MITIGATION OF POWER QUALITY PROBLEMS USING ACTIVE POWER FILTER

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"I declare that this thesis entitled 'MITIGATION OF POWER QUALITY PROBLEMS USING ACTIVE POWER FILTER' is the result of my own effort with the exception of excerpts cited from other works of which the sources were duly noted."

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Date : 5 JUNE 2014

"I declare that I have read this work and in my opinion this work is adequate in terms of scope and quality for the purpose of awarding a Bachelor's Degree of Electronics Engineering (Telecommunication Electronics)."

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Special dedicated to my beloved family, lecturer, friend and those people who have guided and inspired me throughout my journey of education.

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ABSTRACT

One of the most important aspects of both power transmission and distribution level is power quality which can be defined as the delivery of sufficiently high-grade electrical services to the consumer. Harmonic is one of the interference which caused poor power quality. Harmonic disturbance causes electric equipment to heat up and cannot function properly. Thereby, the aim of this project is to design and develop a three phase shunt active filter based on P-Q theory in order to mitigate current harmonics for low voltage distribution system. The MATLAB/SIMULINK software is used for circuit design and its parameters of a three phase shunt active power filter. Based on P-Q theory, the performance of shunt active power filter for harmonic compensation will be analysed. There are four steps involved in developing a harmonic reduction to ensure the objectives of the project are achieved. Firstly, the information related to the project are identified and searched. Second, determine the appropriate circuit design to create a three phase shunt active power filter. The third stage is a simulation of a circuit design using MATLAB/SIMULINK software. Lastly, the final stage is involves final results and analyse the outcome of experiment results. Simulations results of a three phase shunt active power filter effectively designed based on P-Q theory shows that harmonics distortion are mitigated.

ABSTRAK

Salah satu aspek yang paling penting di kedua-dua peringkat penghantaran dan pengagihan adalah kualiti kuasa yang boleh ditakrifkan sebagai penyampaian perkhidmatan elektrik gred tinggi secukupnya kepada pengguna. Harmonik adalah salah satu gangguan yang disebabkan oleh kelemahan kualiti kuasa. Gangguan harmonik menyebabkan peralatan elektrik yang digunakan akan menjadi panas dan tidak boleh berfungsi dengan baik . Oleh itu, tujuan projek ini adalah untuk mereka bentuk dan pembangunan tiga fasa shunt penapis aktif berdasarkan teori PQ untuk mengurangkan arus harmonik dalam sistem pengagihan voltan yang rendah. Perisian MATLAB/SIMULINK digunakan untuk reka bentuk litar dan parameternya daripada tiga fasa Shunt penapis kuasa aktif. Berdasarkan teori PQ, prestasi shunt penapis kuasa aktif untuk pengurangan harmonik akan dianalisis. Terdapat empat langkah yang terlibat dalam membangunkan pengurangan harmonik bagi memastikan objektif projek tercapai. Pertama, maklumat yang berkaitan dengan projek dikenal pasti dan dikaji. Kedua, menentukan reka bentuk litar yang sesuai untuk menghasilkan tiga fasa shunt penapis kuasa aktif. Peringkat ketiga adalah simulasi reka bentuk litar menggunakan perisian MATLAB/Simulink. Akhir sekali, peringkat terakhir adalah melibatkan keputusan akhir dan menganalisis hasil hasil keputusan eksperimen. Keputusan simulasi tiga fasa shunt penapis kuasa aktif yang direka dengan berkesan berdasarkan teori PQ menunjukkan bahawa herotan harmonik dapat dikurangkan.

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AC	-	Alternating Current
DC	-	Direct Current
IGBT	-	Insulated Gate Bipolar Transistor
VSI	-	Voltage Source Inverter
THD	-	Total Harmonics Distortion
IEC	-	International Electrotechnical Commission

CHAPTER 1

INTRODUCTION

1.1 Background of project

Nowadays, power quality problems are becoming a big concern of today's power system. The overvoltage and harmonics are examples of phenomenon that causes an interruption in the electrical system. Harmonics distortion plays an important role in deteriorating power quality. The widespread use of nonlinear loads is the reason of harmonic distortion happen in electric distribution system. Example of non-linear load that can distort the sine wave are office equipment (computers and electronic equipment), power semiconductor switching devices (rectifiers and inverters). By generating harmonic comes from nonlinear load, will involve a major problem in the power distribution system such as increases losses, increase the total harmonic distortion, power factor is low and mitigate the efficiency.

