SIMULATION ON HARMONIC RESONANCE IMPACT OF POWER FACTOR CORRECTION CAPACITOR IN DISTRIBUTION SYSTEM

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Bachelor of Electrical Engineering (Power Industry)

June 2014

" I hereby declare that I have read through this report entitle "Simulation on Harmonic Resonance Impact of Power Factor Correction Capacitor in Distribution System" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

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

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2014

I declare that this report entitle "Simulation on Harmonic Resonance Impact of Power Factor Correction Capacitor in 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.

Signature : ______________________________

Name : NUR ATHYKAH BINTI BASIRAN

Date : 18 JUNE 2014

Specially dedicated to

my beloved father and mother,

to my family and friends.

Thanks for all the encouragement and support.

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ABSTRACT

Today, electricity has become an important need in the world. As the number of modern technologies have increased over the years, it has become increasingly necessary to maintain the system stability and efficiency. These modern technologies may sometimes contribute to high levels of harmonic distortion and resonance in the system. This project aims to analyze the impact of power factor correction capacitor on harmonic distortion and resonance in power system. The analysis was performed for power factor correction capacitor connected to the test system. The test system used in this project to analyze the harmonic interference and resonance are the 2-bus test system and IEEE 5-bus test system. The test systems were simulated by using MATLAB/SimPowerSystem. To investigate the harmonic distortion and resonance phenomenon, frequency scan was conducted while the Fast Fourier Transform analysis was carried out to measure the voltage and current distortion in the system. The results shows that power factor correction capacitor can be used to reduce harmonic distortion and resonance phenomenon in the system.

ABSTRAK

Pada masa kini, bekalan elektrik merupakan keperluan yang amat penting kepada dunia. Bilangan teknologi moden yang kian bertambah sepanjang tahun menyebabkan perlunya untuk mengekalkan kestabilan dan kecekapan sesebuah sistem. Teknologi-teknologi moden ini boleh menyumbang kepada tahap tinggi herotan harmonik dan gema di dalam sistem kuasa. Projek ini menyasarkan untuk menganalisis kesan kapasitor pembetulan faktor kuasa terhadap herotan harmonik dan gema. Analisis dijalankan dengan penyambungan kapasitor pembetulan faktor kuasa dengan sistem ujian. Sistem ujian yang digunakan untuk menganalisis gangguan harmonik dan gema adalah sistem ujian 2-bas dan sistem ujian IEEE 5-bas. Sistem ini diuji dengan menggunakan perisian MATLAB/SimPowerSystem. Untuk menyiasat fenomena herotan harmonik dan gema, imbas frekuensi dijalankan manakala analisis *Fourier Transform dilakukan* untuk mengukur herotan yang berlaku di voltan dan arus. Hasil keputusan menunjukkan bahawa kapasitor pembetulan faktor kuasa boleh digunakan untuk mengurangkan herotan harmonik dan gema di dalam sistem.

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LIST OF ABBREVIATIONS

C	-	Capacitance (Farads)
L	-	Inductance (Henries)
f	-	Frequency (Hertz)
kVAR	-	Reactive Power (Q)
kW	-	Real Power (P)
kVA	-	Apparent Power (S)
V	-	Voltage (Volt)
I	-	Current (Ampere)
PFCC	-	Power Factor Correction Capacitor
pf	-	Power Factor
THD	-	Total Harmonic Distortion
FFT	-	Fast Fourier Transform
APLC	-	Active Power Line Conditioners
DC	-	Direct Current
AC	-	Alternating Current
PWM	-	Pulse Width Modulation
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Power transmission and distribution system are designed for operation with sinusoidal voltage and current waveform in constant frequency. On the other hand, certain type of loads like thyristor drives, converters and arc furnace producing currents and voltages that have integer multiple frequencies of the fundamental frequency. These higher frequencies are known as power system harmonics. Power system harmonics are not a new issue as concern over this problem has been retreated and flowed during the history of electric power systems [1]. Harmonic resonance is caused by the energy exchange between capacitive elements and inductive elements in a system. Since a power system contains numerous inductive and capacitive elements, the phenomenon of harmonic resonance can become quite complicated [2].

