bentuk litar yang menggunakan MATLAB / Simulink perisisan. Fasa terakhir adalah melibatkan keputusan akhir dan menganalisis hasil keputusan eksperimen. Dari simulasi yang dijalankan, rekabentuk dan pembangunan tiga fasa penapis pirau aktif berdasarkan teori PQ boleh menapis dan mengurangkan herotan harmonik dalam sistem kuasa.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Presently, power quality issues are major concern in a power system. Phenomenon causes an interruption in the electrical system such as overvoltage, voltage sags, voltage surges and harmonics [2]. Harmonic happened when rapidly growth of non-linear load. Harmonic distortion problem has existed in the power system for a long time. It causes a waveform of the line current and voltage in the power system to be distorted. At present, the creation of modern equipment, especially electronic equipment and widespread use of non-linear loads in industry has produce harmonic distortion.

Harmonic effects that occur in the electrical system depend on the harmonics source, the location of the power system and network features that allow the propagation of harmonic. The main cause leading to the generation of harmonics the use of non-linear loads such as discharges lamps, office equipment such as computers and electronic equipment, power semiconductor switching devices such as rectifiers and inverters that can distort the sine wave and so on. The waveform of voltage and current in the electrical system is disturbed by harmonics usually no longer pure sine waveform. The waveform of the line voltage is usually satisfactory, but for line current harmonic distortion occurs.

Filter widely used as solution for power quality problem. There are two kinds of filter used to reduce interference harmonic in power supply namely active filter and passive filter. In the past, the passive filter is used as a solution to reduce harmonic problems in power systems. However, according to [4], it presents some disadvantages in its operations. Therefore, in recent time, active filter was developed to overcome these problems.

A three phase shunt active filter is a one of filter used to reduce harmonic distortion in power system. Consequently, the purpose of this project is to design and development of a three phase shunt active filter as an alternative to reduce harmonic distortions which disturb performance of power quality in power system. Shunt active filter was developed with a control system based on P-Q theory. The MATLAB/SIMULINK software is the methods that be used to design the three phase shunt active filter with a control system based on P-Q theory. The simulations were carried out for different waveform either linear or non-linear load. Graph of total harmonic distortion also have been implemented in order to analyse the result from this experiment.

1.2 Problem Statement

Harmonic distortion can cause serious problems to both industrial and electrical consumers. According to an EPRI report, the economic losses due to poor power quality are $400 billion dollars a year in the U.S. alone. Harmonic problem consists of two terms which are harmonic voltage and current. Present of harmonic voltage distortion occur from disturbance that generated by harmonic current resulting voltage drop in the source impedance. It also caused disruption to the sinusoidal wave of voltage. Therefore, all types of loads, linear loads will be distorted by the harmonic carried by supply and harmonic current will be generated. This effect is caused by damage to the sinusoidal waveform voltage. Harmonic current distortion factor can cause the harmonic multiples of 3 that do not have 120^o in the phase shift due to overload occur in the neutral conductor and so on. Based on these problems a mitigation technique for harmonic reduction or compensation was developed in order to eliminate harmonics in electrical network. The powerful solution for harmonics compensation by using active power filter based on P-Q theory. To demonstrate the performance of active filter for current harmonic reduction, a software MATLAB/SIMULINK will be used.

1.3 Project Objective

This project is to analyse, identify, and create the solution of current harmonic reduction in the electrical distribution system due to non-linear load. Objective identified is as follows:

i. To design and develop of a three phase shunt active filter based on PQ theory and its parameter using MATLAB/SIMULINK.

1.4 Scope of Project

The scope of this project is to study the sources and effects of current harmonic distortion in electrical distribution. The best method or solution for current harmonic reduction will be implemented. An active filter based on P-Q theory will be developed as a mitigation device in order to reduce or eliminate harmonic in electrical network. The software based on MATLAB/SIMULINK will be used to model the system. The final projects are only performing the analysis based on simulations the being applied to the MATLAB/SIMULINK block sets.

1.5 Project Outline

Fundamentally, this final year project can be divided into five main sections. The sections were introduction, literature review, methodology, result and conclusion and conclusion and recommendation.

