DESIGN AND DEVELOPMENT OF ACTIVE POWER FILTER FOR HARMONIC REDUCTION IN ELECTRICAL DISTRIBUTION SYSTEM

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"I declare that this report entitle "Design and Development of Active Power Filter for Harmonic Reduction in Electrical Distribution System" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)".

Signature :

Supervisor's Name : Associate Professor Ir. Dr. Rosli Bin Omar

Date : 24th June 2016

"I declare that this report entitle "Design and Development of Active Power Filter for Harmonic Reduction in Electrical Distribution System" 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."

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ABSTRACT

Owing to the loads from power consumers and power equipment manufacturer, electrical equipment application has been grow drastically. These matters become more serious because the effect from the electrical equipment can cause high non-linear load for example electric drills, computer, TVs, printer and electronic equipment like thyristor converter, inverter and etc. This semiconductor can contribute in producing harmonics these is because the above load can produce non-sinusoidal currents from supply and lead to voltage distortion [1]. The effect from the harmonics to distribution system is it can increase a wire failure, overheating of transformer, low power factor, blackout in power system and in neutral current conductor, there is an excessive neutral current. To overcome harmonic distortion, passive and active filter is use. But, passive filter can cause resonance problem thus can affect the stability of the power distribution system. As for active power filter, it can use to extract the harmonic content [3].

For this project, two main objectives need to be achieved. First is to study the concept of active power filter (APF) for harmonic reduction in electrical distribution system and secondly, to model and develop active power filter configuration harmonic reduction. The distorted waveform in term of current and its controller based on PQ theory due to non-linear load in electrical distribution system will be monitored based on proposed circuit design with its controller using MATLAB/Simulink. The simulation results of currents and their THD at

source and load current will be discussed before and after compensation using active power filter (APF).

ABSTRAK

Disebabkan beban daripada pengguna kuasa dan pengeluar peralatan kuasa, permohonan peralatan elektrik telah berkembang secara drastik. Perkara-perkara ini menjadi lebih serius kerana kesan daripada peralatan elektrik boleh menyebabkan beban bukan linear yang tinggi sebagai contoh latihan elektrik, komputer, TV, pencetak dan peralatan elektronik seperti penukar thyristor, inverter dan lain-lain semikonduktor ini boleh menyumbang dalam menghasilkan harmonik ini adalah kerana beban di atas boleh menghasilkan arus bukan bentuk sinus dari bekalan dan membawa kepada voltan penyelewengan.

Kesan dari harmonik untuk sistem pengedaran adalah ia boleh meningkatkan kegagalan wayar, terlalu panas pengubah, faktor kuasa yang rendah, blackout dalam sistem kuasa dan konduktor semasa neutral, ada arus neutral berlebihan. Untuk mengatasi herotan harmonik, penapis pasif dan aktif digunakan. Tetapi, penapis pasif boleh menyebabkan masalah resonans dengan itu boleh menjejaskan kestabilan sistem pengagihan kuasa. Bagi penapis kuasa aktif, ia boleh menggunakan untuk mengeluarkan kandungan harmonik.

Untuk projek ini, dua objektif utama perlu dicapai. Pertama adalah untuk mengkaji konsep penapis kuasa aktif (APF) bagi pengurangan harmonik dalam sistem pengagihan elektrik dan kedua, untuk menjadi dan membangunkan aktif kuasa penapis konfigurasi pengurangan harmonik. Bentuk gelombang silap di dalam tempoh semasa dan pengawalnya berdasarkan teori PQ kerana tidak linear beban dalam sistem pengagihan elektrik akan dipantau berdasarkan reka bentuk litar yang dicadangkan dengan pengawalnya menggunakan

MATLAB / Simulink. Keputusan simulasi arus dan THD mereka di sumber dan beban semasa akan dibincangkan sebelum dan selepas pampasan menggunakan penapis kuasa aktif (APF).

