EVALUATION OF FILTER DESIGN AND HARMONIC ANALYSIS USING PSCAD/ EMTDC

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This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Power Systems)

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NOVEMBER 2010

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DEDICATION

I dedicated to my parents and family members that always inspire, love and stand beside me, my supervisor, my housemates, my fellow colleagues, all faculty lecturers and members.

For your love, care, support and believe in me. Thank you so much.

God bless you all. Amin-

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ABSTRACT

Nowadays, electricity becomes one of the most important necessities to the world. Designing of filter is one of the methods to improve power quality in delivering electrical power to the customer. This project presents the evaluation of filter design and harmonic analysis to the system network. Here, it helps the utility system by increase the capability to power supply with fewer losses. The IEEE test system are used in this project as a base line diagram before any analysis which is load flow analysis, transient stability analysis, harmonics analysis according to active filter that approach to the system. The 4-bus test system and 9-bus test system analyzed by using MATLAB and PSCAD. Generally, power transmission and distribution are design for operation with sinusoidal voltage and current waveform at a constant frequency. However, when non-linear load such as thyristor drives, converters and arc furnace are connected to the system, excessive harmonic currents are generated and this causes both current and voltage distortion. The active filter concept uses power electronics to produce harmonic components which cancel the harmonic components from the nonlinear loads. Evaluation of harmonics filter is crucial to make sure the filter is in optimum design, not under or over design. The result shows the effectiveness of active filter design modeling by PSCAD software and analysis the harmonic in simulation part. As a conclusion, the active filter that design improved the quality of the power system network in distributed electricity to the customer.

ABSTRAK

Pada masa kini, bekalan elektrik merupakan salah satu keperluan yang amat penting kepada dunia. Penggunaan penapis merupakan salah satu idea untuk membaik pulih kualiti dalam proses menghantar bekalan kuasa kepada pengguna. Projek ini membentangkan tentang penilaian penapis aktif dan analisis selaras kepada sistem. Ini dapat membantu sistem untuk membekalkan kuasa tanpa kerugian dalam usaha untuk meningkatkan keupayaan. Sistem ujian *IEEE* digunakan dalam projek ini sebagai litar asas untuk analisis berkaitan arus beban, suntikan selaras kepada penapis aktif sebelum dimasukkan ke dalam sistem. Sistem ujian 4-bas dan 9-bas digunakan untuk menganalisis keupayaan dengan menggunakan perisian MATLAB dan PSCAD. Secara umumnya, sistem kuasa direka untuk operasi voltan dan arus gelombang pada frekuensi yang tetap. Apabila beban bukan linear seperti thyristor, pengubah dan pemancar pembakar berhubung dengan sistem, lebihan arus selaras terhasil dan menyebabkan kesemua arus dan voltan berubah. Penapis aktif menghasilkan komponen selaras dengan membatalkannya daripada beban bukan linear. Keberkesanan rekabentuk penapis menggunakan perisian PSCAD dan menganalisis keselarasan terhasil. Kesimpulannya, penapis aktif direka bagi memperbaiki kualiti sesuatu sistem kuasa sebelum di bahagikan kepada pengguna.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

P	-	Real power
Q	-	Reactive power
S	-	Apparent power
R	-	Resistance
L	-	Inductance
C	-	Capacitance
C_{shunt}	-	Shunt capacitance
V_b	-	Base voltage
S_b	-	Base apparent
R_{act}	-	Actual value of resistance
L_{act}	-	Actual value of inductance
X_{Lact}	-	Actual value of line inductance
X_{Cact}	-	Actual value of line capacitance
L_{pu}	-	Per-unit value of inductance
X_{Lpu}	-	Per-unit value of line inductance
X_{Cpu}	-	Per-unit value of line capacitance
π	-	Pi
ω	-	Angular frequency
f	-	Frequency
b	-	Susceptible line charging

LIST OF ABBREVIATION

PV	-	Generator bus
PQ	-	Load bus
RMS	-	Root-mean-square
DC	-	Direct current

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

Power transmission and distribution system are design for operation with sinusoidal voltage and current waveform in constant frequency. However, when non-linear load like thyristor drives, converters and arc furnace are connected to the system, excessive harmonic currents are generated and this causes both current and voltage distortion. Harmonic filter is the best way to eliminate the distortion from power system network.

This project presents a design of an active filter following to harmonic analysis. It focuses on the performance of active filter through the IEEE standard test system by generating the harmonic analysis. It is one of the methods in reducing the harmonic distortion following the system design. The calculation of design parameters for filter component of harmonic active filter are applied in this project.

1.2 Problem Statement

Harmonic distortion can cause severe disturbance to certain electrical equipment. It is the duty of the electric utility to provide a clean supply. Many countries now set limits to the harmonic distortion allowed on the distribution networks. Evaluation of harmonics filter is crucial to make sure the filter is in optimum design, not under or over design. This project is essential in terms of power efficiency and power handling deliver system network. It is important because this aspect related to the most transmission and distribution system requirement.

1.3 Objectives

The aim of this project is to evaluate the performance of active filters and also to analyze the harmonic distortion cause by harmonic source. To achieve this aim, the project is carried out for the following objectives:

i. to design an active filter in order to reduced harmonic distortion through to the power system network.
ii. to ensure the performance of filter design that approach to the system is efficient.
iii. to determine the distortion that existed through the system by analyze the harmonic.

1.4 Scope of Project

The main focus in this project is by the calculation of design parameters for filter component of harmonic active filter. It affects overall result when any mistakes error forms the calculation. By using PSCAD/ EMTDC, the IEEE standard test system which is 4 bus and 9 bus constructed together with filter circuit before continue the harmonic analysis as the result. An active filter is limited to the performance in test system as power system network using proportional design.

1.5 Literature Review

In electrical power system, transmission and distribution networks are designed to operate with sinusoidal voltage and current having constant frequency. However there are number of non -linear loads, such as thyristor drives and converters that generate harmonics on the network, causing distortion in the voltage and current waveforms.

The harmonic voltage levels on electric power distribution systems are generally increasing due to the changing nature of the system load. Hence, harmonics levels will soon require reduction through the application of tuned filters. Harmonic distortion in electric power systems affects the whole system environment, often at large distances from the original sources. Like many other forms of pollution, harmonics are a form of electrical pollution in the power system.

Harmonic distortion in power systems is increasing with the wide use of nonlinear loads in solid state power devices. Thus it is important to analyze the various harmonic problems, to evaluate the harmonic level and to eliminate harmonics prior to their becoming a serious problem.

Harmonic distortion in power distribution systems can be suppressed using two approaches namely, passive and active powering. Remarkable progress in power electronics had spurred interest in active power filter (APF) for harmonic distortion mitigation. The basic principle of APF is to utilize power electronics technologies to produce specific currents components that cancel the harmonic currents components caused by the nonlinear load. [1]

The filter is design used when the main objective is not the reactive power compensation at the fundamental frequency, but to reduce the harmonic distortion in the supply system. The harmonic filtering is one of the solutions to prevent the troublesome harmonics from entering the rest of the system. [2]

Harmonic filters provide low impedance paths to harmonic currents and thus prevent them from flowing into the power network. Harmonic analysis program computes indices such as total voltage harmonic distortion factor at system buses to evaluate the effect of the harmonic sources and to evaluate the effectiveness of the harmonic filters. [3]

1.6 Report Outline

This report covers all part of evaluation of filter design and harmonic analysis. It is about the quality of power system network that used in daily life. The distortion existed to the system on the harmonic analysis. So that, this project taken for reducing the distortion by design and evaluate the filter as a method to overcome this problem of the system.

Chapter 1 is a brief review of this project. It includes the basic needed for this project. It also mention about the general concept for this project.

Chapter 2 describe about the main topic of this project that is harmonic and filter design. It includes overview of harmonic which is definition, linear and non-linear load concept and harmonic current flow. Besides the harmonic elimination explain about filters which is passive and active filter.

Chapter 3 describe about the modeling of active filter by using PSCAD software. This chapter includes developing the tools that approach to this project which is MATPOWER and PSCAD software. The methodology for this project also explains here.

Chapter 4 describe about result and discussion for this project. The result includes results that show such the configuration of the IEEE 4-bus test system and IEEE 9-bus test system. It also covered the load flow analysis, transient stability analysis and harmonic analysis.

Chapter 5 includes the conclusion for overall project and also future recommendation.

CHAPTER 2

HARMONIC AND FILTER DESIGN

2.1 Introduction

This chapter explains about the overall overview of this project. The first is about test system that being used in this project which is IEEE 4-bus test system and 9-bus test system. It describes overall function of the test system. The data for the system attached in appendix.

Next is about the overview of harmonics includes the definition, linear and non-linear configuration and also harmonic current flow. It more shows on how harmonic existed to the system. Then, this chapter also includes the harmonic filter by further explanation on passive filter and active filter.

2.2 IEEE Standard Test System

A single line diagram of the IEEE 4-bus standard test system is shown in Figure 2.1. It consists of three synchronous machines with IEEE type-1 exciters, three of which are synchronous compensators used only for reactive power support. There are 4 loads in the system totaling 500 MW and 309.9 Mvar. The dynamic data for the generators exciters was selected. The model details are discussed in the following sections, and the corresponding data is given in Appendices A.

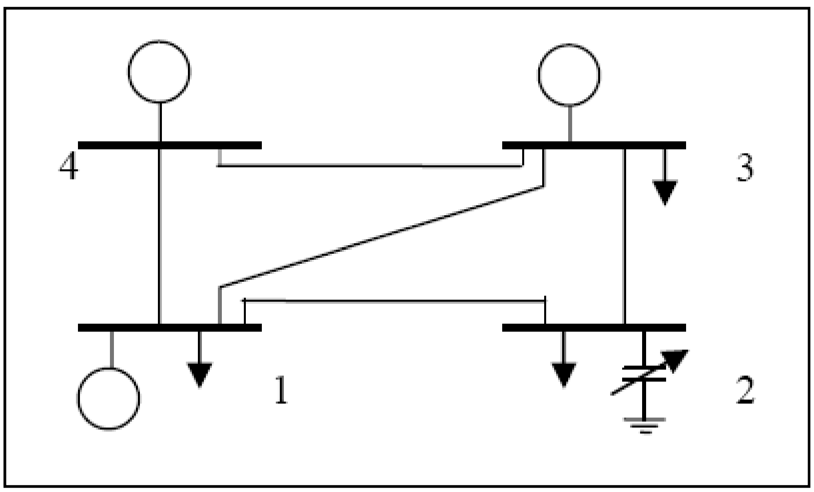


Figure 2.1 IEEE 4-bus test system

A single line diagram of the IEEE 9-bus standard test system extracted from [6] is shown in Figure 2.2. It consists of three synchronous machines with IEEE type-1 exciters, three synchronous generators total up by 820 MW and -900 to 900 Mvar, 3 loads in the system totaling 315 MW and 115 Mvar. The model details are discussed in the following sections, and the corresponding data is given in Appendices B.

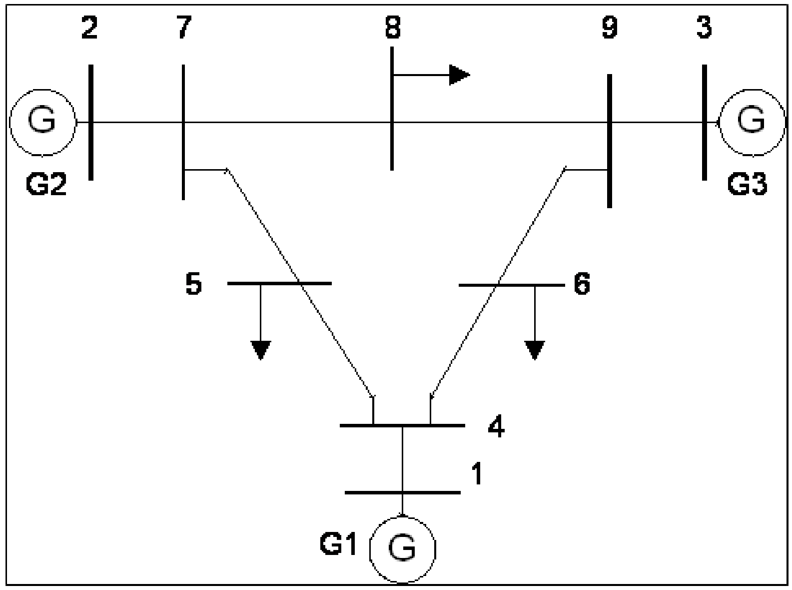


Figure 2.2 IEEE 9-bus test system

2.3 Overview on Harmonics

In this part, the theoretical of harmonics attached. In practically, power system network still have distortion that came from harmonic although theoretically say that harmonic can be cancel up using some kind of method. This part shows the definition of harmonics, types of load and also harmonic current to clearly understand the project.

2.3.1 Definition of Harmonics

Harmonics are the odd integral multiples of fundamental frequency resulting in the distortion of supply waveform due to interference by superposition. Harmonics are defined as the sinusoidal components of a repetitive waveform which consist of frequencies that are exact multiples or harmonic orders of fundamental frequency. [6] A complete set of harmonics then makes up a Fourier series which together represent the original waveform. Harmonics are currents, usually in multiples of the supply fundamental frequency, produced by non-linear loads such as the AC to DC power conversion circuits. For example a 50Hz supply, the 5th harmonic is 250 Hz, 7th harmonic is 350 Hz and other order harmonics.

2.3.2 Linear and Non-linear Load

A linear element in a power system is a component in which the current is proportional to the voltage. In general, this means that the current wave shape will be the same as the voltage. Typical examples of linear loads include motors, heaters and incandescent lamps.

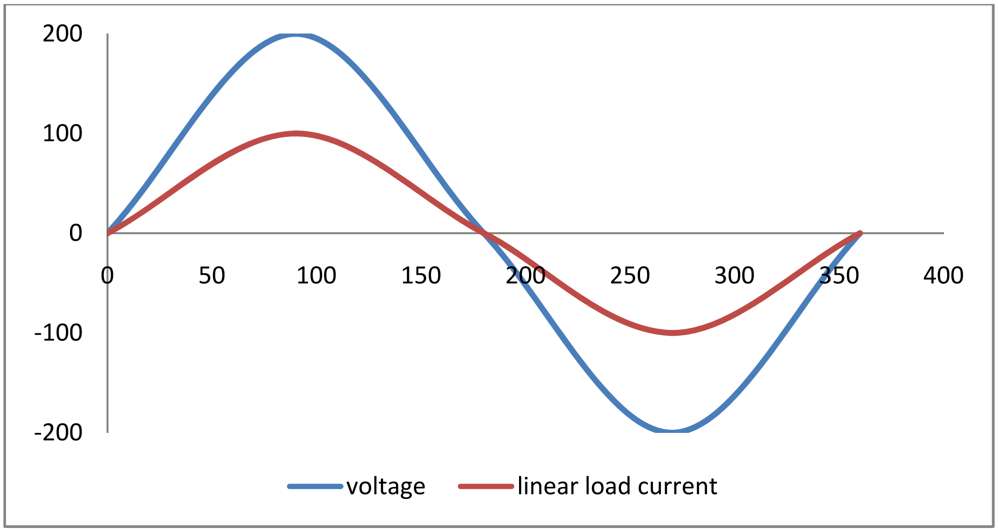


Figure 2.3 Voltage and current waveforms for linear

In the other side, the current wave shape on a non-linear load is not the same as the voltage. Typical examples of non-linear loads include rectifiers like power supplies, discharge lighting, adjustable speed motor drives, ferromagnetic devices, DC motor drives and arcing equipment.