In the electrical system, the effect of harmonic depends on it source and also advance power system and network location that allow the propagation of harmonic. After been affected by the harmonic, sine wave of voltage and current usually will not be in the pure sine wave. Usually the line voltage will not change as the harmonic distortion occurs, but the line current will occur (the harmonic distortion).

Due to the harmonics problem, the usual and common solution to mitigate it was using a filter. Two types of filters are normally used to decrease the harmonic of interference in power supply. They are active and passive filter. Previously, the passive filters can be used as a way to solve the problems of harmonic currents, but there are some disadvantages. Some of them are, they only filter the frequencies they were formerly tuned for. The resonance can occur because of the interaction between the passive filters and others loads, with unexpected results. As the problem occur during implementing the passive filter, the active filter had been use to overcome passive filter.

Other than that, a three phase shunt active filter can mitigate harmonic disturbances in power system. Consequently, the project's objective is to use the three phase shunt active power filter as another solution in mitigation of harmonic distortions. The harmonic distortion also can disturb the performance in power quality for power system. The control system of P-Q theory will be used to develop shunt active power filter. The output waveform will be carried out in a simulation. The simulations will simulate the different waveform for linear and non-linear load. As to analyse the harmonic distortion, appropriate graph of total harmonic distortion also implemented as the result of the project.

1.2 Problem Statement

Nowadays, issues that become a major concern in power system distribution were power quality. Harmonics play an important role in deteriorating power quality, which is called as harmonic disturbances. Problem of harmonics consists of two terms which are harmonic voltage and current. The problem starts when harmonic current resulting a voltage drop in the source impedance. This problem will produce the harmonic voltage distortion. It also causes disruption to the sinusoidal waveform voltage. Therefore, any sorts of loads that connected to the same source will be distorted by the harmonic carried by supply and harmonic current will be generated. By referring to these problems, a harmonic reduction will be solved by mitigation technique that been developed so that it can reduce harmonic in electrical distribution system. For harmonics compensation, the best solution is using active power filter based on P-Q theory. MATLAB/SIMULINK software will be used to show and analyze the performance of shunt active power filter based on the P-Q theory that can be as current harmonic reduction.

1.3 Objectives of Project

The objectives of project aim to analyze, identify, and create the elucidation of current harmonics due to non-linear load happens in the electrical distribution system. The project objectives are shown as below:

i. To identify a solution that can mitigate the harmonics distortion for low voltage 415V in three phase source.
ii. To design and develop a circuit of shunt active power filter by using MATLAB/SIMULINK simulation software based on P-Q theory.

1.4 Scope of Project

This project involves into two major parts which are shunt active filter and P-Q theory. By combining of shunt active filter and P-Q theory, a filter circuit with the 3-phase characteristic can be obtained. The three phase shunt active power filter is used as a solution to mitigate harmonic disturbances which can interfere the power quality performance in electrical distribution. This filter will be design based on 3-phase source but more focuses on low voltage which is about 415V. This project will only use MATLAB/SIMULINK software that will easily demonstrate the result in the real time without using actual 3-phase source.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, literature reviews about the project are explained in details. An overview of some topics that similar to the project and related project design are presented. Below describes in details all literature review that has been done.

2.2 Harmonics

According to [1], in electrical power, harmonics refers to a sinusoidal waveform that a multiple of the frequency of the system. Consequently, the frequency which is three times the fundamental is classified as 3^{rd}harmonics, five times the fundamental is 5^{th} harmonics, and so on. Therefore, the harmonics of a system can be state generally using the equationbelow:

$$f_h = hf_{ac}$$

Where f_h is the h^{th} harmonic and f^{ac} is the fundamental frequency of the system.

Harmonic frequencies are integral multiples of the fundamental supply frequency such as for a fundamental of 50 Hz, the3^{rd} harmonic would be 150 Hz and the 5^{th} harmonic would be 250 Hz. Figure 2.1 shows a fundamental sine wave with 3^{rd} and 5^{th}harmonics.