- Chapter 1 gave slightly entire introduction regarding this project. It was include objective, scope of the project, problem statement and project overview which has been using to inclusive the project.

- Chapter 2 explains about project information that consisting of generation of harmonic, harmonic effect due to the harmonics current distortion problem, harmonic mitigation technique and filters that used to reduce harmonics distortion problem.

- Chapter 3 explains about methodology of this project. It does include the main circuit design, three phase shunt active filter circuit design, control method circuit design that is P-Q theory and its mathematical model equation.

- Chapter 4 shows the result of simulation circuit design. It does include the graph of simulation results without using shunt active filter for load current and source current, graph of simulation results using shunt active filter for load current and source current, graph of total harmonic distortion for source current and load current by using or without using three phase shunt active filter and result of compensating current (active filter current).

- Chapter 5 which is the last chapter discussed the conclusion and recommendation concerning the project which has been implemented.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Harmonics

The voltages and currents in the power circuit are frequently not pure sine waves. The distortion of a voltage or current can be traced to the harmonic. Harmonic content in the electrical system will cause a waveform of voltage and current to be distorted. Harmonic analysis is the process of calculating the magnitude and phase angle of fundamental and harmonic waveform. Set of sine waves in which the lowest frequency is f, and all other frequencies are integral multiples of f. The sine wave having the lowest frequency called the fundamental and the other waves are called harmonics. By theory, the sum of a fundamental voltage and a harmonic voltage yields a non-sinusoidal waveform whose degree of distortion depends upon the harmonics it contains. Harmonic distortion is present in both the current and voltage waveform. Most distortion of current is produced by electronic loads, also known as non-linear load.

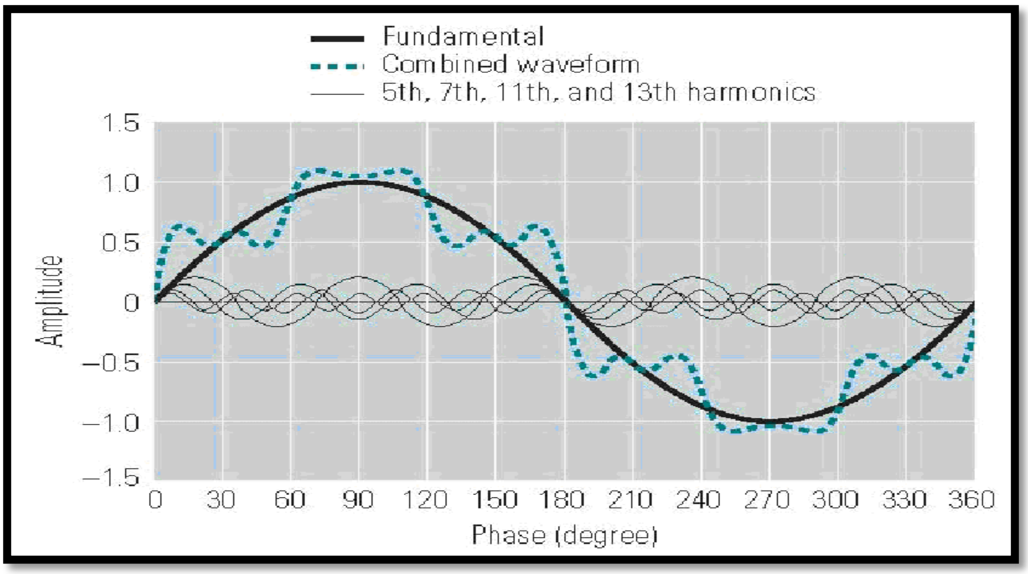

Figure 2.1: Distorted Current Waveform [1]

2.1.1 Linear Loads

In linear system which is a circuit with ideal resistors, capacitors and inductors, the characteristics of the voltage and current are sinusoidal in nature. The current contains only one frequency. The mains frequency or called fundamental. Beside this 50 Hz component, at which the supply system is designed to operate, there are no other frequencies and no harmonic components [2]. A linear element in a power system is a component in which the current is directly proportional to the applied voltage. Equipment that produce linear load are mostly in household appliance such as iron, blender, and toaster.