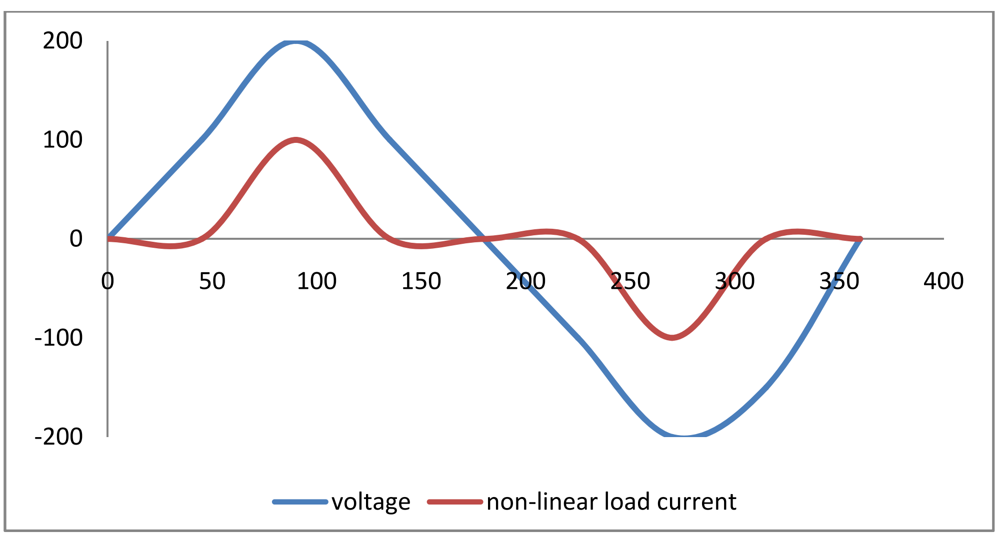


Figure 2.4 Voltage and current waveforms for non-linear loads

The current drawn by non-linear loads is not sinusoidal but it is periodic meaning that the current wave looks the same from cycle to cycle. Periodic waveforms were described mathematically as a series of sinusoidal waveforms that have been summed together. The sinusoidal components are integer multiples of the fundamental where the fundamental, in the United States, is 60 Hz and Malaysia is 50 Hz. The only way to measure a voltage or current that contains harmonics is by using a true-RMS reading meter. If an averaging meter is used, which is the most common type, the error can be significant.

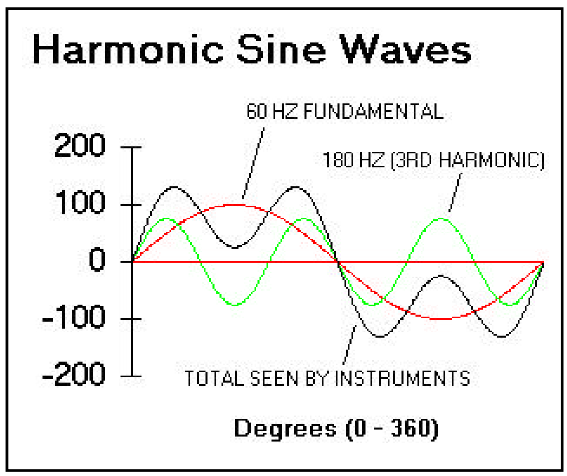


Figure 2.5 Waveform with symmetrical harmonic components

Each term in the series referred as a harmonic of the fundamental. The third harmonic would have a frequency of three times 60 Hz or 180 Hz. Symmetrical waves contain only odd harmonics and un-symmetrical waves contain even and odd harmonics.

A symmetrical wave is one in which the positive portion of the wave is identical to the negative portion of the wave. An un-symmetrical wave contains a DC component or the load is such that the positive portion of the wave is different than the negative portion. An example of un-symmetrical wave would be a half wave rectifier.

Most power system elements are symmetrical. They produce only odd harmonics and have no DC offset. There are exceptions and normally symmetrical devices may produce even harmonics due to component mismatches or failures. Arc furnaces are another common source of even harmonics but they are well known for producing both even and odd harmonics at different stages of the process.

2.3.3 Harmonic Current Flow

When a non-linear load draws current which current passes through all of the impedance that is between the load and the system source. As a result of the current flow, harmonic voltages are produced by impedance in the system for each harmonic.

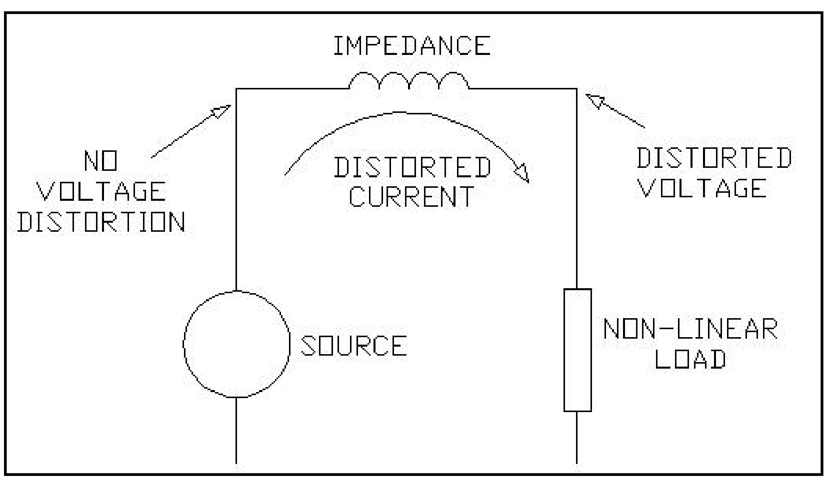


Figure 2.6 Distorted-current induced voltage distortion

These voltages sum and added to the nominal voltage produce voltage distortion. The magnitude of the voltage distortion depends on the source impedance and the harmonic voltages produced.

If the source impedance is low then the voltage distortion will be low. If a significant portion of the load becomes non-linear that is harmonic currents increase or when a resonant condition prevail means system impedance increases, the voltage can increase dramatically.

Power systems are able to absorb a considerable amount of current distortion without problems and the distortion produced by a facility may be below levels recommended in IEEE 519. However, the collective effect of many industrial customers, taken together may impact a distribution system. When problems arise, they are usually associated with resonant conditions.

2.4 Harmonic Filter

Harmonic filter is one of the methods in reducing the distortion that come from harmonic. This part explain in detail about the types of filter includes passive and active filter which the active filter used and installed to the project. All types of active filter should be considered first in order finding the best filter design attached to the system.

2.4.1 Introduction to filter

A filter is a device that passes electric signals at certain frequencies or frequency ranges while preventing the passage of others. Filter circuits are used in a wide variety of applications. In the field of telecommunication, band-pass filters are used in the audio frequency range of 0 kHz to 20 kHz for modems and speech processing. High-frequency band-pass filters in several hundred MHz are used for channel selection in telephone central offices.

In addition, there are filters that do not filter any frequencies of a complex input signal, but just add a linear phase shift to each frequency component, thus contributing to a constant time delay. These are called all-pass filters.

At high frequencies more than 1 MHz, all of these filters usually consist of passive components such as inductors (L), resistors (R), and capacitors (C). They are then called LRC filters.

In the lower frequency range from 1 Hz to 1 MHz, the inductor value becomes very large and the inductor itself gets quite bulky, making economical production difficult.

In these cases, active filters become important. Active filters are circuits that use an operational amplifier known as op amp as the active device in combination with some resistors and capacitors to provide an LRC like filter performance at low frequencies.

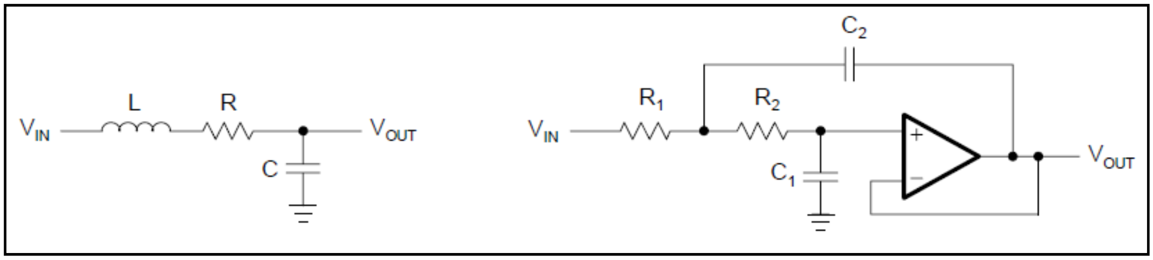


Figure 2.7 Second-Order Passive Low-Pass and Second-Order Active Low-Pass with Op Amp

2.4.2 Passive filter

Shunt passive filters that consisting of LC filters or high-pass filters have been broadly used to improve the power factor and to eliminate line current harmonics. However, shunt passive filters present several disadvantages. [9] Source impedance ac power system highly influences the compensation characteristic of the passive filters.

Parallel resonance occurs when the system inductive reactance equal to the capacitive reactance at some frequency. When parallel resonance occurs it causes amplified harmonic current to oscillate between the energy storage is the inductance and the energy storage in the capacitance. This high oscillating current can cause voltage distortion and interferences.

The passive filter may fail into series resonance with power system, so that voltage distortion produces excessive harmonic currents flowing into the passive filter. The system resonant conditions are the most important factor affecting system harmonic levels. Parallel resonance is high impedance to the flow of harmonic current, while series resonance is low impedance to the flow of harmonic current. It is important to analyze the system frequency response characteristic and to avoid system resonance problem. [10]

Therefore, passive filters cannot be a complete solution for several reasons:

- Design for specific harmonic component
- Undesirable series and parallel resonances
- Bulky filters components heavy and large in size
- Increased cost and losses
- Filter contribute to slow system response

2.4.3 Active Filter

Active filters measure the harmonic voltages or current through the controllable voltage source introduce the appropriate compensating voltages or currents into the network. The active filter voltage or current waveforms are modulated in such a way that they are in phase opposition to the harmonic voltage or current, thus cancelling out the harmonic quantities.

The advantages using active filters are the harmonic attenuation achievable by the filter is very high on the whole frequency range. The comparatively small size of the filter installation makes it easy for the filter to be transported or relocated. Besides modifications to filter characteristics only require changes to be made to the control software, as no hardware changes are necessary, updates can be made quickly and with minimum additional cost incurred.

The amplifier powering the filter can be used buffer to the filter from the electronic components. It drives or is fed from variations in which could otherwise significantly affect the shape of the frequency response. Active filters that use amplifying elements especially op amps with resistors and capacitors in their feedback loops are to synthesize the desired filter characteristics. It can have high input impedance, low output impedance and virtually gain. Active filters are usually easier to design than passive filters. Possibly their most important attribute is that lack inductors which reducing the problems associated with those components. The problems of accuracy and value spacing also affect capacitors although to a lesser degree.

Performance at high frequencies is limited by the gain bandwidth product of the amplifying elements but within the amplifier's operating frequency range, the op amp-based active filter can achieve very good accuracy. It provided that low tolerance resistors and capacitors are used. Active filters will generate noise due to the amplifying circuitry but this can be minimized by the use of low noise amplifiers and careful circuit design.

2.5 Summary

From this chapter, it summarized that in getting the best result of evaluation, the design of filter that will attached to the system should be suitable in real power system network. The effort of distortion that include in this system was taken by the event that happened in real system.

CHAPTER 3

MODELLING OF ACTIVE FILTER USING PSCAD/ EMTDC

3.1 Introduction

This chapter explains about software development such as procedures and method design for active filter that attached to the IEEE standard test system. This chapter also explains about the software interface of MATPOWER and PSCAD that going been used for. Besides, the configuration of active filters also approaches in this chapter.

Before looking at the details of all methods below, it is good to begin with brief review of the problem that is considered in filter design. The types of filter design should be considered to get the best output result for harmonic analysis solution.

3.2 Flow Chart of Project

Firstly, this project started by running the load flow analysis in MATPOWER configuration in Matlab software. This stage actually is a preliminary stage or testing stage to ensure the load flow analysis that will be used in the correct value or not. The test system that used for this stage can be any bus standard system. So that IEEE 4-bus and 9-bus standard test system used in this project.

If the stage is success, the result on the load flow analysis will used to model in PSCAD. The actual project attached by model IEEE 4-bus and 9-bus standard test system in PSCAD by using the data from MATPOWER. The data change first to the actual value from the per unit data.

After that, the comparison stage involved as the next stage by comparing the result between Matlab and PSCAD software that design by modelling the test system. If the comparison is success, it proceed to another stage.

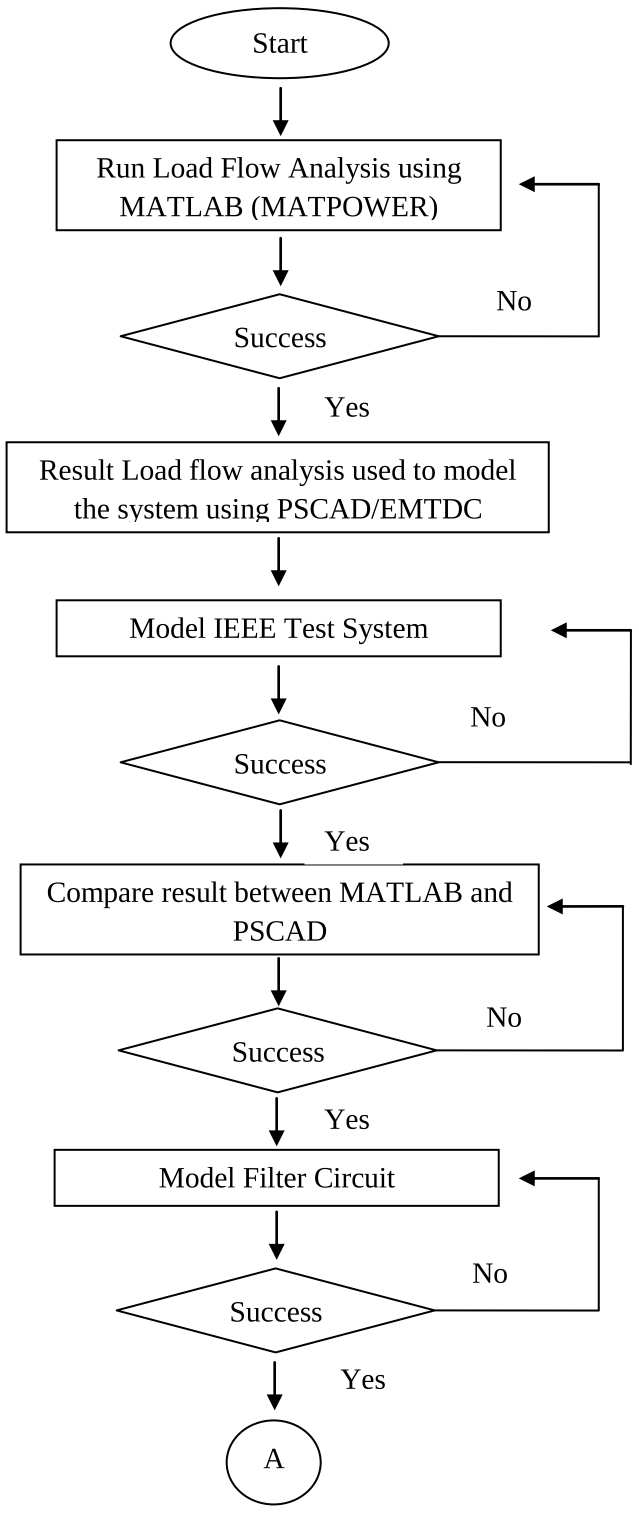
After the stage is success, the injection of harmonic current added so that the early harmonic distortion graph preview before continue to the other stage.

Then, the next stage is model filter circuit in PSCAD. The design of filter that includes is about an active filter circuit. All the value should be added to the circuit so that no other mistaken data interrupt to the system.

The next stage is applied the filter circuit through to the IEEE standard test system that was design in the previous stage. The location of attached the filter circuit should be reasonable place considered to the distortion that existed to the system.

After the stage in success condition, the analysis of filter design can be determined in order by validate the graphical harmonic as the output result. Then the analysis of harmonic distortion explains to determine the actual function of filter design that attached to the system is suitable or not.

