STUDY AND ANALYSIS OF POWER FACTOR IMPROVEMENT AND THE RELATIONSHIP WITH HARMONICS

By

MOHD PURYADIN BIN SUDIRMAN

FINAL REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(Ms. Khairul Nisak Bt. Md Hasan)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2007

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD PURYADIN BIN SUDIRMAN (4086)

ABSTRACT

The title of this project is 'Study and analysis of power factor improvement and the relationship with harmonics'. In industrial practice, it is important to maintain the power factor of the power system to a certain level to ensure that the power can be delivered to the system efficiently. Capacitor banks have been a conventional method of improving the low power factor problems. Power in AC circuits can be divided into three components namely active power, reactive power and apparent power. The power factor is defined as ratio of the effective to the apparent power. The harmonics distortion occurs when the signals is having the frequency components that is an integral multiple of the fundamental. The project execution consists of procedure identification, research and study, case study simulation and analysis of the project. The project research and study is carried out to understand the principle and the problem related to the power factor and harmonics. Simulation was carried out show the power factor improvement impact on the system and also its relationship with harmonics. Tanjung Langsat Port project have been selected to be analyzed and studied. From the study, it is found out that the insertion of capacitor banks will compensates for the reactive power of the system and thus improving the power factor. Consequently, the improvement of power factor will reduce the system losses. The insertion of the capacitor will introduce harmonics resonance in the network. From the simulation, it is noted that as the capacitor kVAR value is increased, the resonance will occur at lower frequency. Harmonics distortions analysis at each busbar shows that the Total Harmonic Distortions (THD) is highest when the injection sources are placed at both HV bus and LV bus. Finally the conclusion will summarize about the project and also the importance of considering the harmonics when installing the power capacitor to correct the power factor.

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THD - Total Harmonic Distortions

VAR - Volt-Ampere-Reactive

AC - Alternating Current

CHAPTER 1

INTRODUCTION

1.1 Background of study

In industrial facilities, it is important to maintain the power factor of the power system to meet the requirement by the power producers. Having low power factor (typically less than 0.85) will cause the power utilities to be penalized by the power producer which is not good economically. Power factor correction has been a conventional of improving the power factor and effective ways of saving the money. The intent of this study is to analyze the power factor improvement effect and also to show relationship between the power factor improvements with harmonics.

1.2 Problem statement

1.2.1 Problem identification

Power factor of the system can be improved by installing a capacitor bank or by using the synchronous motor. Normally, the usage of capacitor banks is more popular and favorable. However, installation of the capacitor banks will leads to the harmonic problems in the system which is undesirable. Furthermore, a more critical condition may occur when resonance occurs in the network. This project will also focus on the harmonics effect and problems in the system due to the power factor improvement and insertion of capacitor bank.

1.2.2 Significant of the project

Towards the completion of the project the concept of the power factor improvement shall be clearly understood. The sparks of the usage of the power electronics and nonlinear loads have greatly contributed to the harmonics problem in the power system. The harmonics resonance due to the insertion of capacitor will also be investigated and clearly understood. This knowledge can be implemented further in selecting the capacitor banks to be used for compensation. Also the analysis will help in getting better view of the harmonics impact after the capacitor bank insertion. Therefore, a prior corrective action can be taken to reduce the effect of harmonics.

1.3 Objectives and scope of study

1.3.1 The Relevancy of the Project

Power factor can be a good measure and indicator to determine the quality and transmission efficiency of the power system. System with good power factor tells us that the load is utilizing the current that it draws from the AC supply efficiently. A good system is having power factor as close as possible to unity to ensure that the power is transmitted efficiently. Whereas, a low power factor in the power system will result in more losses in the transmission. Ideally the unity power factor is desired, but this is practically unrealizable due to the use of the inductive load in the power system.

System with low of power factor will cause a penalty charges imposed by the power producer. This penalty will cost more money to the industrial utilities and not economically desirable. Study on the power factor improvement will help in understanding the power factor itself and how to correct them so that the system can operate more efficient as well as to save money.

Installation of power factor improvement capacitor somehow has a drawback to the system itself. It leads to the contribution of harmonic impact in the system. If the harmonics is not treated properly and the capacitor banks is not properly sized and designed, the impact of the harmonic distortion can be severe to the power system.