CHAPTER 1

INTRODUCTION

This chapter covers the introduction of the project focusing on the research background. The motivation and significant of the research is will be explain in this chapter. Based on motivation, the problem statement of this project has been identified. The objectives for this project will be discussed briefly and the project scopes are determined and lastly, the report outline is implemented.

1.1 Introduction

Higher demand of power electronics equipment has contributed to increase in harmonics in the power system. One of the examples that contribute to higher current harmonics occurs is nonlinear load. These will lead to effect in a power factor reduction, decrease in efficiency, power system voltage instabilities and communications interference. It can be consider that harmonic can be categorized as pollutant in electrical power system. Conventionally, LC filters was used as a solution for the problems caused by the system harmonics, since they are easy to design, have simple structure, low cost and high efficiency but it also bring disadvantages like controllers many drawbacks. It provides only fixed compensation,

generates resonance problems and is massive in size. To overwhelmed these weaknesses, active power filters are introduced which recompense for the current harmonics and reduces the total harmonic distortion. The APF is connected in parallel with the line through a coupling inductor. Its main power circuit contains of a three phase current source inverter with a DC link capacitor. An active power filter operates by generating a compensating current with 180 degree phase opposition and injects it back to the line so as to cancel out the current harmonics introduced by the nonlinear load. This will thus defeat the harmonic content present in the line and make the current waveform sinusoidal.

So the process includes of detecting the harmonic component present in the line current, producing the reference current, generating the switching pulses for the power circuit, making a compensating current and injecting it back to the line.

1.2 Motivation and Significant of the Research

Non-linear load can produce a distorted waveform in term of current and voltage in power system thus can reduce the performance of the system in short term or long term. The effect from the harmonic frequencies in the power grid is a common cause of power quality problems. Harmonics in power systems result in increased heating in the equipment and conductors, failing in variable speed drives, and torque pulsations in motors. Due to this, it is very important to protect the system supply from harmonic using APF. These devices will mitigate any harmonic due to nonlinear load.

1.3 Problem Statement

Current harmonics is very normal in electrical distribution system. The main problem of harmonic will distort electrical system due to high contents of harmonic. In order to avoid harmonic in electrical distribution, a proposed method based on filtering will be investigated. The proposed topology of a three phase active power filter will be modelling using MATLAB/SIMULINK. The load in electrical distribution system can be categories as linear and non-linear load. Non-linear load can produce non-sinusoidal current starting the load and top to distort and damage the electrical supply. Therefore, the current which contain high harmonic in system can be reducing. The main determination of this project is to design and develop of a three phase active filter for harmonic reduction in electrical system.

1.4 Objectives

Based on this project, objective that have been identified are as follows:

1. To study the concept of active power filter for harmonic reduction in electrical distribution system.
2. To model and develop active power filter configuration and its controller based on P-Q theory for harmonic reduction using MATLAB/SIMULINK.

1.5 Scope

The scope of this project will be focusing on model, develop of an APF based on P-Q theory. The performance of APF will be monitoring and analyzing before and after filter installation.

1.6 Report Outline

This report starts with the introduction of the research; the general view on harmonics reduction and active power filter is stated. Next, the motivation is build based on the previous research that have been done and upgraded it by using different ways. The problem statement is stated based on motivation. Then, the objectives to overcome the problem are itemized. Next, the research confines are stated in the project scope.

CHAPTER 2

LITERATURE REVIEW

For this chapter, it will cover theory and basic principle of active power filter, review of previous works and also summary and discussion of the review. For the section theory and basic principle, it covers the harmonics, the basic of active power filter and passive power filter. As for review of previous related works, it covers method use to mitigate the harmonic reduction in power system. Lastly, for the summary and discussion of the review it will extract the features of the previous study and try to implement to this project.

2.1 Theory and basic principle

2.1.1 Power Filter Topology

The limitation for the harmonic distortion is needed to be considering as a serious problem for both suppliers and also customer views. There are some standard that determine the maximum allowable for harmonic distortion. Two type of common filter is use which is capacitor and inductor. When there is any excessive harmonic current or voltage generated, the filter will be act to diminish the harmonic distortion.