Below is the flows chart that been used for this project:



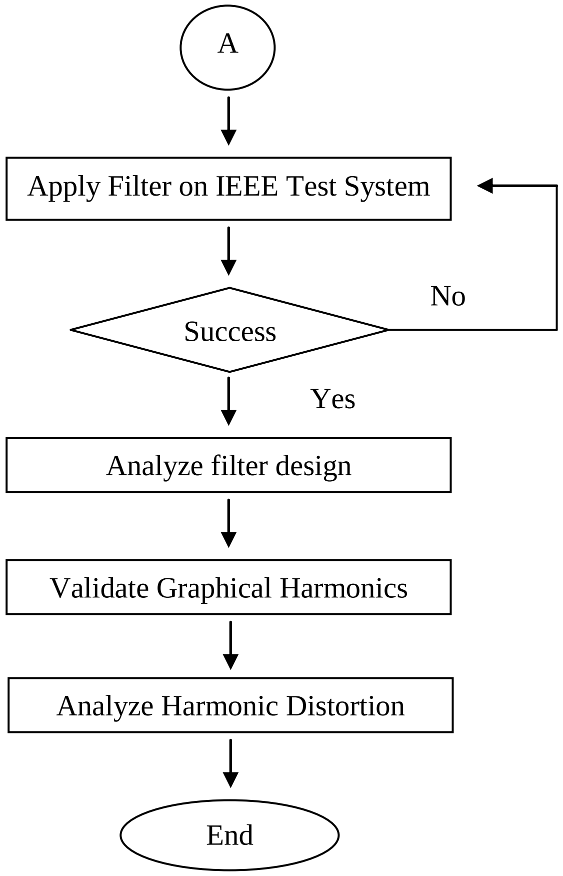


Figure 3.1 Flow chart of project

3.3 Tools

There are two software uses in this project which is MATPOWER and PSCAD. Before the test system run in PSCAD, the data was confirmed first using MATPOWER in MATLAB software. The comparison to ensure the similarity of the data needed to avoid any error and mistaken data before start the project.

3.3.1 MATPOWER

MATPOWER is a package of Matlab M-files for solving power flow and optimal power flow problems. It is intended as a simulation tool for researchers and educators that are easy to use and modify. MATPOWER is designed to give the best performance possible while keeping the code simple to understand and modify. The primary functionality of MATPOWER is to solve power flow and optimal power flow (OPF) problems. This involves preparing the input data defining the all of the relevant power system parameters, invoking the function to run the simulation and viewing and accessing the results that are printed to the screen and saved in output data structures or files.

MATPOWER employs all of the standard steady state models typically used for power flow analysis. The AC models are described first, then the simplified DC models. The magnitudes of all values are expressed in per unit and angles of complex quantities are expressed in radians. Due to the strengths of the Matlab programming language in handling matrices and vectors, the models and equations are presented here in matrix and vector form.

The data files used by MATPOWER are Matlab M-files or MAT-files which define and return a single Matlab struct. The fields of the struct are base MVA, bus, branch, gen and optionally gencost, where base MVA is a scalar and the rest are matrices. In the matrices, each row corresponds to a single bus, branch, or generator.

The standard power flow or load flow problem involves solving for the set of voltages and flows in a network corresponding to a specified pattern of load and generation. All of MATPOWER solvers exploit the sparsity of the problem and except for Gauss-Seidel scale well to very large systems. Currently, none of them include any automatic updating of transformer taps or other techniques to attempt to satisfy typical optimal power flow constraints such as generator, voltage or branch flow limits.

3.3.3 PSCAD/EMTDC

PSCAD (Power Systems Computer Aided Design) is a powerful and flexible graphical user interface to the world-renowned, EMTDC solution engine. PSCAD enables the user to schematically construct a circuit, run a simulation, analyze the results and manage the data in a completely integrated and graphical environment. Online plotting functions, controls and meters are also included, so that the user can alter system parameters during a simulation run and view the results directly.

PSCAD comes complete with a library of pre-programmed and tested models, ranging from simple passive elements and control functions to more complex models such as electric machines, FACTS devices, transmission lines and cables. If a particular model does not exist, PSCAD provides the flexibility of building custom models, either by assembling those graphically using existing models or by utilizing an intuitively designed design editor.

PSCAD/EMTDC is an industry standard simulation tool for studying the transient behaviour of electrical networks. Its graphical user interface enables all aspects of the simulation to be conducted within a single integrated environment including circuit assembly, run-time control and analysis of results and reporting. Its comprehensive library of models supports most ac and dc of power plant components and controls such a way that FACTS, custom power and HVDC systems can be modelled with speed and precision. It provides a powerful resource for assessing the impact of new power technologies in the power network.

Simplicity of use is one of the outstanding features of PSCAD/EMTDC. It is great many modelling capabilities and highly complex algorithms and methods are transparent to the user, leaving free to concentrate efforts on the analysis of results rather than on mathematical modelling. For the purpose of system assembling, the user either uses the large base of built-in components available in PSCAD/EMTDC or to its own user-defined models.

To show the effectiveness and simplicity of the proposed models, the ac network modelling capabilities of PSCAD/ EMTDC are simplified as much as practicable such that standard features such as synchronous generator, transformer saturation and frequency-dependent transmission line and cable models are not used in our test circuits.

3.4 Active Filter Configuration

The active filter configuration investigated is based on a pulse-width modulated (PWM) voltage source inverter that interfaces to the system through a system interface filter. In this configuration, the filter is connected in parallel with the load being compensated. The configuration is often referred to as an active parallel filter. The voltage source inverter used in the active filter makes the harmonic control possible. The inverter uses dc capacitors as the supply and can switch at a high frequency to generate a signal which will cancel the harmonics from the nonlinear load.

The active filter does not need to provide any real power to cancel harmonic currents from the load. Reduction in the harmonic voltage distortion occurs because the harmonic currents flowing through the source impedance are reduced. Therefore, the dc capacitors and the filter components must be rated based on the reactive power associated with the harmonics to be cancelled and on the actual current waveform that must be generated to achieve the cancellation. The current waveform for cancelling harmonics is achieved with the voltage source inverter and an interfacing filter.

The filter consists of a relatively large isolation inductance to convert the voltage signal created by the inverter to a current signal for cancelling harmonics. The rest of the filter provides smoothing and isolation for high frequency components. The desired current waveform is obtained by accurately controlling the switching of the gate turn off-thyristor (GTO) in the inverter.

Control of the current wave shape is limited by the switching frequency of the inverter and by the available driving voltage across the interfacing inductance. The driving voltage across the interfacing inductance determines the maximum di/dt that can be achieved by the filter. This is important because relatively high values of di/dt may be needed to cancel higher order harmonic components. A larger inductor is better for isolation from the power system and protection from transient disturbances. However, the larger inductor limits the ability of the active filter to cancel higher order harmonics.

3.5 Model Active Filter

The voltage source inverter is the heart of the active filter. The three-phase, full-wave Inversion Bridge is built using three identical GTO inverter legs. A dc link neutral is established by equally dividing dc capacitance between the positive and negative poles. This design combined with separate controls of the individual legs allows the filter to compensate for unbalanced loads or even single phase loads.

In this configuration, parallel active filter applied to the system. The control accomplished by monitoring the current to the non-linear load and then generating gating signals for inverter to create a current waveform. It will cancel the harmonics in the load current. There are many different control methods that can used to generate the compensating current that cancel the harmonics in the load current.

The method that used in this project is Fast Fourier Transform (FFT) method. It determined the harmonic magnitude and phase of the input signal as a function of time. The input signals first sampled before it decomposed into chosen harmonic. In the case of three inputs, the component can provide output in the form of sequence components. Figure 3.2 below shows the component of FFT.

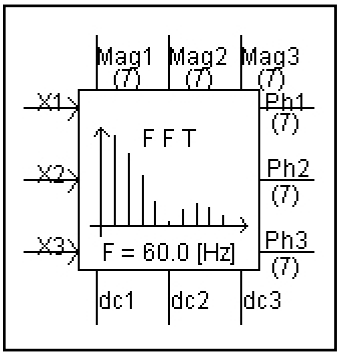


Figure 3.2 On-line Frequency Scanner (FFT)

This method compensates for individual harmonic components in the load current by performing a rolling FFT on the sampled load current waveform. Then, reproducing a current waveform that has the same harmonic components with the opposite phase angle. This calculation is performed each cycle and the desired compensation is implemented in the successive cycle. This one cycle of delay could be a problem for nonlinear loads with rapidly varying characteristics.

The strategy active filter controls roughly categorized approaches to where the filter control is designed to cancel out all measureable harmonics on the line. Theoretically, increasing the inverter operating frequency helps to get a better compensating current waveform. However, the actual performance of the active filter becomes limited by the isolating inductance once a high enough switching frequency is achieved. Control of the average frequency is realized by introducing a hysteresis characteristic into the PWM firing pulse generation logic.

3.6 Summary

This chapter summarized all about the method that using to success the project. The flow chart that attached in this chapter give clearly understand to overall project and ensure the flow should be follow without any unsuccessful flow to proceed the next part. The active filter configuration includes to identifying the control of system.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter included the result and discussion that done for the project. All the result basically follows the flow chart of the project. The early stage present here after the 4-bus test system used as a testing data before starting the actual project system.

The model of IEEE 9-bus test system using PSCAD also include in this chapter. It presents the modeling the system in PSCAD software. In this chapter, the load flow analysis, injection of harmonics and attachment of active filter through to the system will be discussed.

The result shows the test system that built up in PSCAD software for the part of load flow analysis, injection of harmonic and also the designation of an active filter that involved in the system. All of this part done in two test system that is in 4-bus test system and 9-bus test system.

4.2 IEEE 4-bus test system configuration using MATPOWER

The actual data from MATPOWER that open by MATLAB software attached in appendix A. The IEEE 4-bus test system was design through in PSCAD software. The model of the test system is depend on the data that taken from MATPOWER. Below are the calculations converting per unit data to actual data for this test system:

$$\text{Per Unit Value} = \frac{\text{Actual Value}}{\text{Base Value}}$$

$$\text{Actual Value} = \text{Per Unit Value x Base Value}$$

$$R_{act} = R_{pu}\left(\frac{V_B^2}{S_B}\right)$$

$$X_{L\,act} = X_{L\,pu}\left(\frac{V_B^2}{S_B}\right)$$

$$X_{L\,act} = 2\pi fL$$

$$L_{act} = \frac{X_{Lact}}{2\pi f}$$

$$Xc_{pu} = \frac{1}{b_{pu}}$$

$$Xc_{act} = Xc_{pu}\left(\frac{V_B^2}{S_B}\right)$$

$$C_{act} = \frac{1}{2\pi fXc_{act}}$$

$$C_{shunt} = \frac{C_{act}}{2}$$

<u>Bus 1 to 2</u>

$$R_{12}^{act} = 0.01008 \times \left(\frac{230k}{100M}\right)^2 = 5.3323\Omega$$

$$X_{L12}^{act} = 0.0504 \times \left(\frac{230k}{100M}\right)^2 = 26.6616$$

$$L_{12}^{act} = \frac{26.6616}{2\pi(60)} = 0.07072\text{H}$$

$$Xc_{12}^{pu} = \frac{1}{0.1025} = 9.7561$$

$$Xc_{12}^{act} = 9.7561 \times \left(\frac{230k}{100M}\right)^2 = 5160.97561$$

$$C_{12}^{act} = \frac{1}{2\pi(60)(5160.97561)} = 0.5140\mu F$$

$$C_{12}^{shunt} = \frac{0.5140}{2} = 0.25698\mu F$$

<u>Bus 1 to 3</u>

$$R_{13}^{act} = 0.0074 \times \left(\frac{230k}{100M}\right)^2 = 3.9358\Omega$$

$$X_{L13}^{act} = 0.0372 \times \left(\frac{230k}{100M}\right)^2 = 19.6788$$

$$L_{13}^{act} = \frac{19.6788}{2\pi(60)} = 0.0522\text{H}$$

$$Xc_{13}^{pu} = \frac{1}{0.0775} = 12.9032$$

$$Xc_{13}^{act} = 12.9032 \times \left(\frac{230k}{100M}\right)^2 = 6825.8065$$

$$C_{13}^{act} = \frac{1}{2\pi(60)(6825.8065)} = 0.3886\mu F$$

$$C_{13}^{shunt} = \frac{0.3886}{2} = 0.194305\mu F$$

Bus 2 to 4

$$R_{24}^{act} = 0.0074 \times \left(\frac{230k}{100M}\right)^2 = 3.9358\Omega$$

$$X_{L24}^{act} = 0.0372 \times \left(\frac{230k}{100M}\right)^2 = 19.6788$$

$$L_{24}^{act} = \frac{19.6788}{2\pi(60)} = 0.0522\text{H}$$

$$Xc_{24}^{pu} = \frac{1}{0.0775} = 12.9032$$

$$Xc_{24}^{act} = 12.9032 \times \left(\frac{230k}{100M}\right)^2 = 6825.8065$$

$$C_{24}^{act} = \frac{1}{2\pi(60)(6825.8065)} = 0.3886\mu F$$

$$C_{24}^{shunt} = \frac{0.3886}{2} = 0.194305\mu F$$

Bus 3 to 4

$$R_{34}^{act} = 0.01272 \times \left(\frac{230k}{100M}\right)^2 = 6.7289\Omega$$

$$X_{L34}^{act} = 0.0636 \times \left(\frac{230k}{100M}\right)^2 = 33.6444$$

$$L_{34}^{act} = \frac{33.6444}{2\pi(60)} = 0.08924\text{H}$$

$$Xc_{34}^{pu} = \frac{1}{0.1025} = 7.8431$$

$$Xc_{34}^{act} = 7.8431 \times \left(\frac{230k}{100M}\right)^2 = 4149.0196$$

$$C_{34}^{act} = \frac{1}{2\pi(60)(4149.0196)} = 0.6393\mu F$$

$$C_{24}^{shunt} = \frac{0.6393}{2} = 0.319664\mu F$$

Table 4.1 below shows the value of resistor (R), inductor (L), and capacitor (C) after all the calculation involved. The table built up to easier understanding the value that actually used to add in test system.

Table 4.1 Line data of 4-bus test system

From bus	To bus	R (Ω)	L (H)	C (μF)
1	2	5.3323	0.07072	0.25698
1	3	3.9358	0.05220	0.194305
2	4	3.9358	0.05220	0.194305
3	4	6.7289	0.08924	0.319664

Figure 4.1 shows the test system of 4-bus test sytem that built by using PSCAD. The value taken from the calculation before. The system used standard IEEE to ensure the system can be used in practically.

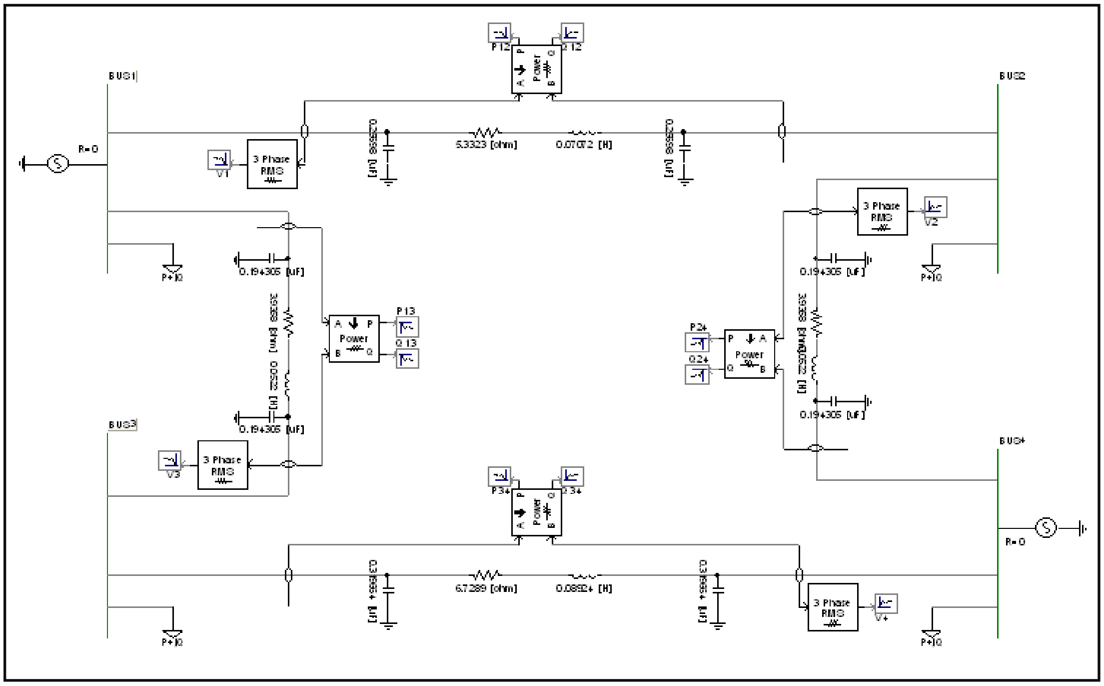


Figure 4.1 A single line diagram of 4-bus test system

4.2.1 Load flow analysis

To ensure the result from MATLAB and PSCAD are similar, this analysis has been done. From the MATLAB, the load flow built up by 3 iteration of Newton's Method. In PSCAD, the load flow is obtained by modeling single line diagram of 4-bus test system, originally data from MATLAB. The result is in steady-state condition.