1.3.2 Feasibility of the Project within the Scope and Time frame

Improvement of the power factor is widely implemented and used in the industry. One project from Tanjung Langsat Port in Johor Bharu will be taken as an example to be simulated and analyze towards the end of the project. The timeframe given for this particular project is two semesters which are fourteen weeks for FYP 1 and another fourteen weeks for FYP 2. The project is feasible to be completed within the given period. All the activities and planning of the FYP 1 project are prescribed in the Gantt chart. (*Appendix A*)

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Power components in AC circuits

In an Alternating Current (AC) circuits, there are three power components namely; the active power, reactive power and also the apparent power. The component that we most familiar with is the active power or sometimes called the real power which is measured in kilowatt (kW). Active power is produced when the current and voltage are in phase. Real power is the power consumed by the equipment and being converted to another form of energy (e.g. heat, light and mechanical power) [1],[7].

Another power component in the AC supply is the reactive power which is measured in volt-ampere-reactive (VAR). Reactive power does not used to do work but it is used to operate electrical equipment like motor, transformer and power electronics. The reactive power is used in producing the magnetic field in the equipment [7].

Apparent power consists of both real and reactive power. It is a product obtained by multiplying the voltage with current without taking into account the phase displacement. The power in AC circuit can be represented in a triangle which also called the power triangle. The power triangle for the AC supply is shown in figure 1;

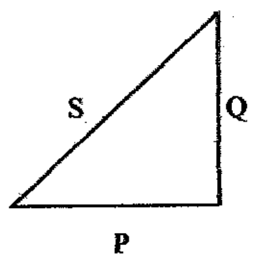


Figure 1: Power Triangle

The three power components can be related with the following equations

$$S^2 = P^2 + Q^2$$

Where,

S = Apparent Power

P = Real Power

Q = Reactive Power

The Displacement power factor is defined as the displacement of power components. This power factor is often denoted as cosine of the phase angle between the voltage and current waveform [3]. This power factor is useful in when analyzing for a linear loads.

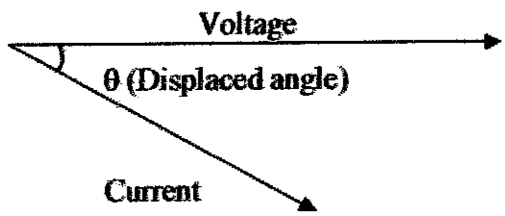


Figure 2: Phasor diagram showing current and voltage displacement

For a pure sinusoidal situation, the total power factor is defined as the ratio between the real powers to the apparent power, and represents how much real power is consumed by the electrical equipment. This power factor is sometimes called the true power factor. True power factor is useful in analyzing the circuit with nonlinear loads and when the harmonics distortion is considered.

$$\text{Total/true p.f.} = \frac{\text{Real power (Watt)}}{\text{Apparent power (Volt-Ampere)}}$$

2.2 Power factor problems and the corrections

In some industrial application, there are conditions where they have a problem of low power factor. This low power factors is due to some factors like the use of the inductive loads like induction motors and the use of the fluorescent lamp and rectifiers. These loads can reduce the overall power factor of the system. This will lead to inefficient power transmission and more energy losses in the system.

This low power factor should be corrected to improve the system performance. A unity power factor is an optimum value which would result in minimum losses and voltage drops along the transmission. A conventional way of correcting power factor is by installing the capacitor banks in the system. Other method that can be used is by using synchronous motors which operates at leading power factor or overexcited to supply the leading current to the system. The effect of the power factor before and after correction is depicted in figure 3. The figure indicates that, improvement of the power factor in the system will only compensates the reactive power (Q) whereas the active power (P) is remain the same.

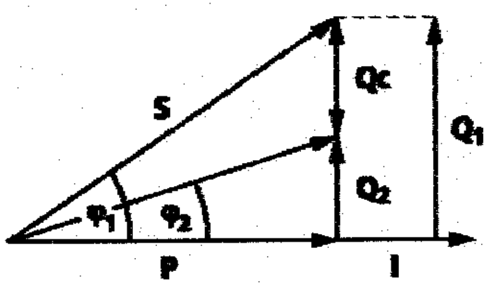


Figure 3: Power triangle showing the effect of correction

Where;

Qc = Corrected reactive power by the capacitor

Q_1 = Reactive power before correction

Q_2 = Reactive Power after correction

Φ_1 = Power factor angle before correction

Φ_2 = Power factor angle after correction

2.3 Power factor improvement calculation

The concept of power factor correction is to reduce the reactive power (VAR) of the system. Therefore the power factor calculations will find the value of the amount of reactive power that need to be corrected by the capacitor. Among the data needed to perform the calculation are the total power, the initial power factor and the desired level of power factor. The formula for the power factor calculation is as follows.