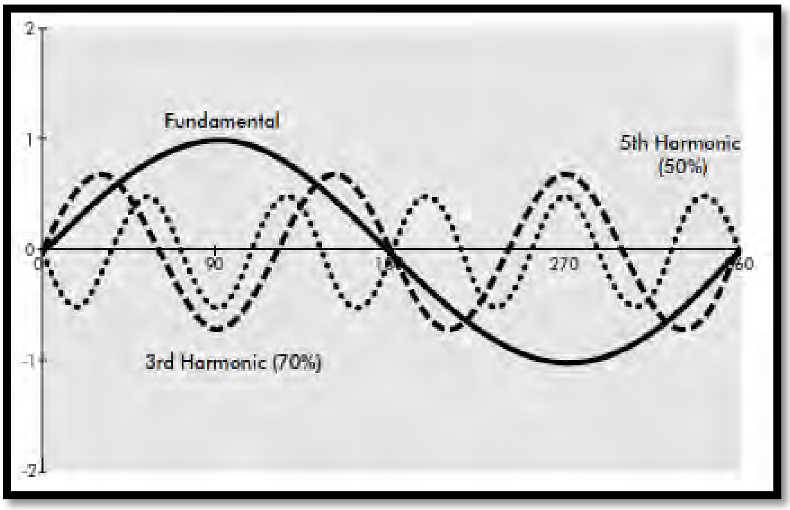

Figure 2.1: Fundamental with 3^{rd} and 5^{th} harmonics

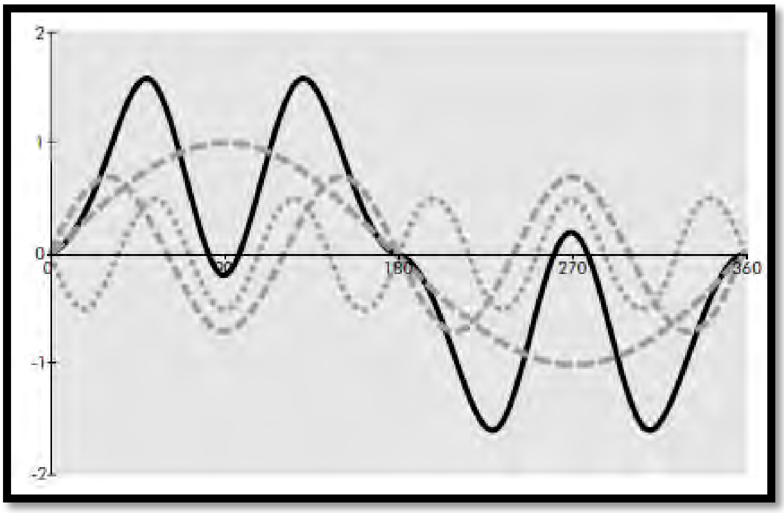

Figure 2.2: Distorted current waveform

Figure 2.2 shows a fundamental with 70 % 3^{rd} harmonic and 50 % 5^{th} harmonic added. However, in practical, more distorted current waveforms will be much more complex than this example, which are containing much harmonics with a much complex phase relationship. This waveform is obviously not a sine wave and that means the normal measurement equipment such as rms-calibrated multimeters, will give inaccurate readings. [2]

2.3 How Harmonics are Generated

The current and voltage waveforms are pure sinusoids in a real clean power system. However, in practice, result will be non-sinusoidal currents when the current that flowing in the load is not linearly to the applied voltage. Figure 2.3 shows the condition where the load with simple full-wave rectifier and capacitor, for example the input stage of a switched mode power supply. In this situation, the flowing of current only occurs when the supply voltage exceeds that is stored on the reservoir capacitor, such as close to the voltage sine wave's peak, as shown by the shape of load line.

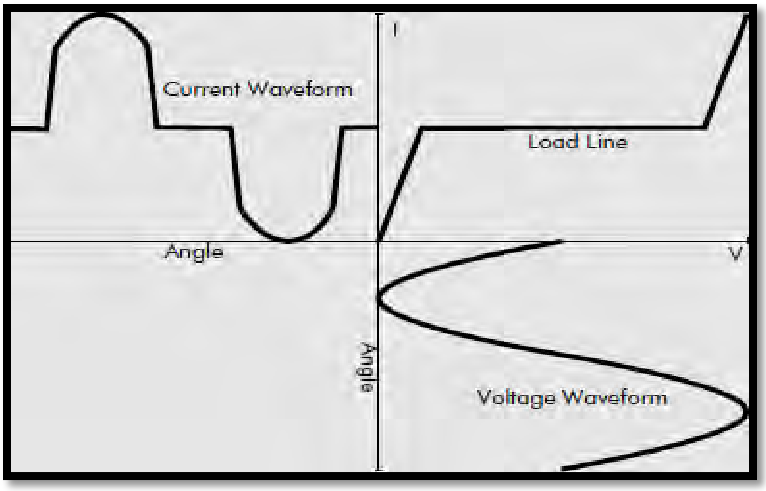

Figure 2.3: Current waveform in a non-linear load

In practice also, the load line (hence the current waveform) is likely to be more complex than shown in the example mention above. There may be some asymmetry and the breakpoints and slopes will alter with loading.