The real power flows from a greater to a smaller voltage angle. These, the reactive power also flow in the same direction of voltage direction. The voltage magnitude and voltage angle setting based on the data from MATLAB. Table 4.2 below showing the data from the MATLAB used to the system.

Table 4.2: Voltage magnitude and Voltage angle from MATLAB

Bus No.	Voltage Magnitude (pu)	Voltage angle (deg)
1	1.000	0.000
2	0.982	-0.976
3	0.969	-1.872
4	1.020	1.523

Table 4.3(a) and Table 4.3(b) below show the result of load injection bus from MATLAB and PSCAD. The result has been taken without any injection of harmonic data through to the system. It shows the approximately result although some of it is different. The different result between MATLAB and PSCAD in small value because it using the different type of tools to run it. The different losses exist in different tools of software used.

Table 4.3(a): The Load Flow in MATLAB

Branch No.	From Bus	To Bus	From Bus Injection		To bus Injection	
			P (MW)	Q (MVar)	P (MW)	Q (MVar)
1	1	2	38.69	22.30	-38.46	-31.24
2	1	3	98.12	61.21	-97.09	-63.57
3	2	4	-131.54	-74.11	133.25	74.92
4	3	4	-102.91	-60.37	104.75	56.93

Table 4.3(b): The Load Flow in PSCAD

Branch No.	From Bus	To Bus	From Bus Injection		To bus Injection	
			P (MW)	Q (MVar)	P (MW)	Q (MVar)
1	1	2	38.7664	27.4607	-38.5383	-26.323
2	1	3	98.1408	65.0692	-97.1067	-59.9105
3	2	4	-131.63	-70.3861	133.352	78.9752
4	3	4	-102.931	-54.3594	104.771	63.5377

Figure 4.2(a) and Figure 4.2(b) show the graphical data of load flow for this MATLAB and PSCAD. This figure is for the comparison of real and reactive power from bus injection. Besides, Figure 4.3(a) and Figure 4.3(b) show the graphical data of load flow for this MATLAB and PSCAD for the comparison of real and reactive power to bus injection.

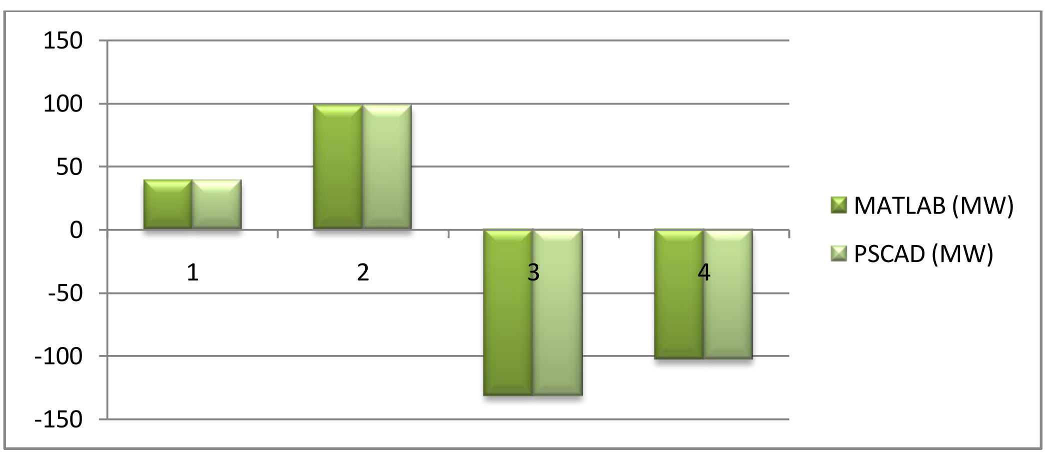


Figure 4.2(a) Comparison Graph of Real Power from Bus Injection between MATLAB and PSCAD

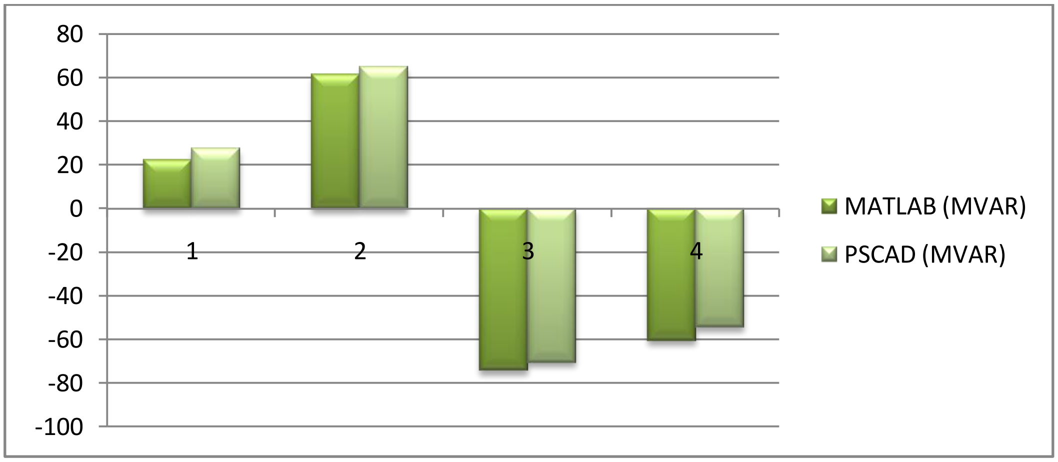


Figure 4.2(b) Comparison Graph of Reactive Power from Bus Injection between MATLAB and PSCAD

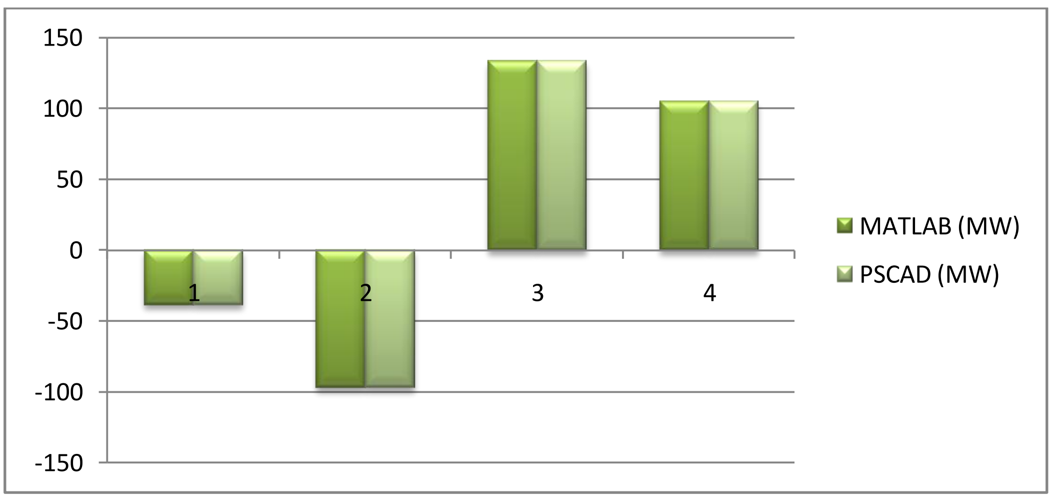


Figure 4.3(a) Comparison Graph of Real Power to Bus Injection between MATLAB and PSCAD

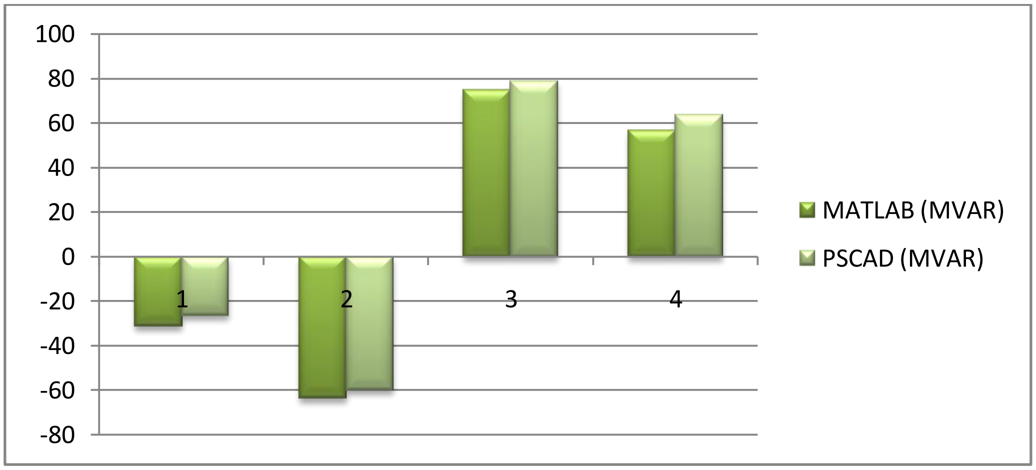


Figure 4.3(b) Comparison Graph of Reactive Power to Bus Injection between MATLAB and PSCAD

Table 4.4 above shows the comparison of power losses in MATLAB and PSCAD. The losses between it are similar.

Table 4.4: Power Losses in MATLAB and PSCAD

Branch No.	MATLAB	PSCAD	Different Value	MATLAB	PSCAD	Different Value
	P (MW)	P (MW)	MW	Q (MW)	Q (MW)	MW
1	0.227	0.2281	0.0011	1.13	1.1377	0.0077
2	1.031	1.0341	0.0031	5.16	5.1587	-0.0013
3	1.715	1.722	0.007	8.58	8.5891	0.0091
4	1.835	1.84	0.005	9.18	9.1783	-0.0017

4.2.2 Harmonic analysis

Harmonic analysis can be done after all the distortion involved in case to disturb the system. The harmonic analyzed in terms of 3rd, 5th, and 7th order of harmonic. The designation of active filter include as a rescuer to the system. Figure 4.4 below shows the IEEE-4bus test system after inject the harmonic present on nonlinear load.

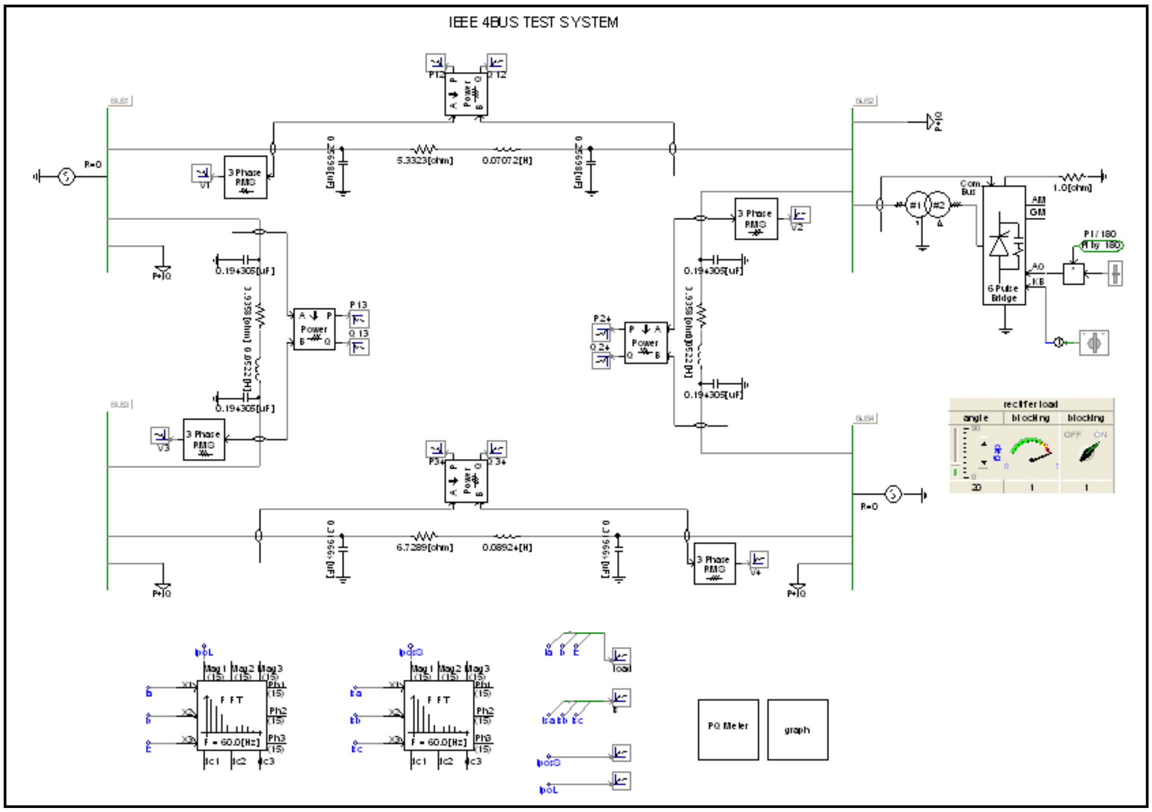


Figure 4.4 IEEE 4-bus test system with nonlinear load

Figure 4.5 below shows the test system that attached harmonic current injection and active filter. The filter circuit controlled by Pulse Width Modulation (PWM) voltage source harmonic which is gate-turn off thyristor.

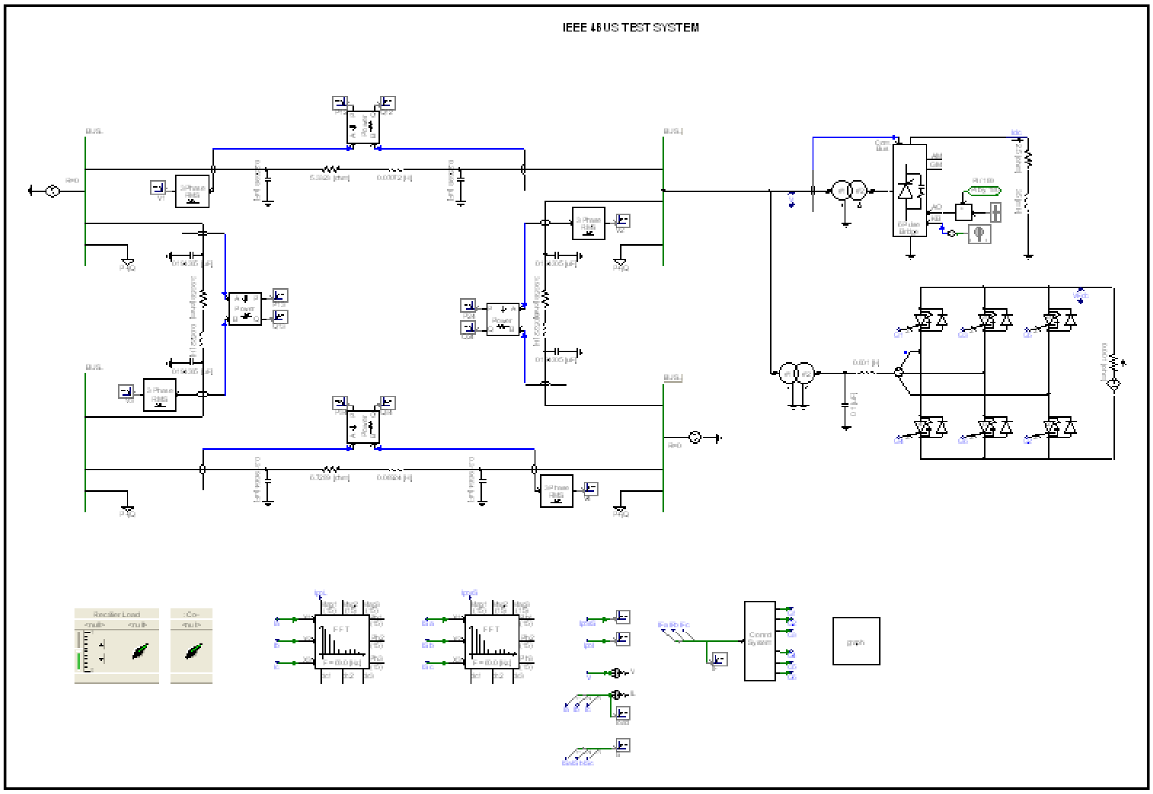


Figure 4.5 Injection of harmonic current and active filter on 4-bus test system

Figure 4.6 below shows the control system that used for overall system. The value and connection should in right way, so that any error or mistaken can be avoid. Besides figure 4.7 shows the analysis from the project for 4-bus test system. It has shown the source and load of harmonic for 15_{th} order harmonic. The source current and load current for 3-phase attached and the filter current from result shown that it smaller value compared to source and load current.