The consequences of the harmonic resonance that result in their premature failure are the cause of overheating and it increases the dielectric stress of power capacitors. Capacitors can interact with harmonics which lead to harmonic amplifications at the resonant frequency. This causes the capacitors or the components of the system to be damaged. Furthermore, high power factor cannot be achieved because of the harmonic distortion. These have encouraged the requirement for a different method in power factor correction [3].

This project presents a simulation of power factor correction capacitor (PFCC) in the distribution system following to harmonic resonance analysis. It focuses on the impact of PFCC through the system by generating the harmonic resonance analysis. It is one of the methods used in reducing the harmonic distortion in the system.

1.2 Problem Statement

Harmonic distortion can cause severe disturbance to certain electrical equipment. It is the role of the electric utility to provide a clean supply to customers. Many countries now set limits to the harmonic distortion and resonance allowed on the distribution networks [4]. Evaluation of harmonic resonance filter is crucial to make sure the filter is in optimum design, not under or over design. The design must be able to reduce the harmonic distortion and resonance in the system. Therefore, the estimation of the power factor correction capacitor is crucial to make sure that it is suitable in reducing harmonic distortion and resonance phenomenon. It is important because this aspect related to the distribution system requirement.

1.3 Objectives

The aim of this project is:

1. To evaluate the performance of power factor correction capacitor (PFCC) in the distribution system.
2. To investigate the significance of PFCC in power system.
3. To analyze the impact of the PFCC devices on harmonic distortion.

1.4 Scope of Project

Based on the objectives, the scopes of study are highlighted as follows:

1. The PFCC was tested using MATLAB/SimPowerSystem.
2. The test systems used in this project are the 2-bus test system and IEEE 5-bus test system.

1.5 Thesis Outline

This thesis is divided into five chapters. Chapter 1 is a brief review of this project. This chapter generally discussed about the background of research, problem statement and scope of the project. Chapter 2 is the literature review which is done based on journals, books, internet resources and IEEE paper related to this project. This chapter describes about the main topic of this project that is harmonic resonance and PFCC.

In Chapter 3 presents on the methodology of the project, which is consisted of use case, flow chart, design and details description on how this project was implemented. Chapter 4 describes about the result and discussion gained through this project. It also covered the harmonic resonance analysis. Finally, Chapter 5 consists of a conclusion in project implementation and thus any recommendation for future development.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will explain the basic concept about the power factor correction capacitor, harmonic distortion and resonance. The review of the previous studies is important in order to develop the system.

2.2 Theory and Basic Principles

Devices causing harmonics are present in all industrial, commercial and residential installations. Harmonics are caused by nonlinear loads. The loads become nonlinear when the current it draws does not have the same waveform as the supply voltage. The circuit is said to be resonant when the voltage applied to an electrical network contains resistance, inductance and capacitance are in phase with the resulting current. At resonance, the equivalent network impedance is purely resistive since the supply voltage and current are in phase.

2.2.1 Harmonic Distortion

Harmonic distortion is the change in the waveform of the supply voltage from the ideal sinusoidal waveform. It is caused by the interaction of distorting customer loads with the impedance of the supply network. Its major adverse effects are the heating of induction motors, transformers and capacitors and the overloading of neutrals [5].