Any cyclical waveform can be deconstructed into a sinusoid at the frequency of the fundamental plus a number of sinusoids at the harmonic frequencies. Thus the distorted current waveform in Figure 2.3 can be represented by the fundamental plus a percentage of 2^{nd} harmonic plus a percentage of 3^{rd} harmonic and so on, possibly up to the 30^{th} harmonics. [2]

2.4 Harmonics Generation

The actual cause of harmonics generation is the current harmonics. As load draws a non-linear current from a sinusoidal voltage the harmonics will be generated. Then, the wave shape for the currents sometimes seriously distorted while the line voltages will maintain a same wave shape without distortion. At the harmonic itself, it can trace the distortion of a voltage or current. Generating of harmonics was cause by the current harmonic.

Harmonics can be obtained by increasing use of non-linear devices for example, rectifier, variable speed motor drives, and computer. At present, Switch Mode Power Supplies (SMPS) have been used for personal computer which is convert AC voltage to regulate low DC voltage. Any SMPS equipments have an inherent property to generate nonstop distortion of the power source and then put more load on the system and the components installed in it. The number of the rectifier in the power system can control the variable speed drives.

The connected neutral phase of three phase four wire distribution system can produce positive, negative and zero sequence harmonics currents, and also single phase electronic loads from all electronic load. Harmonic can be divided into three types of components. They are positive, negative and zero sequence. Harmonic also can be separated into different components. The components show the rotational direction of the harmonic phase with respect to the fundamental frequency. For positive sequence harmonics is 1st, 4th, 10th, 13th, and so on. For negative sequence harmonics is 2nd, 5th, 8th, 11th, 14th, and so on whereas for zero sequence is triple harmonics that is 3rd, 6th, 9th, 12th, and so on. Harmonics also separated into even and odd harmonics part. [1]

2.5 Effects of Harmonic

All equipment in any power system can be practically effect by harmonic. The contribution of the harmonics distortion was also come in various effects. Several adverse effects of harmonics listed as below:

- The electronics devices can’t function properly.
- Measurements error
- The harmonic pulses causes lamp to be flicker.
- Distortion of main supply voltage, unwanted currents flowing in the supply network generate extra energy losses.
- Defective operation of regulating devices, disturbed operation of fluorescent lamps, television receivers or other equipment.
- High harmonic amplitudes can overload the power distribution network and the neutral conductor can be overheat and become the reason to burn out.

2.6 Mitigation Technique of Harmonic and Filters

Due to the intensive use of the non-linear loads, it can be observed arising deterioration voltage and current waveforms of the power systems. The presence of harmonics in the system power lines produces in greater power losses in distribution, interference trouble in communication systems and malfunction of electronic equipments, which are more sensitive since they consists of microelectronic control systems, that is work with very low energy levels. Because of these problems, the issue of the power quality delivered to the end consumers is an object of great concern.

Filters widely used as a method for reducing power quality problem by referring to [7]. Effects from harmonic can be minimize by using filters for non-linear loads and connected in the distribution system network. Then, to reduce harmonic will be achieved when using filter. To overcome this problem, filter needed is depending on non-linear load. Referring to the offer a simple and inexpensive alternative, filter come with a high advantage. Disturbance of harmonic in electrical distribution network can be categorized by two, which are passive power filter and active power filter.

Usually, the passive power filters are simple and cheaper cost. Nevertheless, passive power filter comes with their disadvantages itself, for example the frequencies is only filtered which is formerly tuned for, the interaction between the passive filters and other loads can causes to resonances, with unpredictable results. Recent efforts have been focused in the improvement of active filters to overcome disadvantages.