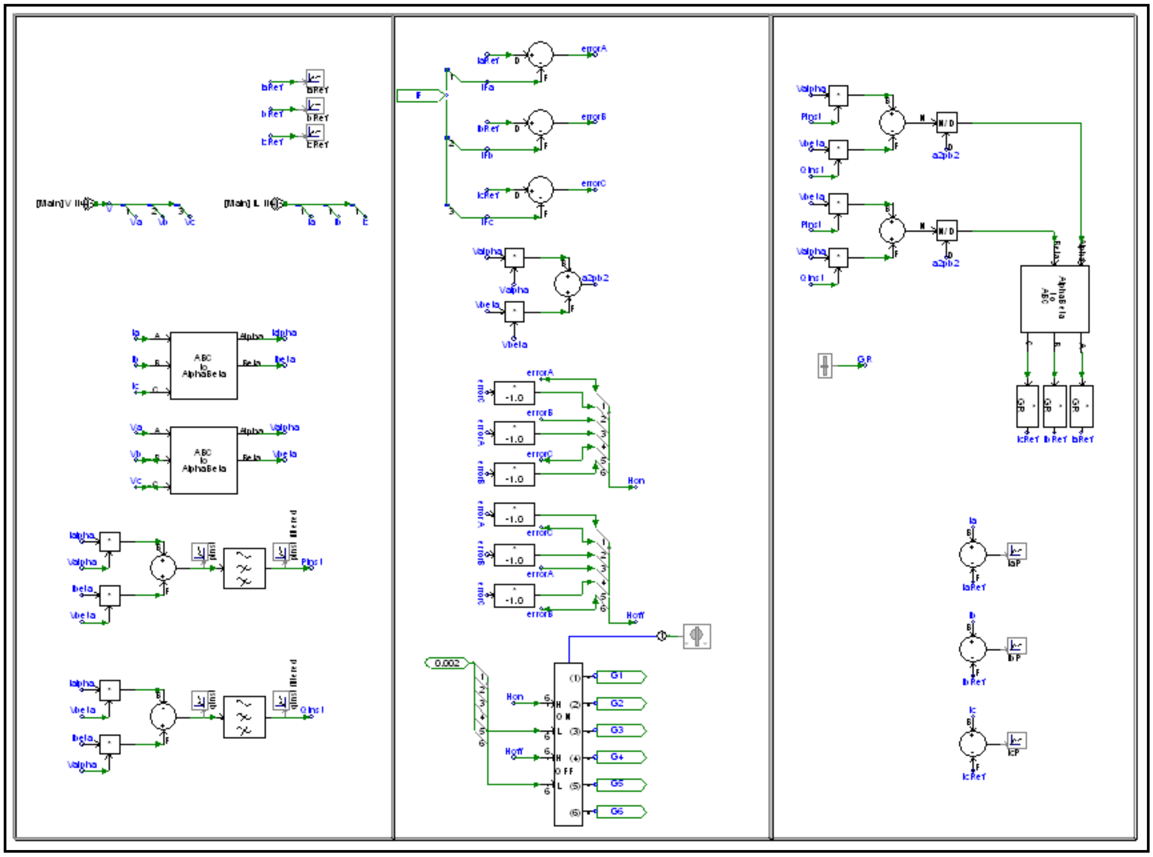


Figure 4.6 Control circuit for test system

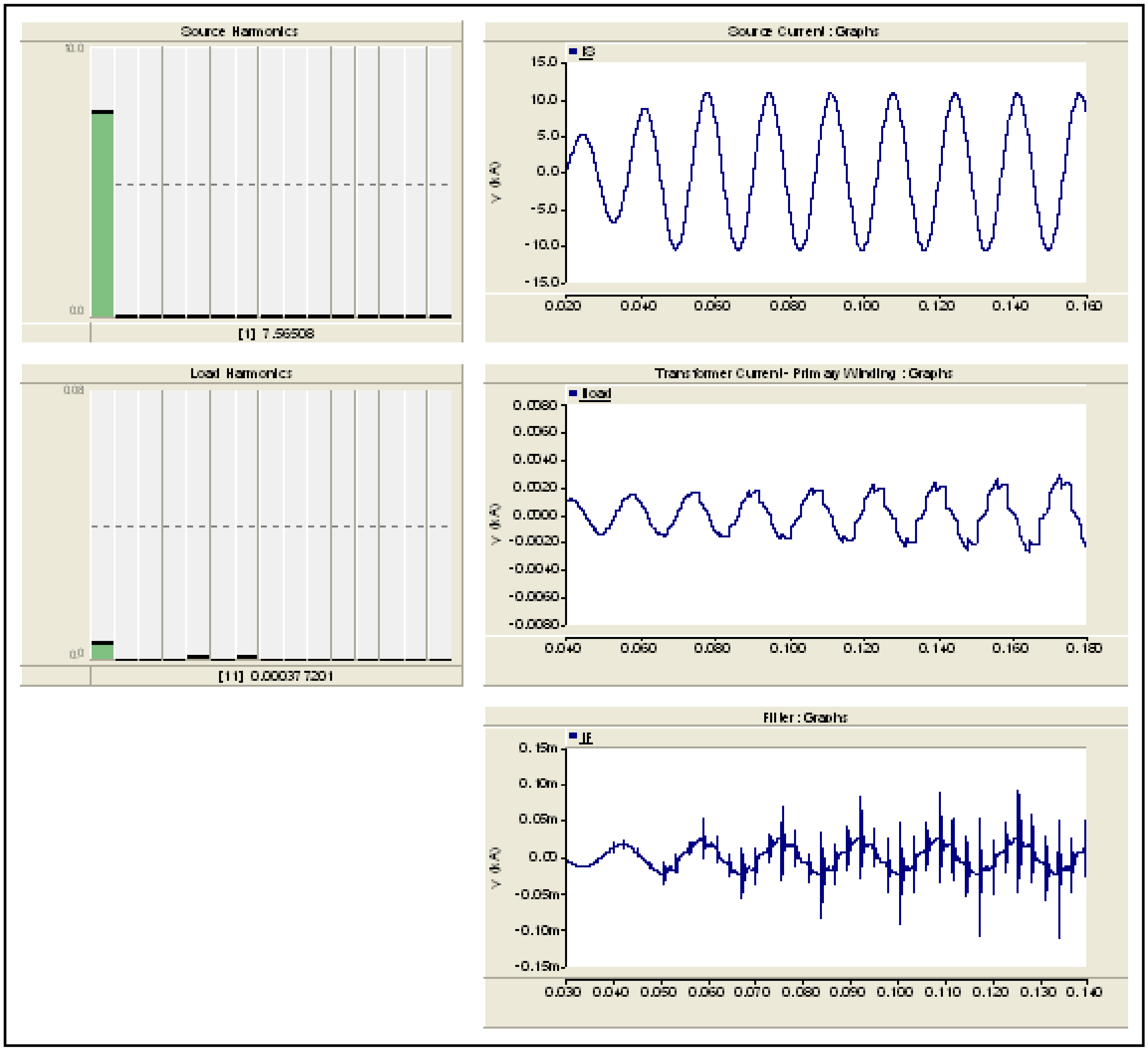


Figure 4.7 Analysis for IEEE 4-bus test system

4.2.3 Transient Stability Analysis

In this part, transient stability of load that attached as harmonic cause that is non-linear load discussed. The non-linear load that used is 6-pulse Bridge and attached to the load bus. It is actually disturb the overall test system result. The customer has not experiencing to the outage event in case of abnormal condition of fault in transmission line and distribution system.

4.3 IEEE 9-bus test system configuration using MATPOWER

The analysis is similar with the first test system which is 4-bus test system. This system has three loads and three generators. In this case, the load flow analysis, injection harmonics and designing of active filter approach to the system. Below are the calculations converting per unit data to actual data for this test system:

Bus 1 to 4

$$R_{14}^{act} = 0 \times \left(\frac{345k}{100M}\right)^2 = 0\Omega$$

$$X_{L14}^{act} = 0.0576 \times \left(\frac{345k}{100M}\right)^2 = 68.5584$$

$$L_{14}^{act} = \frac{68.5584}{2\pi(60)} = 0.181856804\text{H}$$

$$Xc_{14}^{pu} = \frac{1}{0} = 0\Omega$$

$$Xc_{14}^{act} = 0 \times \left(\frac{345k}{100M}\right)^2 = 0$$

$$C_{14}^{act} = \frac{1}{2\pi(60)(0)} = 0F$$

$$C_{14}^{shunt} = \frac{0}{2} = 0F$$

Bus 4 to 5

$$R_{45}^{act} = 0.017 \times \left(\frac{345k}{100M} \right)^2 = 20.23425\Omega$$

$$X_{L45}^{act} = 0.092 \times \left(\frac{345k}{100M} \right)^2 = 109.503$$

$$L_{45}^{act} = \frac{109.503}{2\pi(60)} = 0.290465728\text{H}$$

$$Xc_{45}^{pu} = \frac{1}{0.158} = 6.329113924\text{H}$$

$$Xc_{45}^{act} = 6.329113924 \times \left(\frac{345k}{100M} \right)^2 = 7533.227848$$

$$C_{45}^{act} = \frac{1}{2\pi(60)(7533.227848)} = 0.352117636\mu F$$

$$C_{45}^{shunt} = \frac{0.352117636}{2} = 0.176058818\mu F$$

Bus 5 to 6

$$R_{56}^{act} = 0.039 \times \left(\frac{345k}{100M} \right)^2 = 46.41975\Omega$$

$$X_{L56}^{act} = 0.17 \times \left(\frac{345k}{100M} \right)^2 = 202.3425$$

$$L_{56}^{act} = \frac{202.3425}{2\pi(60)} = 0.536730151\text{H}$$

$$Xc_{56}^{pu} = \frac{1}{0.358} = 2.793296089$$

$$Xc_{56}^{act} = 2.793296089 \times \left(\frac{345k}{100M} \right)^2 = 3324.72067$$

$$C_{56}^{act} = \frac{1}{2\pi(60)(3324.72067)} = 0.797836163\mu F$$

$$C_{56}^{shunt} = \frac{0.797836163}{2} = 0.398918081\mu F$$

Bus 3 to 6

$$R_{36}^{act} = 0\times\left(\frac{345k}{100M}\right)^2 = 0\Omega$$

$$X_{L36}^{act} = 0.0586\times\left(\frac{345k}{100M}\right)^2 = 69.74865$$

$$L_{36}^{act} = \frac{69.74865}{2\pi(60)} = 0.18501404\text{H}$$

$$Xc_{36}^{pu} = \frac{1}{0} = 0\text{H}$$

$$Xc_{36}^{act} = 0\times\left(\frac{345k}{100M}\right)^2 = 0$$

$$C_{36}^{act} = \frac{1}{2\pi(60)(0)} = 0F$$

$$C_{36}^{shunt} = \frac{0}{2} = 0F$$

Bus 6 to 7

$$R_{67}^{act} = 0.0119\times\left(\frac{345k}{100M}\right)^2 = 14.163975\Omega$$

$$X_{L67}^{act} = 0.1008\times\left(\frac{345k}{100M}\right)^2 = 119.025$$

$$L_{67}^{act} = \frac{119.025}{2\pi(60)} = 0.315723618\text{H}$$

$$Xc_{67}^{pu} = \frac{1}{0.209} = 4.784688995\text{H}$$

$$Xc_{67}^{act} = 4.784688995\times\left(\frac{345k}{100M}\right)^2 = 5694.976077$$

$$C_{67}^{act} = \frac{1}{2\pi(60)(5694.976077)} = 0.46577586\mu F$$

$$C_{67}^{shunt} = \frac{0.46577586}{2} = 0.23288793\mu F$$

Bus 7 to 8

$$R_{78}^{act} = 0.0085 \times \left(\frac{345k}{100M}\right)^2 = 10.117125\Omega$$

$$X_{L78}^{act} = 0.072 \times \left(\frac{345k}{100M}\right)^2 = 85.698$$

$$L_{78}^{act} = \frac{85.698}{2\pi(60)} = 0.227321005\text{H}$$

$$Xc_{78}^{pu} = \frac{1}{0.149} = 6.711409396\text{H}$$

$$Xc_{78}^{act} = 6.711409396 \times \left(\frac{345k}{100M}\right)^2 = 7988.255034$$

$$C_{78}^{act} = \frac{1}{2\pi(60)(79988.255034)} = 0.332060302\mu F$$

$$C_{78}^{shunt} = \frac{0.332060302}{2} = 0.166030151\mu F$$

Bus 8 to 2

$$R_{82}^{act} = 0 \times \left(\frac{345k}{100M}\right)^2 = 0\Omega$$

$$X_{L82}^{act} = 0.0625 \times \left(\frac{345k}{100M}\right)^2 = 74.390625$$

$$L_{82}^{act} = \frac{74.390625}{2\pi(60)} = 0.197327261\text{H}$$

$$Xc_{82}^{pu} = \frac{1}{0} = 0\text{H}$$

$$Xc_{82}^{act} = 0 \times \left(\frac{345k}{100M}\right)^2 = 0$$

$$C_{82}^{act} = \frac{1}{2\pi(60)(0)} = 0F$$

$$C_{82}^{shunt} = \frac{0}{2} = 0F$$

Bus 8 to 9

$$R_{89}^{act} = 0.032 \times \left(\frac{345k}{100M} \right)^2 = 38.088\Omega$$

$$X_{L89}^{act} = 0.161 \times \left(\frac{345k}{100M} \right)^2 = 191.63025$$

$$L_{89}^{act} = \frac{191.63025}{2\pi(60)} = 0.508315025\text{H}$$

$$Xc_{89}^{pu} = \frac{1}{0.306} = 3.267973856\text{H}$$

$$Xc_{89}^{act} = 3.267973856 \times \left(\frac{345k}{100M} \right)^2 = 3889.705882$$

$$C_{89}^{act} = \frac{1}{2\pi(60)(3889.705882)} = 0.681949346\mu F$$

$$C_{89}^{shunt} = \frac{0.681949346}{2} = 0.340974673\mu F$$

Bus 9 to 4

$$R_{94}^{act} = 0.01 \times \left(\frac{345k}{100M} \right)^2 = 11.9025\Omega$$

$$X_{L94}^{act} = 0.085 \times \left(\frac{345k}{100M} \right)^2 = 101.17125$$

$$L_{94}^{act} = \frac{101.17125}{2\pi(60)} = 0.268365075\text{H}$$

$$Xc_{94}^{pu} = \frac{1}{0.176} = 5.681818182$$

$$Xc_{94}^{act} = 5.681818182 \times \left(\frac{345k}{100M} \right)^2 = 6762.784091$$

$$C_{94}^{act} = \frac{1}{2\pi(60)(6762.784091)} = 0.392232303\mu F$$

$$C_{94}^{shunt} = \frac{0.392232303}{2} = 0.196116152\mu F$$

Table 4.5 below shows the value of resistor (R), inductor (L), and capacitor (C) after all the calculation involved for 9-bus test system. It is easier way in understanding the value that actually used to add in test system.