The role of this filter is connected to the power system is to shrink the harmonic distortion also for the converter method it provide some of the reactive power to be absorb. By installing this filter, it will hoped that it can help to reduce the harmonic distortion and make power system become more stable and the power pollution plus low power factor can be overcome.

2.1.2 Introduction in harmonics

The distortion happen on current and voltage waveform is called harmonic distortion. Harmonic is produce when there is non-linear load occurs in electric power system and can affecting the line systems [2]. Thus, it will affect the high losses for the system and also the quality of power produce. This phenomenon in the power system is not new. So, this is very important to overcome or to reduce the harmonic reduction.

Cause of affecting harmonic is the current flow is too high. Besides that, the length of the cable also can affect the high voltage distortion; it also can come from inverters, DC converters, switch mode power supplies, and AC or DC motor supplies [3]. There are many ways to overcome this problem. The basic thing that can be done by adding the filter means that by blocking the current flow or supply the harmonic current. Besides that, modify the frequency response also can prevent this happens by filter, capacitor or inductance. Plus, by reduce the harmonic current from the source also can be one of the ways [4][5].

There are two types of harmonic, current harmonics and also voltage harmonics. As for current harmonics, it occurs when a non-linear load for example rectifier has been mention above is connected to the system and draws a current that is so complex in sinusoidal waveform depending on the type of load used. So, it is impossible to produce a perfect and

smooth sinusoidal waveform. As for voltage harmonics, it caused by the current harmonics. Due to the source impedance, the voltage produce from the voltage source will be distorted from the current harmonics. If the source of voltage impedance is small, the voltage of harmonics also small due to current harmonics [2] [3].

2.1.2.1 The Impact of Harmonic in Electrical Distribution System

Based on power regulation and consumption, power quality becomes the main role in producing the high quality of power. When there is a harmonic in a system, it gives drastic effects onto the system. Harmonics occurs when power source acts as non-linear load. Below is an example of impact of harmonic in electrical distribution system.

- Transformers

Due to increase iron losses, it will affect the harmonics current at harmonic frequency and will result increase in core losses for example eddy current and hysteresis. If high rate of voltage is present, it will cause copper losses increase and stray flux losses produce heating and winding insulation stresses. Temperature cycling and resonance between transformer winding inductance and supply capacitance can contribute to additional losses. Normally, "K factor" rated unit be present typically acclaimed for non-linear load especially the distribution transformers used in four wire [6].

- Induction Motors

As in similar way, affect of harmonic distortion cause the raise of losses in AC induction motor. Thus, it can produce motor heating, due to losses iron and copper in the stator winding, rotor circuit and rotor lamination. Harmonic current in the stator and rotor end windings produce additional stray frequency eddy current dependent losses because of leakage magnetic field. Due to high frequency induced current and rapid flux changes in the stator and rotor, it will produce iron losses. Overheating can reduce the bearing lubrication and effect in bearing collapsed. The life span of the motor also can be reduced to 50% if the overheating always occurs. The squirrel cage motor can withstand in high temperature rather than wound motor [6].

- Cables

When the impedance is least, the current tend to flow near the surface of the conductor and this phenomenon called Skin Effect. This phenomenon occurs due to the arrangements of inductance of conductor is in closely parallel in one another. This effect depends on the conductor size, frequencies, resistivity and the permeability of the conductor material. When

- Lighting

A repeated fluctuation in light intensity is one of the phenomenon's that we called "flicker". Lighting is highly sensitive to rms voltage changes even there is only a slight deviation is perceptible to human eyes in some types of lamps. Causes of light flickers in incandescent lamp and fluorescent lamp are superimposed interharmonic voltage in distribution systems [6].