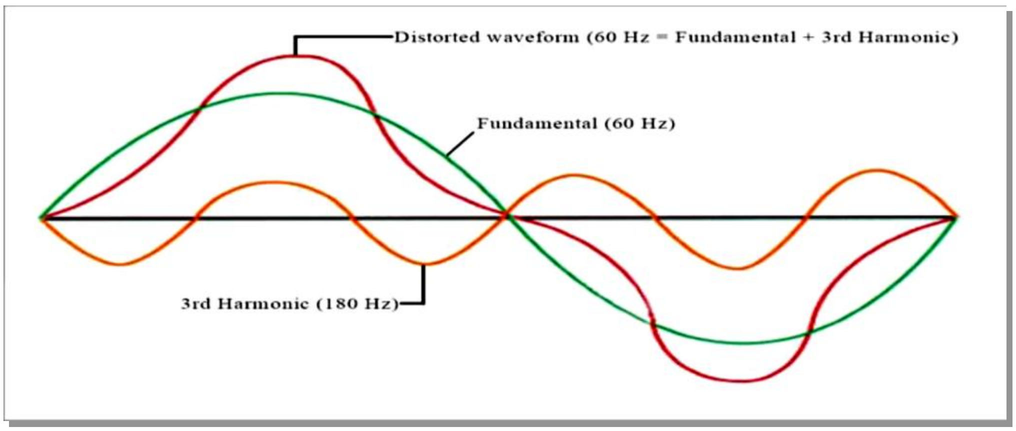

Figure 2.1: Harmonic distortion of the electrical current waveform [6].

Figure 2.1 shows the waveform of harmonic distortion on current in the electrical system. Equipment responds to harmonics differ depending on their method of operation. On the other hand, induction motor windings are overheated by harmonics, causing accelerated degradation of insulation and loss of life. Harmonic voltages can give correspondingly higher currents than do 50 Hz voltages and one can easily underestimate the degree of additional heating in the motor.

Harmonics have frequencies that are integer multiple of the waveform's fundamental frequency. For example, given a 60 Hz fundamental waveform, the 2^{nd}, 3^{rd}, 4^{th} and 5^{th} harmonic components will be at 120 Hz, 180 Hz, 240 Hz and 300 Hz respectively. Thus, harmonic distortion is the degree to which a waveform deviates from its pure sinusoidal values as a result of the summation of all these harmonic elements.

Total harmonic distortion, THD is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave;

$$\mathrm{THD} = \frac{\sqrt{{V_2}^2 + {V_3}^2 + {V_4}^2 + \cdots + {V_n}^2}}{V_1} \times 100\% \qquad (2.1)$$

Where,

$V_1 = \text{Fundamental voltage value}$

$V_n(n = 2, 3, 4, \text{etc} \ldots) = \text{Harmonic voltage values}$

Equation (2.1) shows the calculation for THD on a voltage signal. The end result is a percentage comparing the harmonic components to the fundamental component of a signal. The higher the percentage, the more distortion that is present on the mains signals [7].

2.2.2 Resonance

The operation of nonlinear loads in a power distribution system creates harmonic currents that flow throughout the power system. The inductive reactance of that power increases and the capacitive reactance decreases as the frequency increases, or as the harmonic order increases. At a given harmonic frequency in any system where a capacitor exists, there will be a crossover point where the inductive and the capacitive reactance are equal. This crossover point, called the parallel resonant point, is where the power system has a coincidental similarity of system impedances [8].

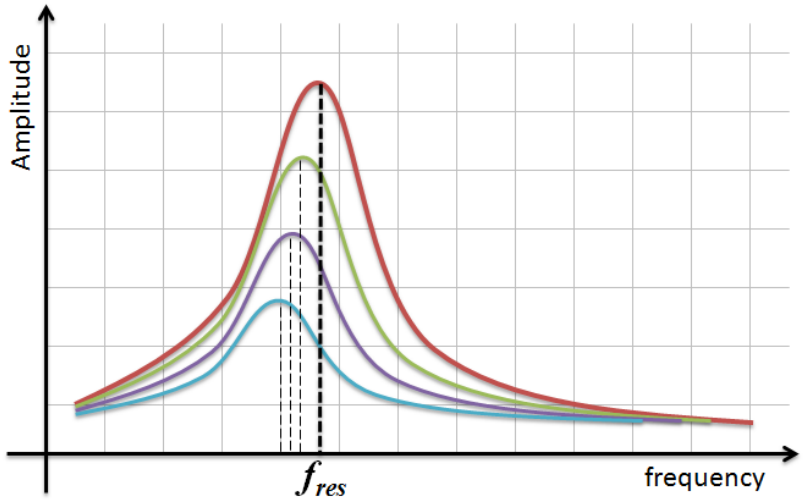

Figure 2.2: Resonance frequency graph [9]

Figure 2.2 shows the graph of a system undergoing resonance at its resonance frequency. Parallel resonance causes problems only if a source of harmonic exists on the frequency where the impedances match. This is typically called harmonic resonance results in very high harmonic currents and voltages at the resonant frequency.