Table 4.5 Line data of 4-bus test system

From bus	To bus	R (Ω)	L (H)	C (μF)
1	4	0	0.181856804	0
4	5	20.23425	0.290465728	0.176058818
5	6	46.41975	0.536730151	0.398918081
3	6	0	0.18501404	0
6	7	14.163975	0.315723618	0.23288793
7	8	10.117125	0.227321005	0.166030151
8	2	0	0.197327261	0
8	9	38.088	0.508315025	0.340974673
9	4	11.9025	0.268365075	0..196116152

Figure 4.8 shows the test system of 4-bus test sytem that built by using PSCAD. The value taken from the calculation before. The system used standard IEEE to ensure the system can be used in practically.

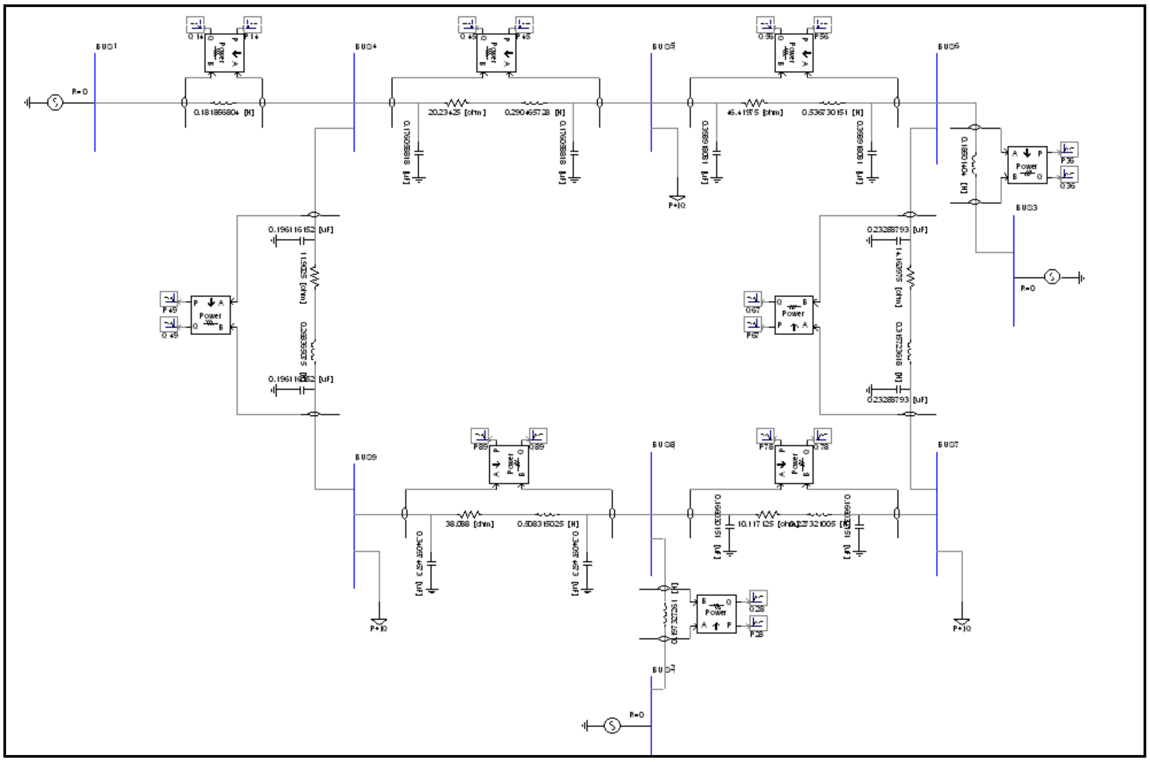


Figure 4.8 A single line diagram of 9-bus test system

4.3.1 Load flow analysis

The load flow from MATLAB data built up by 4 iteration of Newton's Method. The load flow is obtained by modeling single line diagram of 9-bus test system, originally data from MATLAB using PSCAD. The result is in steady-state condition.

In this system, the load flow step is almost similar with 4-bus test system. The voltage magnitude and voltage angle setting based on the data from MATLAB. Table 4.6 below showing the data from the MATLAB used to the system.

Table 4.6 Voltage magnitude and Voltage angle from MATLAB

Bus No.	Voltage Magnitude (pu)	Voltage angle (deg)
1	1.000	0.000
2	1.000	9.669
3	1.000	4.771
4	0.987	-2.407
5	0.975	-4.017
6	1.003	1.926
7	0.986	0.622
8	0.996	3.799
9	0.958	-4.350

Table 4.7(a) and Table 4.7(b) above show the result of load injection bus in MATLAB and PSCAD. It shows the approximately result although some of it is different without any injection of harmonic data through to the system. The different result between MATLAB and PSCAD in small value because it using the different type of tools to run it.

Table 4.7(a): The Load Flow in MATLAB

Branch No.	From Bus	To Bus	From Bus Injection		To bus Injection	
			P (MW)	Q (MVar)	P (MW)	Q (MVar)
1	1	4	71.95	24.07	-71.95	-20.75
2	4	5	30.73	-0.59	-30.55	-13.69
3	5	6	-59.45	-16.31	60.89	-12.43
4	3	6	85.00	-3.65	-85.00	7.89
5	6	7	24.11	4.54	-24.01	-24.40
6	7	8	-75.99	-10.60	76.50	0.26

7	8	2	-163.00	2.28	163.00	14.46
8	8	9	86.50	-2.53	-84.04	-14.28
9	9	4	-40.96	-35.72	41.23	21.34

Table 4.7(b): The Load Flow in PSCAD

Branch No.	From Bus	To Bus	From Bus Injection		To bus Injection	
			P (MW)	Q (MVar)	P (MW)	Q (MVar)
1	1	4	71.9605	24.0499	-71.9594	-20.7337
2	4	5	30.8051	7.13733	-30.6303	-6.19297
3	5	6	-59.4574	0.72284	60.908	5.5948
4	3	6	85.0586	-3.62577	-85.0577	7.87333
5	6	7	24.1445	15.073	-24.0486	-14.2682
6	7	8	-75.902	-3.31248	76.4079	7.5899
7	8	2	-162.914	2.35256	162.918	14.3658
8	8	9	86.5023	12.6363	-84.0355	-0.238054
9	9	4	-40.8852	-27.6094	41.1513	29.8655

The comparison of real and reactive power from bus injection sees in the graph. Figure 4.10(a) and Figure 4.10(b) show the graph of load flow in MATLAB and PSCAD for the comparison of real and reactive power to bus injection.

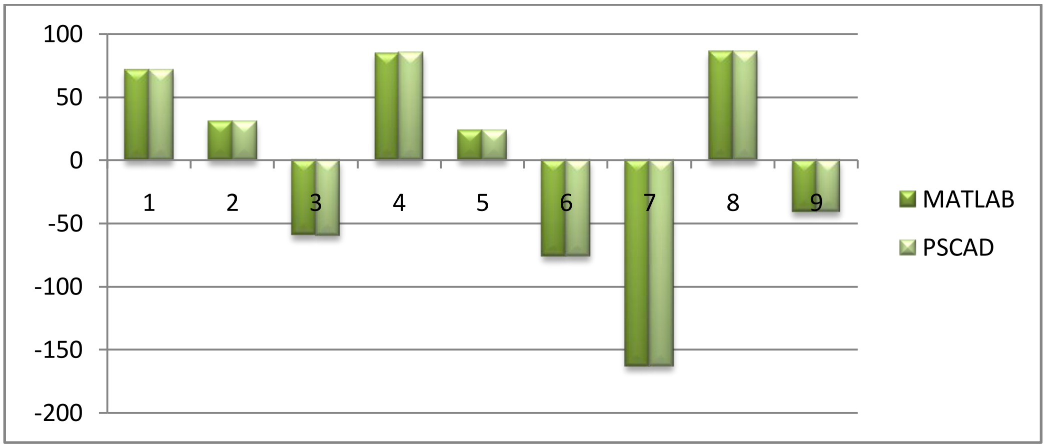


Figure 4.9(a) Comparison Graph of Real Power from Bus Injection between MATLAB and PSCAD

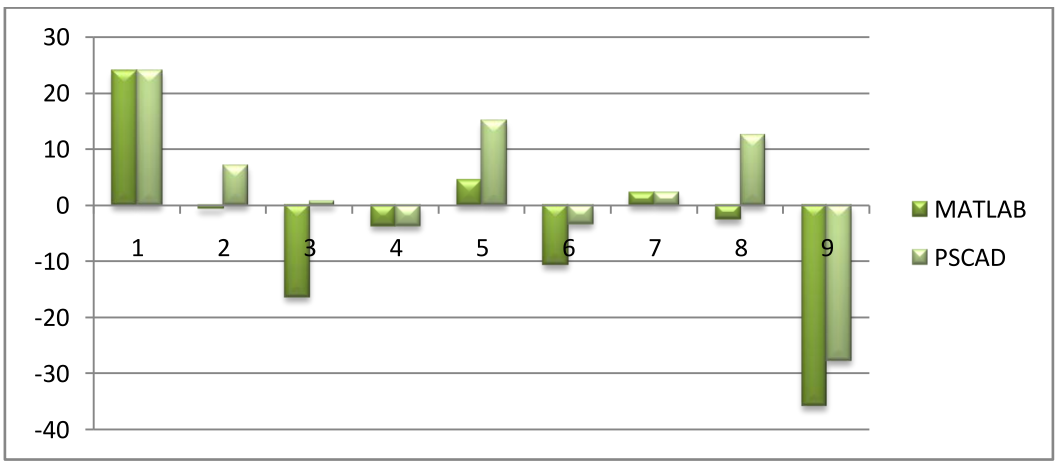


Figure 4.9(b) Comparison Graph of Reactive Power from Bus Injection between MATLAB and PSCAD

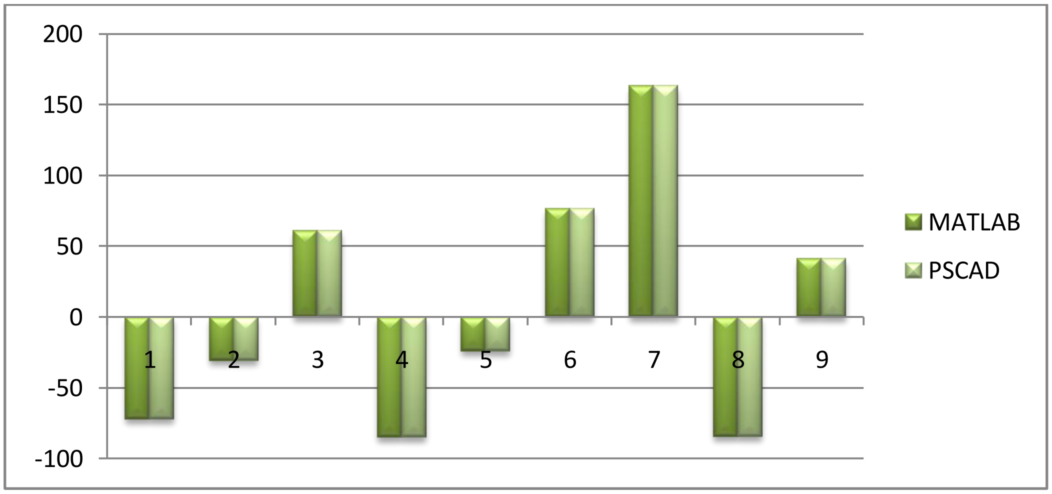


Figure 4.10(a) Comparison Graph of Real Power to Bus Injection between MATLAB and PSCAD

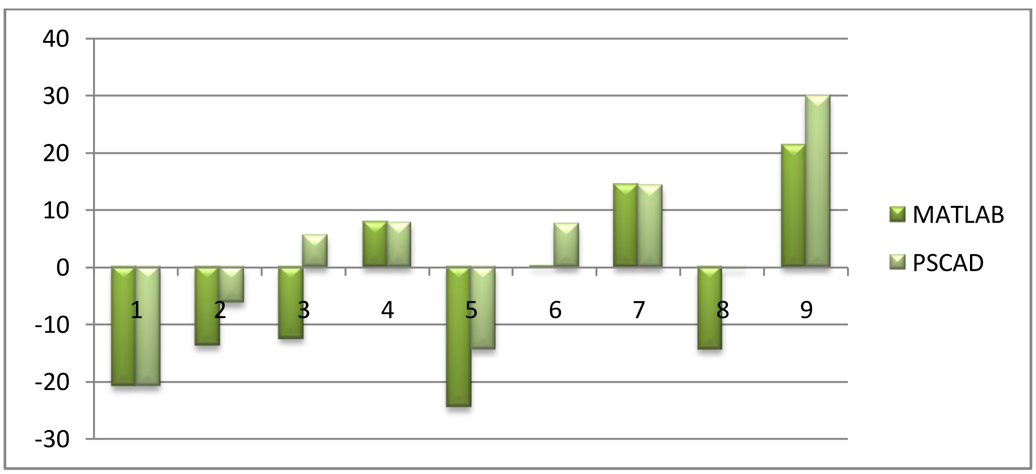


Figure 4.10(b) Comparison Graph of Reactive Power to Bus Injection between MATLAB and PSCAD

Table 4.8 above shows the comparison of power losses in MATLAB and PSCAD. The losses between it are approximately similar.

Table 4.8 Power Losses in MATLAB and PSCAD

Branch No.	MATLAB	PSCAD	Different Value	MATLAB	PSCAD	Different Value
	P (MW)	P (MW)	MW	Q (MW)	Q (MW)	MW
1	0.000	0.0011	0.0011	3.32	3.3162	-0.0036
2	0.174	0.1748	0.0008	0.94	0.94436	0.00436
3	1.449	1.4506	0.0016	6.31	6.31764	0.00764
4	0.000	0.0009	0.0009	4.24	4.24756	0.00756
5	0.095	0.0959	0.0009	0.81	0.80480	-0.0052
6	0.506	0.5059	-0.0001	4.29	4.27742	-0.01258
7	0.000	0.0040	0.004	16.74	16.71836	-0.02164
8	2.465	2.4668	0.0018	12.40	12.398246	-0.001754
9	0.266	0.2661	0.0001	2.26	2.2561	-0.0039

4.3.2 Harmonic analysis

Harmonic analysis can be done after all the distortion involved in case to disturb the system. The harmonic analyzed in terms of 3^{rd}, 5^{th}, and 7^{th} order of harmonic. The designation of active filter include as a rescuer to the system. Figure 4.4 below shows the IEEE-4bus test system after inject the harmonic present on nonlinear load.