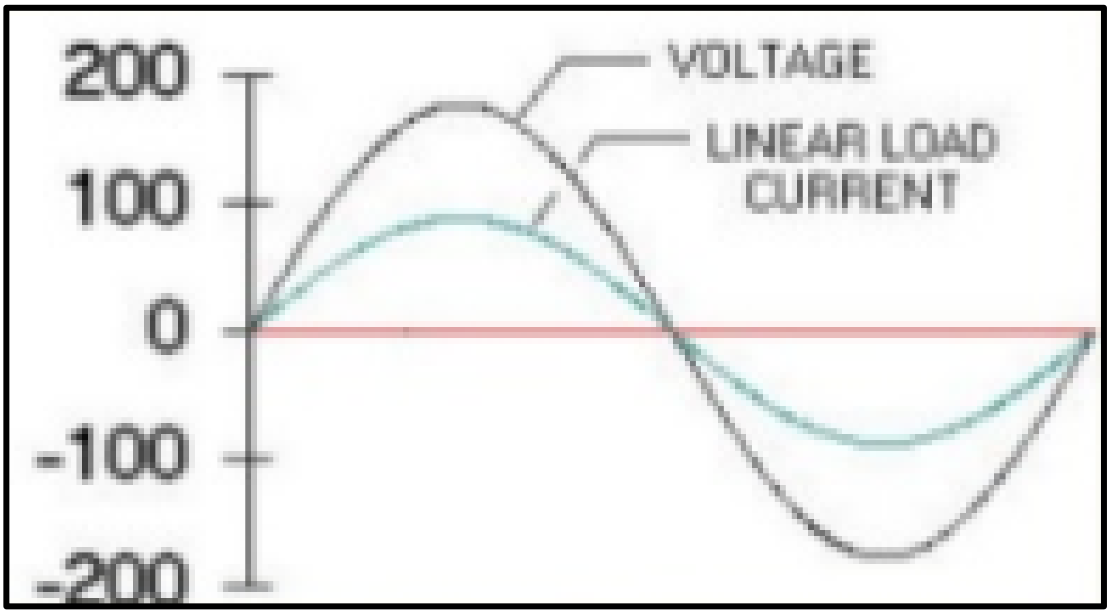

Figure 2.2: Linear Load Waveform [2]

2.1.2 Non-linear Loads

Non-linear loads occur when the impedance is not constant. Non-linear load cause current is not proportional to the applied voltage. The current drawn by non-linear loads is not sinusoidal but is periodic, that means the current waveform looks the same from cycle to cycle [2]. In non-linear load, the consumer pays for unused an energy due to both voltage and current distortion. Non-linear loads consist of two types. There are single phase and three phase.

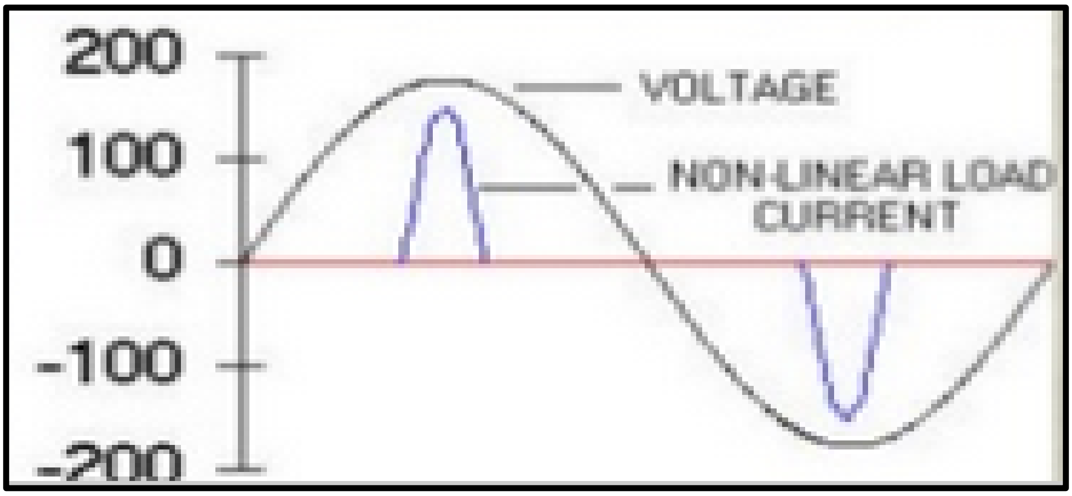

Figure 2.3: Non-linear Load Waveform [2]

2.1.3 Single Phase and Three Phase Load Harmonics

Single phase non-linear loads like electronics ballast, personal computers, and other electronic equipment. Single phase non-linear loads generate odd harmonics that is 3th, 5th, 7th, 9th and so on. The troublesome harmonics for single phase loads are 3rd harmonic and triplen harmonics or so called multiple of 3rd harmonics that is 9th, 15th and so on.