2.1.3 Types of devices been used in electrical distribution system in order to mitigate harmonic.

Other types of devices that can mitigate the harmonics besides filter is as follow:

- ✓ Using 6 pulse, 12 pulse, 18 pulse or 24 pulse rectifier

Six-pulse diode rectifier is the common rectifier use in three-phase PWM drives. The advantage of this rectifier is, rugged, robust and cheap but the input current have high low order harmonics. Two six-pulse rectifier have to be connect in parallel to feed the same DC bus for twelve pulse rectifier to be formed. By fed through a special transformer with two secondaries, it produce a smooth current waveform other than single six-pulse rectifier. The 18 and 24 pulse have same by connecting three or four six pulse rectifier and it cost a lot for the installation [14].

- ✓ Using an active IGBT rectifier

An active Insulated Gate Bipolar Transistor (IGBT) rectifier is a rectifier that can be used to control the power from the source of network. This can effect the power factor to be close to unity as rectifier is use to decrease the harmonic.

The advantage of IGBT rectifier is low sinusoidal current, unity power factor, voltage boost capability and possibility to generate reactive power. Compare to diode rectifier, the main drawback is high [15].

- ✓ Pulse Width Modulation Technique (PWM)

Pulse Width Modulation Technique (PWM) is a modulation technique used to encode a massage into signal pulse. PWM have two types which is Sinusoidal Pulse Width Modulation and Non-Sinusoidal Pulse Width Modulation.

- ✓ Sinusoidal Pulse Width Modulation

In sinusoidal pulse width modulation, all the pulse are modulated individually. Each pulse have to be related to the orientation sinusoidal pulse before being modulate . after that, it will create a waveform which is equal to the reference waveform [13].

- ✓ Non-sinusoidal Width Modulation

For non-sinusoidal width modulation, all pulse that have the equal pulse width will be modulated self-possessed. To remove the harmonics of the systems, the pulse width of pulse are attuned together in same quantity [13].

2.1.4 Active Filter

Modern active filter harmonic is more specialize in filtering performance, smaller in physical size and also more flexible in application. The highlight part for this filter is that it is faintly lower in cost and operating losses. This active filter can be divided into two categories which are single phase filter and three phase filter. Mostly, researcher only focus on three phase filter because single phase filter are narrow to lower power application nonetheless for electric traction or rolling stock[7][8] .

Besides that, active filter can be classified into Pure Active Filters and Hybrid Active Filters based on circuit structure. For Pure Active Filters, it can be used for example voltage source PWM with dc capacitor or current source PWM with dc inductor. Between this two, mostly voltage source PWM with dc capacitor is use due to cost, physical, size and efficiency. For Hybrid Active Filter, it consists of single or multiple voltage-sources PWM converters and also passive components (Capacitor, inductor and/or resistors). Hybrid Active Filter is more attractive than Pure Active Filters because of viability and economical points of view, and

also particularly for high power application [9].The combination of series and parallel filter configuration is called as Hybrid Active Filter. These combinations can bring a lot of advantages to the both active and shunt filter. Besides that, the characteristics for shunt can be upgrade [10].

2.1.5 Passive Filter

Passive filter is commonly used to limit the flow of current in distribution system. But, only a few of harmonics only can be used and they also can produce resonance in power system. For each of frequency, a separate filter is needed. Two main components are used in this passive filter which is inductor and capacitor. Usually, shunt-tuned LC filters and shunt low pass LC filter is used among others passive filter.

The advantages for passive filters is simplicity, reliability, efficiency and cost but on the bad sides is that, this passive filter produce multi resonance into the AC supply as mention before [11][12]. Two types of passive filter that currently used in power system to reduce harmonic distortion, Shunt Passive Filter and Series Passive Filter. Single phase and three phase power system can use this type of filter. But, there are slightly diverse between this filter. Firstly, the series passive filter can carries full load current but for the shunt passive filter can only carry one part of the total load. Besides that, the series filter more expansive relate to the shunt passive filter [11] [12].