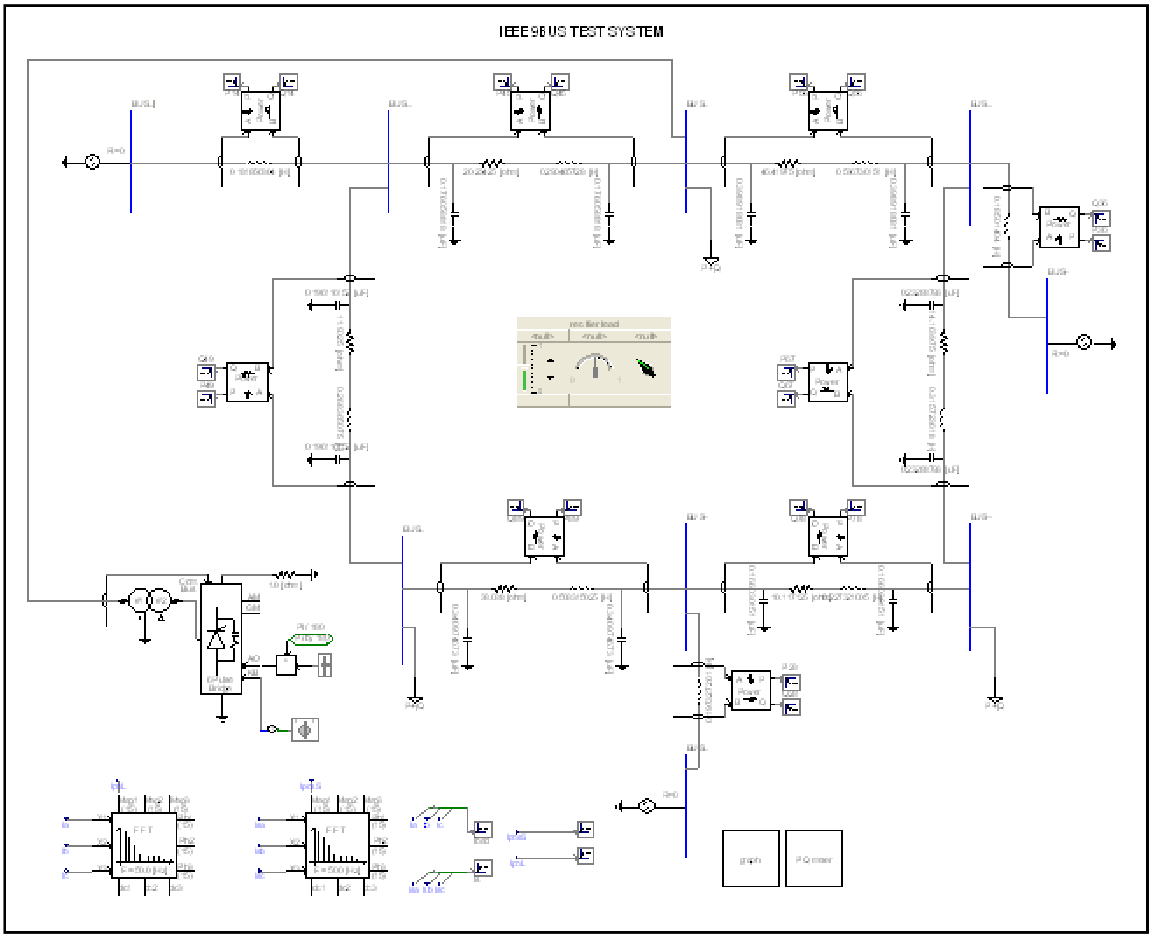


Figure 4.11 IEEE 9-bus test system with nonlinear load

Figure 4.5 below shows the test system that attached harmonic current injection and active filter. The filter circuit controlled by Pulse Width Modulation (PWM) voltage source harmonic which is gate-turn off thyristor.

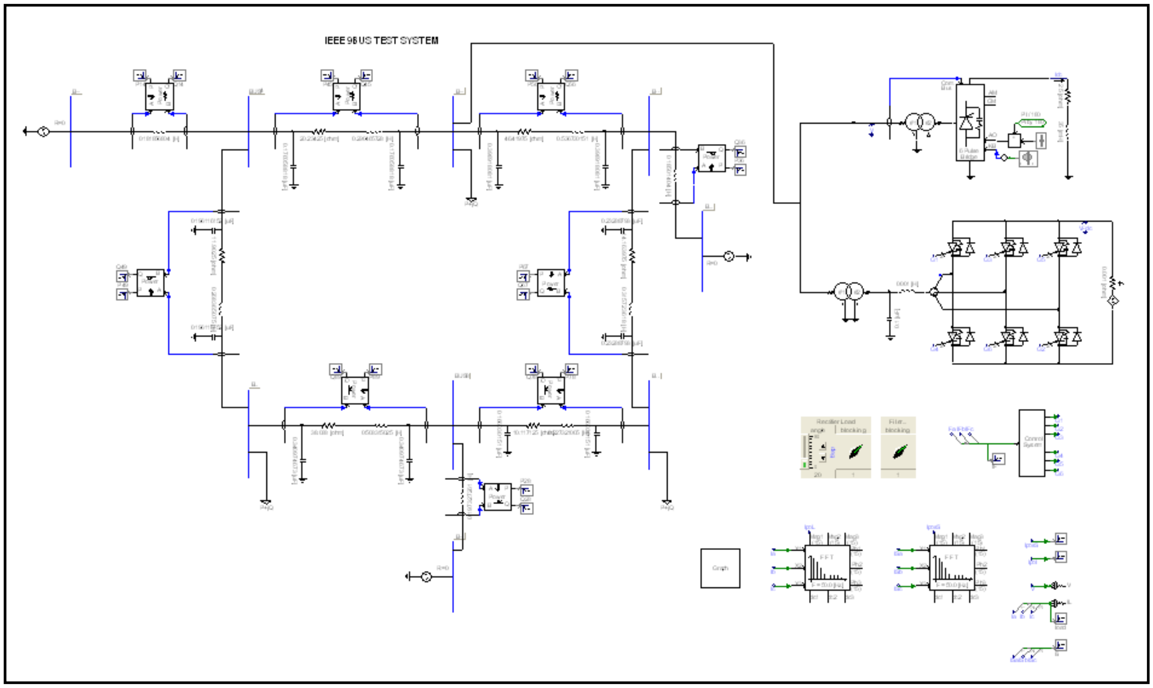


Figure 4.12 Injection of harmonic current and active filter on 9-bus test system

Figure 4.6 below shows the control system that used for overall system. The value and connection should in right way, so that any error or mistaken can be avoid. Besides figure 4.7 shows the analysis from the project for 4-bus test system. It has shown the source and load of harmonic for 15_{th} order harmonic. The source current and load current for 3-phase attached and the filter current from result shown that it smaller value compared to source and load current.

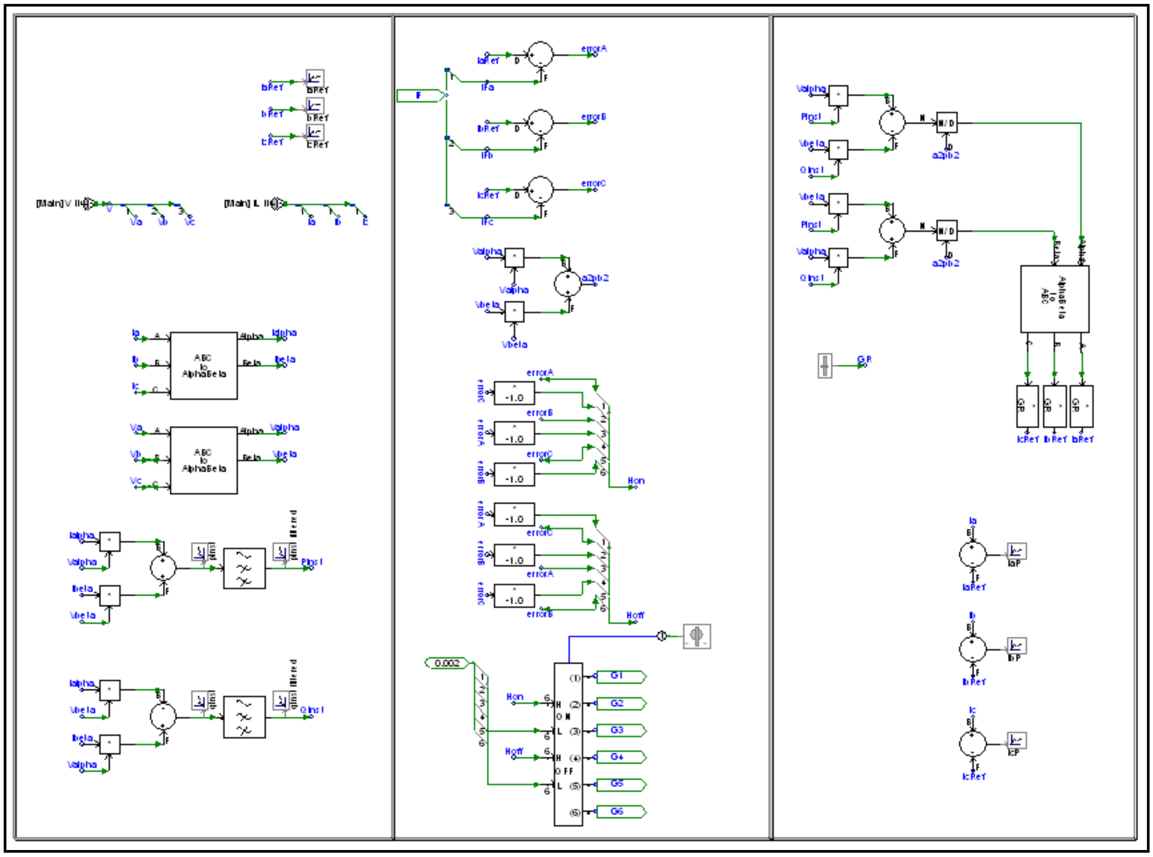


Figure 4.13 Control circuit for test system

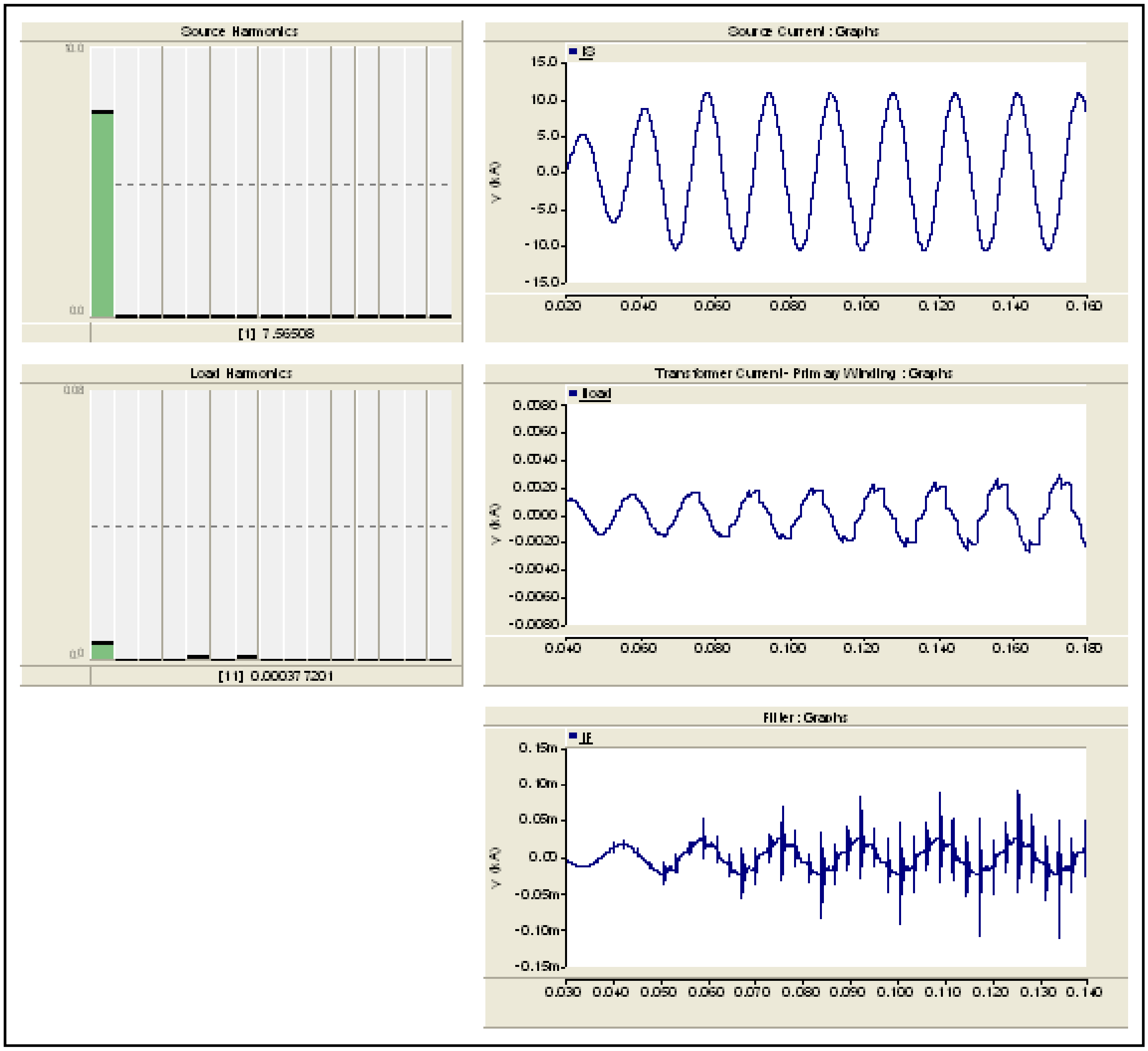


Figure 4.14 Analysis for IEEE 9-bus test system

4.3.3 Transient Stability Analysis

In this part, transient stability of load that attached as harmonic cause that is non-linear load discussed. The non-linear load that used is 6-pulse Bridge and attached to the load bus. It is actually disturb the overall test system result. The customer has not experiencing to the outage event in case of abnormal condition of fault in transmission line and distribution system.

4.4 Summary

It summarized that load flow, harmonic and transient stability analysis can be handling for those IEEE 4-bus and 9-bus test system. The load flow analysis follow successfully by running first the data from MATPOWER and using the data, the design of single line diagram of test system approach using PSCAD. The injection of harmonic current by using FFT method and injection of nonlinear load cause system distorted. The existed of active filter design parallel with nonlinear load will recover the system back to normal and steady-state condition.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From this project, the analysis of harmonic was identified in case of the designation of active filter that approach to the system. The harmonic analysis discussed about the order waveform that performed to the system. The designation of active filter has achieved by analyzing the harmonic distortion first before any clear up system successfully run. It also reduces the power quality problems.

This project base on IEEE standard tests system this is 4-bus and 9-bus test system. The comparison between Matlab and PSCAD data taken ensure that the correct data. A designation of active filter involved to the system after the injection of harmonic current attached to the system. The result explained by graphical data.

From load flow analysis, we have to know that there are power losses in transmission line due to the flowing of real and reactive power. The real and reactive power due to flowing direction is depends on their voltage magnitude and voltage angle.

Harmonic analysis discussed about the impact of current before and after injection of harmonic current. The impact of current after designation of active filter attached to the system also validate by graphical analysis. The filter current small compared to the source current and load current.

The transient stability analysis has achieved by analyzing the load angle of the generator. It takes time before the system become to steady-state condition. The load angle is experiencing on transient stability because of reactance in the generator.

5.2 Recommendation

From this project, there have some recommendation to improve the reliability of pure system with less distortion. There are few recommendations which are included as following:

i. Add or place the active filter at all distribution system to make sure all load has been supplied and not only for critical load. It will reduce the current flow the system impact from the existed distortion.

ii. Using active filter in different type of built in for each bus attached. Here it recommend because of each types of filter have their own advantages and disadvantages.

iii. Using the other software which much easily to obtain the result of load flow, harmonic analysis and transient analysis. In this case PSCAD is one of the sophisticated software just like DigSilent, Matlab and other software. It unique in certain part compared to others but PSCAD software is very sensitive because of if one of parameter or other configuration does not change in correct method, the result totally changed immediately. PSCAD should be explored in lecture class in any related subject, so that student can handle it better than now.