There are two types of active filter for mitigate the harmonics which are series active power filter and shunt active power filter. However, shunt active power filter is the one of the best active filter which is making three phase circuit between the sources of voltage with a non-linear load. After that, the circuit will be connected in parallel to the shunt active power filter in order to reduce harmonic disturbances which can be interfere to the power quality performances in electrical distribution.

2.7 Shunt Active Power Filter with P-Q Controller

The function of active filter controller with P-Q theory is to determine reference currents. Both load current waveform and source voltage waveform are the input of this controller. The designing of shunt active power filter is to decreases harmonic distortion of current that comes from non linear load.

Instantaneous reactive power theory which is formally known as P-Q theory was proposed by *Akagi et al*. (Hirfumi 1983 and Hirfumi 1984) to control active filters [8]. It is based on a set of instantaneous powers defined in time domain. It can be applied to three-phase systems with or without a neutral wire for three-phase voltage and current waveforms [5].

The voltages and currents in P-Q theory convert from *a-b-c* to *α-β-o* coordinates, and based on these coordinates, instantaneous power is defined. The *α-β-o* transformation also can be defined as the *Clarke* transformation. These include a matrix form that converts three-phase current and voltages into the *α-β-o form.* The *α-β-o* transformation or the *Clarke* transformation maps the *a-b-c* phases of three-phase voltages and current into the *α-β-o* axes of instantaneous voltages and currents [5].

According to [9], the *Clarke* Transformation (Hirfumi 1999) of three-phase generic voltages and load currents are stated as below:

$$\begin{bmatrix} v_o \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} i_o \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (2)$$

The instantaneous powers of the P-Q theory are:

$P_o = v_o i_o$ is the instantaneous zero-sequence power (3)

$P = v_\alpha i_\alpha + v_\beta i_\beta$ is the instantaneous real power (4)

$q = v_\alpha i_\beta - v_\beta i_\alpha$ is the instantaneous imaginary power (5)

Moreover, the power components p and q in three phase three wire systems are related to the same αβ voltages and currents. This can be written together as below equation:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (6)$$

These quantities for an electrical system distribution represented in *a-b-c* coordinates are illustrated in Figure 2.4 and have the following physical meaning:

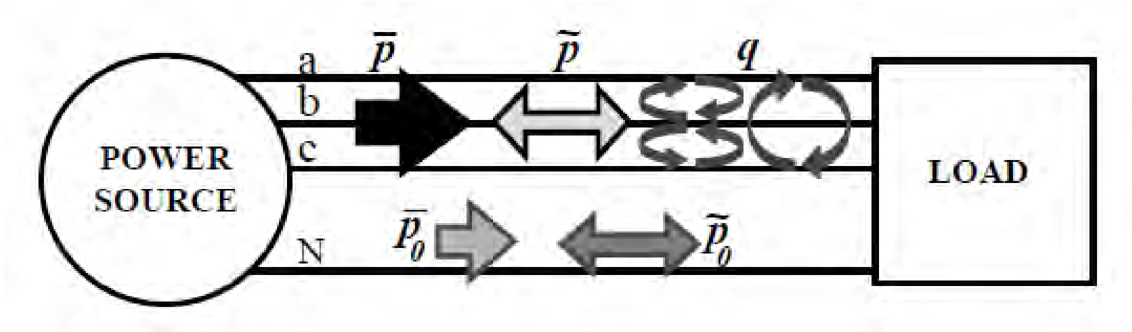

Figure 2.4: Power components of the p-q theory in *a-b-c* coordinates.

The value of the instantaneous zero-sequence power can be referred as $\bar{P}o$. It is corresponds to the energy per time which is transferred from the main power supply to the load through the zero-sequence components of the current and voltage.

The alternated value of the instantaneous zero-sequence power can be referred as $\tilde{P}o$. The energy per time unity is exchanged between the power supply and load through the zero-sequence components. The zero-sequence power only occurs in three phase systems distribution with neutral wire. Moreover, the systems have unbalanced currents and voltages and/or 3rdharmonics in both current and voltage of at least one phase.

The value of the instantaneous real power can be referred as $\bar{p}$. It corresponds to the energy per time unity which is transferred from the main power supply to the load, in a balanced way (it is the desired power component) through the *a-b-c* coordinates.

The alternated value of the instantaneous real power can be referred as $\tilde{p}$. It is the energy per time unity that is exchanged between the power supply and the load through the *a-b-c* coordinates.