Reactive power (kVAR) = Real power (Watt) x tan Φ

Reactive power to be corrected by the capacitor Qc

Q_c = Real power (Watt) x (tan Φ_1 – tan Φ_2)

Where,

Q_c = Reactive power need to be corrected
$\Phi_1 = Cos^{-1}\ pf_1$ = initial power factor angle
$\Phi_2 = Cos^{-1}\ pf_2$ = final power factor angle

For simplification, table kVAR can be used to do the calculations. The table has tabulated the original power factor and the desired power factor improvement. (Refer appendix B for the table)

2.4 Benefits of the Power Factor Improvement

There are several other benefits of power factor improvement on the power system. These benefits and improvement are as the result from the reactive power reduction in the system. Some of the benefits are as the following;

i. Lower utility cost if a power-factor clause is enforced or the utility charges for the kVA demand
ii. Release of electrical capacity (the system does not carry unnecessary VARs)
iii. Voltage improvement (less reactive voltage drop)
iv. Lower system losses (less current)
v. Longer plant life
vi. Increase the capacity of existing system and equipment
vii. To reduce energy losses – if high reactive current is supplied, the conductor cannot be fully utilised to transmit the useful power and therefore it will be over-dimensioned during the design stage

2.5 Power factor improvement using capacitor banks

Capacitor bank installation is very much related to the power factor improvement in the power system. The concept of capacitor as a VAR or reactive power generators is beneficial to help in understanding the power factor improvement by using the power capacitors.

The concept for the power factor correction can be explained in terms of the energy stores in the capacitors and the induction devices. When voltage increase from zero to maximum, power capacitor will charge itself by storing the energy in its electrostatic field. The induction devices will gives up the energy in terms of the magnetic field. As the voltage passes maximum and start to decrease, the capacitor will discharge or supply the energy to the induction devices. The induction devices will absorb or consume the energy to build up the magnetic field in the equipment.

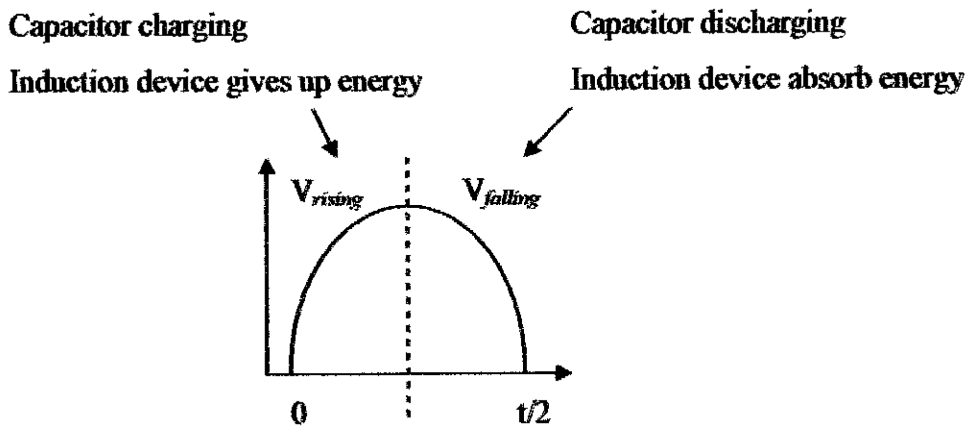


Figure 4: Charging and discharging of energy in capacitor

2.6 Configuration for capacitor bank installation

There are several methods employed in installing the capacitor bank in the network. These configurations are used based on the system configuration and how the capacitor bank can be utilized efficiently to improve the power factor. Some of the configurations are as follows:

Individual power factor corrections

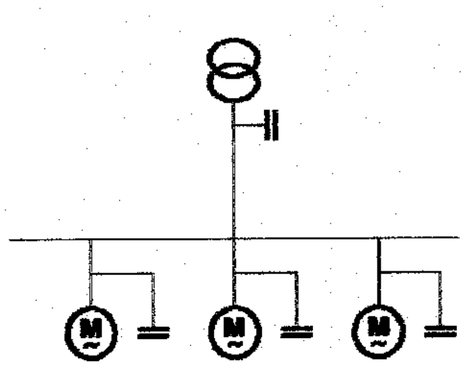


Figure 5: Typical individual power factor correction

This method employs a capacitor banks on the equipment for example in the induction motors. The capacitor will be connected in parallel with the equipment. This will eliminates the additional loads on the cabling and the transmission line in the power generation. However, the disadvantage of this method is the capacitor is only used in during the time that is associated machines is in operation. Furthermore, the cost of installation of capacitor is also high if there are so many equipments to install with the capacitor [7].