2.2.3 Power Factor Correction Capacitor (PFCC)

Several IEEE transaction papers have been written and published which introduce the theory and implementation of advanced techniques for controlling harmonic current flow such as magnetic flux compensation, harmonic current injection, DC ripple injection, series/shunt active filter systems, and pulse width modulated static Var harmonic compensators. However, these practical systems have not been extensively installed and are not available on the market yet. It may take more time before these advanced techniques are fully developed and readily available [7].

The very important aspect of improving the quality of supply is the control of power factor. When low power factor produced, it means that the electrical system has poor efficiency. The lower the power factor, the higher the apparent power drawn from the distribution network [9]. Figure 2.3 shows the relationship between real power, reactive power and apparent power.

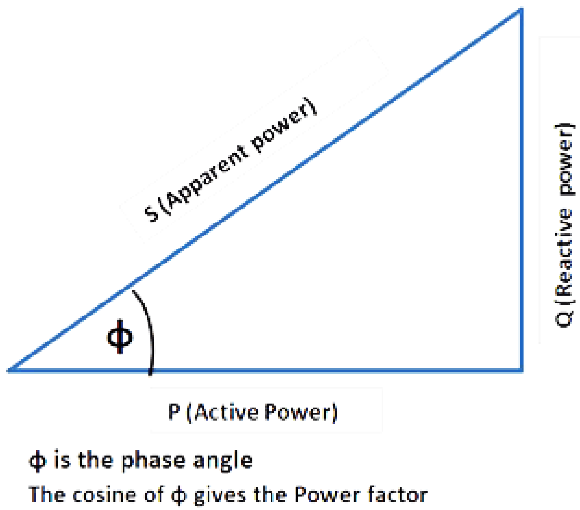

Figure 2.3: The power triangle [10].

In general, power is the capacity to do the work. In electrical domain, electrical power is the amount of electrical energy that can be transferred to some other form (heat, light etc.) per unit time. Mathematically, it is the product of voltage drop across the element and electric current flowing through it. Both inductor and capacitor offer certain amount of impedance given by,

$$X_L = 2\pi fL \quad (2.2)$$

$$X_C = \frac{1}{2\pi fC} \quad (2.3)$$

The power that involves,

$$\text{Active power, } P = VI\cos\theta \tag{2.4}$$

$$\text{Reactive Power, } Q = VI\sin\theta \tag{2.5}$$

These powers are represented in the form of triangle in Figure 2.3.

2.3 Review of Previous Related Works

There are several ways to solve the harmonic resonance. As in [14], it submits a combined system of a passive filter and a small-rated active filter, which are connected in series with each other. The passive filter will eliminate the harmonic currents produced by the load, whereas the active filter improves the filtering characteristics of the passive filter and acts as a “harmonic isolator” between the source and the load. The primary circuit of the active filter with a rating of 0.5 kVA is a three-phase voltage-source PWM inverter using six MOSFET’s. The role of a small-rated LC filter is to restrain switching ripples generated by the active filter. Whereas in [15] points out that the shunt active filter is superior in stability based on detection of voltage at the stage of installation to others. The shunt filter which will be installed by an electric utility, putting much emphasis on the control strategy and the best point of installation of the shunt active filter on a feeder in a power distribution system. The aim of the shunt active filter is to damp harmonic propagation, which results from harmonic resonance line inductors in the feeder, rather than to minimize voltage distortion throughout the feeder.

By referring to [1], in this paper, the commonly employed solutions when harmonics become a problem is by limiting the harmonic current injection from nonlinear loads. The harmonics in a three-phase system can be reduced by using parallel delta-delta and Wye-delta transformers to yield net 12-pulse operation, or by using delta connected transformers to block