Three phase non-linear loads like three phase DC driven, three phase rectifier, and not generate current triplen harmonics (3rd, 9th, 15th,). Three phase non-linear loads generate primarily 5th and 7th current harmonics and a lesser amount of 11th, 13th and higher order [2].

2.2 Generation of Harmonics

Harmonics are generated when a load draws a non-linear current from a sinusoidal voltage. The line voltages usually have a satisfactory wave shape but the currents are sometimes badly distorted. The distortion of a voltage or current can be traced to the harmonics it contains. The current harmonics is the actual cause of generation of harmonics.

Harmonics are created by increased use of non-linear devices such as uninterruptible power supplies (UPS) system, variable speed motor drives, rectifier and personal computer. Presently, all computers use Switch Mode Power Supplies (SMPS) that convert AC voltage to regulate low voltage DC for internal electronics [1]. Any SMPS equipment installed anywhere in the system have an inherent property to generate continuous distortion of the power source that puts an extra load on the utility system and the components installed in it [1]. Variable speed drives are usually depends on the number of rectifiers in the power system [2].

All electronic loads produce positive and negative sequence harmonics currents, zero sequence harmonics currents, and single phase electronic loads connected phase neutral in a 3 phase 4 wires distribution system [2]. Harmonics are consists of three type of components that are positive, negative and zero sequence. Harmonics components are divided into different components [2]. The components show the rotational direction of the harmonic phase with respect to the fundamental frequency. For positive sequence harmonics is 1^{st}, 4^{th}, 10^{th}, 13^{th}, and so on. For negative sequence harmonics is 2^{nd}, 5^{th}, 8^{th}, 11^{th}, 14^{th}, and so on whereas for zero sequence is triplen harmonics that is 3^{rd}, 6^{th}, 9^{th}, 12th, and so on. Harmonics also divided into even and odd harmonics.

2.2.1 Equipment that Generate Harmonics

Referring to [4], all non-linear loads cause of harmonics load currents. There is a lot of type of industrial equipment that generate harmonics. The loads can be divided into two types single phase loads and three phase loads. The examples of single phase loads are switched mode power supplies (SMPS), small uninterruptible power supplies (UPS) units, and electronic fluorescent lighting ballasts. The examples of three phase loads are variable speed drives and large UPS units.

Presently, all computers use Switch Mode Power Supplies (SMPS) that convert AC voltage to regulate low voltage DC for internal electronics [1] where in the past, step down transformer and rectifier used to convert AC voltage to DC voltage for electrical and electronic equipment. The advantage of used a SMPS are such as the power units can be made in almost any required form factor, less cost, small size and more light.

While, the disadvantage of SMPS are such as the power supply unit will generate a current pulse that contains a large amount of the 3rd harmonics and high frequency significantly as shown in Figure 2.4 [4].

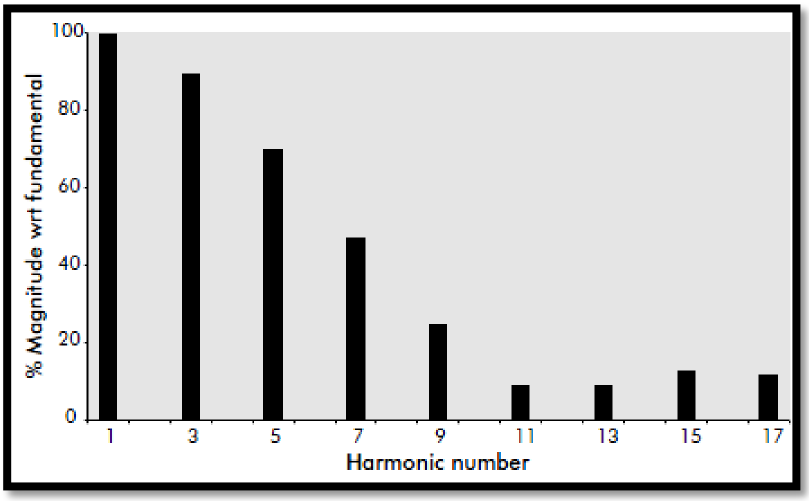

Figure 2.4: Harmonic spectrum of a typical PC [4]