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APPENDIX A

The m-file of 4-bus Test System

```
function [baseMVA, bus, gen, branch] = case4gs
%CASE4GS  Power flow data for 4 bus, 2 gen case from Grainger &
Stevenson.
%   Please see 'help caseformat' for details on the case file format.
%
%   This is the 4 bus example from pp. 337-338 of "Power System
Analysis",
%   by John Grainger, Jr., William Stevenson, McGraw-Hill, 1994.

%   MATPOWER
%   $Id: case4gs.m,v 1.1 2005/01/27 22:57:59 ray Exp $

%%-----  Power Flow Data  -----%%
%% system MVA base
baseMVA = 100;

%% bus data
%   bus_i   type    Pd  Qd  Gs  Bs  area    Vm  Va  baseKV  zone
Vmax    Vmin
bus = [
    1   3   50  30.99   0   0   1   1   0   230 1   1.1 0.9;
    2   1   170 105.35  0   0   1   1   0   230 1   1.1 0.9;
    3   1   200 123.94  0   0   1   1   0   230 1   1.1 0.9;
    4   2   80  49.58   0   0   1   1   0   230 1   1.1 0.9;
];

%% generator data
%   bus Pg  Qg  Qmax    Qmin    Vg  mBase   status  Pmax    Pmin
gen = [
    4   318 0   100 -100    1.02    100 1   318 0;
    1   0   0   100 -100    1   100 1   0   0;
];

%% branch data
%   fbus    tbus    r   x   b   rateA   rateB   rateC   ratio   angle
status
branch = [
    1   2   0.01008 0.0504  0.1025  250 250 250 0   0   1;
    1   3   0.00744 0.0372  0.0775  250 250 250 0   0   1;
    2   4   0.00744 0.0372  0.0775  250 250 250 0   0   1;
    3   4   0.01272 0.0636  0.1275  250 250 250 0   0   1;
];

return;
```

The m-file of 9-bus Test System

```
function [baseMVA, bus, gen, branch, areas, gencost] = case9
%CASE9    Power flow data for 9 bus, 3 generator case.
%   Please see 'help caseformat' for details on the case file format.
%
%   Based on data from Joe H. Chow's book, p. 70.

%   MATPOWER
%   $Id: case9.m,v 1.7 2007/09/17 16:07:48 ray Exp $

%%-----  Power Flow Data  -----%%
%% system MVA base
baseMVA = 100;

%% bus data
%   bus_i   type    Pd  Qd  Gs  Bs  area    Vm  Va  baseKV  zone
Vmax    Vmin
bus = [
    1   3   0   0   0   0   1   1   0   345 1   1.1 0.9;
    2   2   0   0   0   0   1   1   0   345 1   1.1 0.9;
    3   2   0   0   0   0   1   1   0   345 1   1.1 0.9;
    4   1   0   0   0   0   1   1   0   345 1   1.1 0.9;
    5   1   90  30  0   0   1   1   0   345 1   1.1 0.9;
    6   1   0   0   0   0   1   1   0   345 1   1.1 0.9;
    7   1   100 35  0   0   1   1   0   345 1   1.1 0.9;
    8   1   0   0   0   0   1   1   0   345 1   1.1 0.9;
    9   1   125 50  0   0   1   1   0   345 1   1.1 0.9;
];

%% generator data
%   bus Pg  Qg  Qmax    Qmin    Vg  mBase   status  Pmax    Pmin
gen = [
    1   0   0   300 -300    1   100 1   250 10;
    2   163 0   300 -300    1   100 1   300 10;
    3   85  0   300 -300    1   100 1   270 10;
];

%% branch data
%   fbus    tbus    r   x   b   rateA   rateB   rateC   ratio   angle
status
branch = [
    1   4   0   0.0576  0   250 250 250 0   0   1;
    4   5   0.017   0.092   0.158   250 250 250 0   0   1;
    5   6   0.039   0.17    0.358   150 150 150 0   0   1;
    3   6   0   0.0586  0   300 300 300 0   0   1;
    6   7   0.0119  0.1008  0.209   150 150 150 0   0   1;
    7   8   0.0085  0.072   0.149   250 250 250 0   0   1;
    8   2   0   0.0625  0   250 250 250 0   0   1;
    8   9   0.032   0.161   0.306   250 250 250 0   0   1;
    9   4   0.01    0.085   0.176   250 250 250 0   0   1;
];

%%-----  OPF Data  -----%%
%% area data
```

```
areas = [
    1   5;
];

%% generator cost data
%   1   startup shutdown    n   x1  y1  ... xn  yn
%   2   startup shutdown    n   c(n-1)  ... c0
gencost = [
    2   1500    0   3   0.11    5   150;
    2   2000    0   3   0.085   1.2 600;
    2   3000    0   3   0.1225  1   335;
];

return;
```

APPENDIX B

Load flow result from MATLAB of 4-bus test system

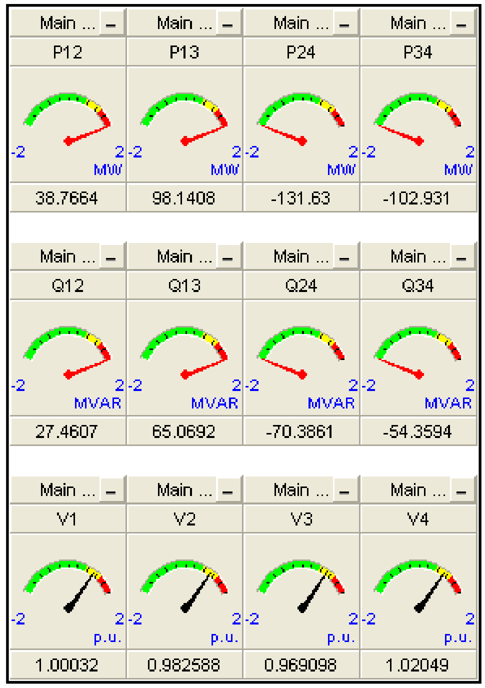
```
Newton's method power flow converged in 3 iterations.

Converged in 1.58 seconds
================================================================================
|     System Summary                                                           |
================================================================================

How many?                How much?              P (MW)            Q (MVAr)
---------------------    -------------------  -------------  -----------------
Buses                4     Total Gen Capacity     318.0           -200.0 to 200.0
Generators           2     On-line Capacity       318.0           -200.0 to 200.0
Committed Gens       2     Generation (actual)    504.8              295.9
Loads                4     Load                   500.0              309.9
  Fixed              4       Fixed                500.0              309.9
  Dispatchable       0       Dispatchable           0.0 of 0.0         0.0
Shunts               0     Shunt (inj)              0.0                0.0
Branches             4     Losses (I^2 * Z)         4.81              24.05
Transformers         0     Branch Charging (inj)    -                 38.0
Inter-ties           0     Total Inter-tie Flow     0.0                0.0
Areas                1

                          Minimum                      Maximum
                 -------------------------  --------------------------------
Voltage Magnitude   0.969 p.u. @ bus 3          1.020 p.u. @ bus 4
Voltage Angle      -1.87 deg   @ bus 3          1.52 deg   @ bus 4
P Losses (I^2*R)             -                  1.84 MW    @ line 3-4
Q Losses (I^2*X)             -                  9.18 MVAr  @ line 3-4

================================================================================
|     Bus Data                                                                 |
================================================================================
 Bus      Voltage          Generation             Load
  #   Mag(pu) Ang(deg)   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)
----- ------- --------  --------  --------  --------  --------
    1  1.000    0.000   186.81    114.50     50.00     30.99
    2  0.982   -0.976      -         -      170.00    105.35
    3  0.969   -1.872      -         -      200.00    123.94
    4  1.020    1.523   318.00    181.43     80.00     49.58
                        --------  --------  --------  --------
               Total:   504.81    295.93    500.00    309.86

================================================================================
|     Branch Data                                                              |
================================================================================
Brnch   From   To    From Bus Injection   To Bus Injection     Loss (I^2 * Z)
  #     Bus    Bus    P (MW)   Q (MVAr)   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)
-----  -----  -----  --------  --------  --------  --------  --------  --------
   1      1      2     38.69     22.30    -38.46    -31.24     0.227      1.13
   2      1      3     98.12     61.21    -97.09    -63.57     1.031      5.16
   3      2      4   -131.54    -74.11    133.25     74.92     1.715      8.58
   4      3      4   -102.91    -60.37    104.75     56.93     1.835      9.18
                                                             --------  --------
                                                    Total:     4.809     24.05
```

Load flow result from MATLAB of 9-bus test system

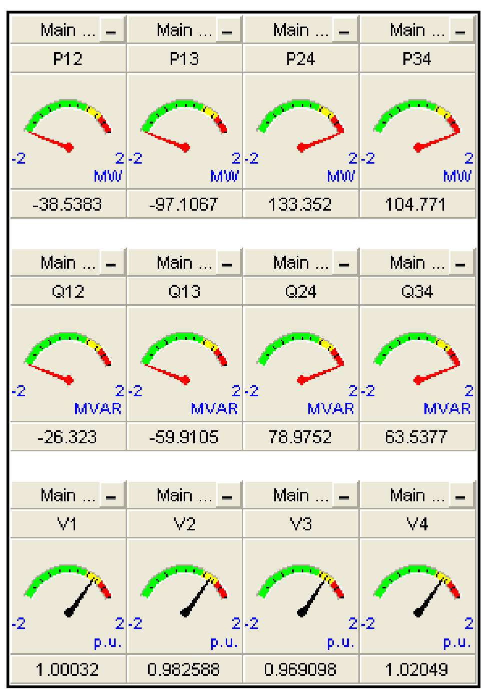
```
Newton's method power flow converged in 4 iterations.

Converged in 2.84 seconds
================================================================================
|     System Summary                                                           |
================================================================================

How many?                How much?              P (MW)            Q (MVAr)
---------------------    -------------------  -------------  -----------------
Buses              9     Total Gen Capacity     820.0           -900.0 to 900.0
Generators         3     On-line Capacity       820.0           -900.0 to 900.0
Committed Gens     3     Generation (actual)    320.0               34.9
Loads              3     Load                   315.0              115.0
  Fixed            3       Fixed                315.0              115.0
  Dispatchable     0       Dispatchable           0.0 of 0.0         0.0
Shunts             0     Shunt (inj)              0.0                0.0
Branches           9     Losses (I^2 * Z)         4.95              51.31
Transformers       0     Branch Charging (inj)     -               131.4
Inter-ties         0     Total Inter-tie Flow     0.0                0.0
Areas              1

                          Minimum                      Maximum
                 -------------------------  --------------------------------
Voltage Magnitude   0.958 p.u. @ bus 9          1.003 p.u. @ bus 6
Voltage Angle      -4.35 deg   @ bus 9          9.67 deg   @ bus 2
P Losses (I^2*R)             -                  2.46 MW    @ line 8-9
Q Losses (I^2*X)             -                 16.74 MVAr  @ line 8-2

================================================================================
|     Bus Data                                                                 |
================================================================================
 Bus      Voltage          Generation             Load
  #   Mag(pu) Ang(deg)   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)
----- ------- --------  --------  --------  --------  --------
    1  1.000    0.000    71.95     24.07       -         -
    2  1.000    9.669   163.00     14.46       -         -
    3  1.000    4.771    85.00     -3.65       -         -
    4  0.987   -2.407      -         -         -         -
    5  0.975   -4.017      -         -       90.00     30.00
    6  1.003    1.926      -         -         -         -
    7  0.986    0.622      -         -      100.00     35.00
    8  0.996    3.799      -         -         -         -
    9  0.958   -4.350      -         -      125.00     50.00
                        --------  --------  --------  --------
               Total:    319.95     34.88    315.00    115.00

================================================================================
|     Branch Data                                                              |
================================================================================
Brnch   From   To    From Bus Injection   To Bus Injection     Loss (I^2 * Z)
  #     Bus    Bus    P (MW)   Q (MVAr)   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)
-----  -----  -----  --------  --------  --------  --------  --------  --------
   1      1      4     71.95     24.07    -71.95    -20.75     0.000      3.32
   2      4      5     30.73     -0.59    -30.55    -13.69     0.174      0.94
   3      5      6    -59.45    -16.31     60.89    -12.43     1.449      6.31
   4      3      6     85.00     -3.65    -85.00      7.89     0.000      4.24
   5      6      7     24.11      4.54    -24.01    -24.40     0.095      0.81
   6      7      8    -75.99    -10.60     76.50      0.26     0.506      4.29
   7      8      2   -163.00      2.28    163.00     14.46     0.000     16.74
   8      8      9     86.50     -2.53    -84.04    -14.28     2.465     12.40
   9      9      4    -40.96    -35.72     41.23     21.34     0.266      2.26
                                                             --------  --------
                                                    Total:     4.955     51.31
```

APPENDIX C

Load flow result from PSCAD of 4-bus test system

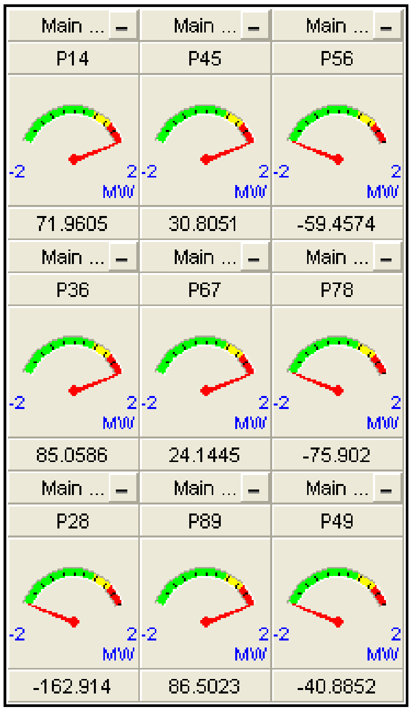


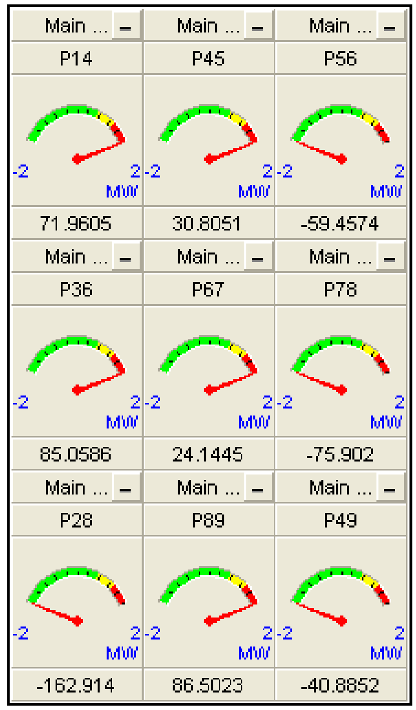
Result for real and reactive power from bus injection



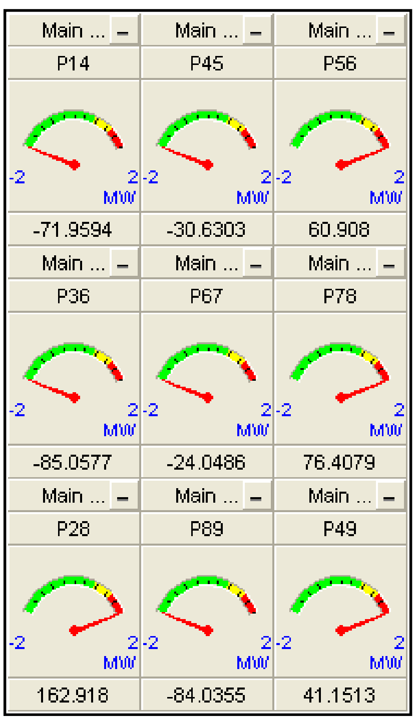
Result for real and reactive power to bus injection

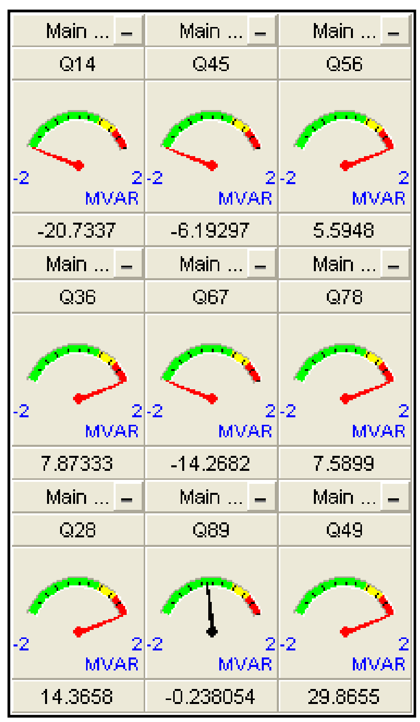
Load flow result from PSCAD of 9-bus test system





Result for real and reactive power from bus injection





Result for real and reactive power to bus injection