Referring to [4], fluorescent lighting ballasts is one of equipment that generate harmonics. In recent years, electronic lighting ballasts have become popular due to improving energy efficiency. However, the efficiency of electronic ballasts and magnetic ballast are only slightly different if more efficient magnetic ballast used. The advantages of fluorescent lighting ballasts is light level can be maintained throughout a long life by feedback control of current flow while the disadvantage using fluorescent lighting ballasts is it will generate harmonics in the supply current.

Presence, compact fluorescent lamps (CFL) are selling as a substitute of tungsten filament bulbs that consists of a small of electronic ballast that housed in connector casing, folded 8mm control fluorescent tube diameter. Referring in [4], these lamps are widely used to replace filament bulbs especially in hotel that domestic properties where serious harmonic problems are suddenly becoming common. Figure 2.5 shows the graph of harmonic current of typical CFL that also contains a large amount of the 3rd harmonics and high frequency significantly. The graph shown for each harmonic that consists of fundamental (1st), 3rd harmonic, 5th harmonic, 7th harmonic, 9th harmonic, 11th harmonic, 13th harmonic,15th harmonic, 17th harmonic.

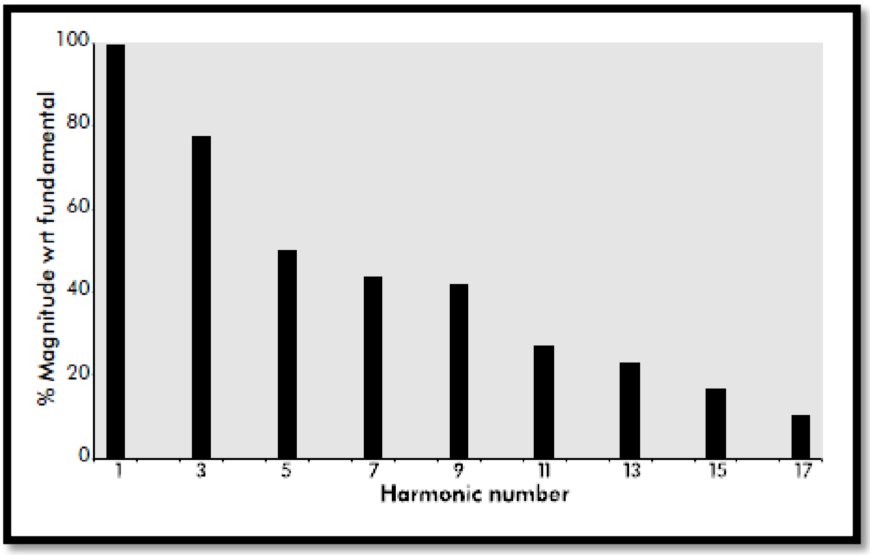

Figure 2.5: Harmonic spectrum of a typical CFL [4]

2.3 Harmonic Effects

Harmonics practically effect to every equipment in the power system. Many effects had been contributed from harmonics distortion. Some adverse effects of harmonics listed as follows [4]:

- Malfunction in electronics devices and computer equipment
- Errors in measurements
- Overheating and over stressing of insulations
- Lamp flicker when harmonic pulses involved
- Sometimes machine vibrates
- Blowing out of small auxiliary devices like fluorescent lamp capacitors.
- Distortion of main supply voltage, unwanted currents flowing in the supply network generate additional energy losses.
- Defective operation of regulating devices, disturbed operation of fluorescent lamps, television receivers or other equipment.
- Telephone interference
- High harmonic amplitudes may not only cause malfunctions, additional losses and overheating, but also overload the power distribution network and overheat the neutral conductor and cause it to burn out.