Group power factor corrections

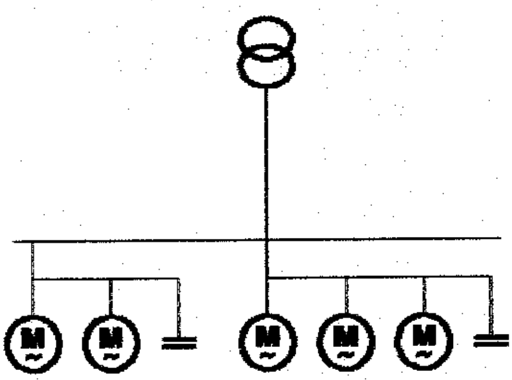


Figure 6: Typical group power factor correction

This method group several equipments to be installed by the capacitor and use single capacitor banks to cater the compensation and have a joint correction factor. This is more economical as compared to the individual power factor correction especially for a large amount of machines because less capacitor will be required. However, this method is restricted only to application that has a group of machines run together at the same time [7].

Central power factor corrections

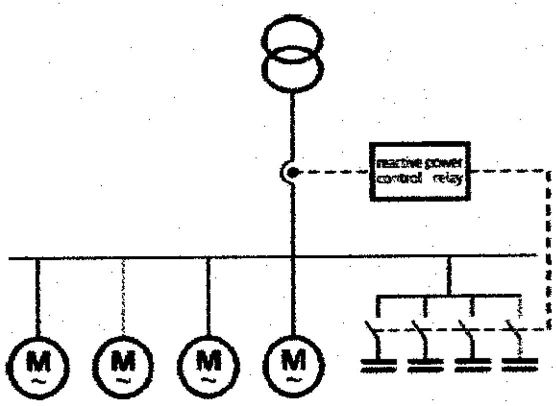


Figure 7: Typical central power factor correction

A central power factor correction is more practical and widely used in the industrial applications. The capacitor will be installed in a centralized system for example at the low voltage distribution board. The system will cover the VAR demand for the buses. Capacitors will also divided into several sections which can be automatically switched on and off by the control relays to suit the load requirements. This method is easier to be monitored and maintain as it is centralized in one location [7].

Hybrid power factor correction methods

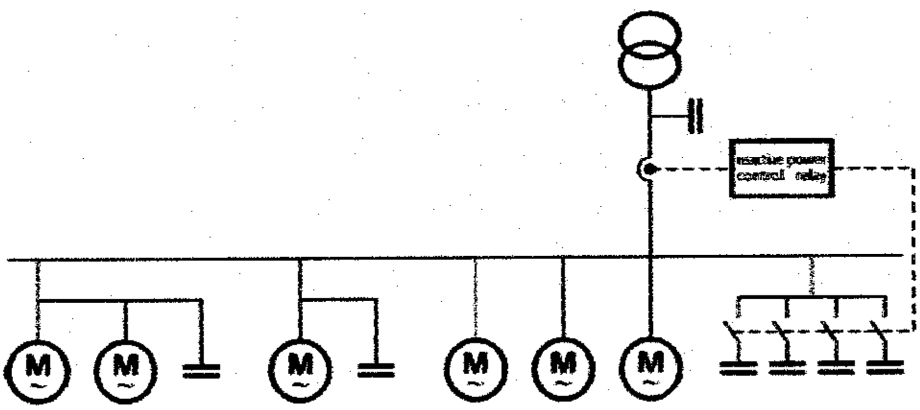


Figure 8: Typical hybrid power factor correction

The previous types of installation above show the basic configurations on how to install the capacitor to compensate for the power factor. The hybrid method is combining all the three of the above and configuring the best way to suits the system requirements. This is very practical especially when the factors like economics and system reliability are considered. As we can see, different method will have its own advantage and disadvantages. Therefore, it is the engineers' responsibility to decide which method to be implemented to suit the design requirements [7].

2.7 Power factor improvement with synchronous motors (Condenser)

Synchronous motors also can be used as power factor improvement equipment. Synchronous motor operates by converting the electrical power to the mechanical output. In power system, it can also be used as a power factor improvement device when the motor operates at leading power factor or the motor is being overexcited.

This can be done by varying the field current on the motor so that the motor will operates at leading power factor. At leading power factor, the armature current will leads the terminal voltage and thus supplying the reactive power (Q) to the system and act as a capacitor. Therefore, we know that by controlling the field current of the synchronous motors, we can control the reactive power supplied by the motor to the system.

A plot of armature current versus field current can be used to explain and understand the effect of varying the field current and the power factor. This plot is called a synchronous motor V curve shown in Figure 9. It is drawn for several power levels namely no load, half full load and full load conditions.

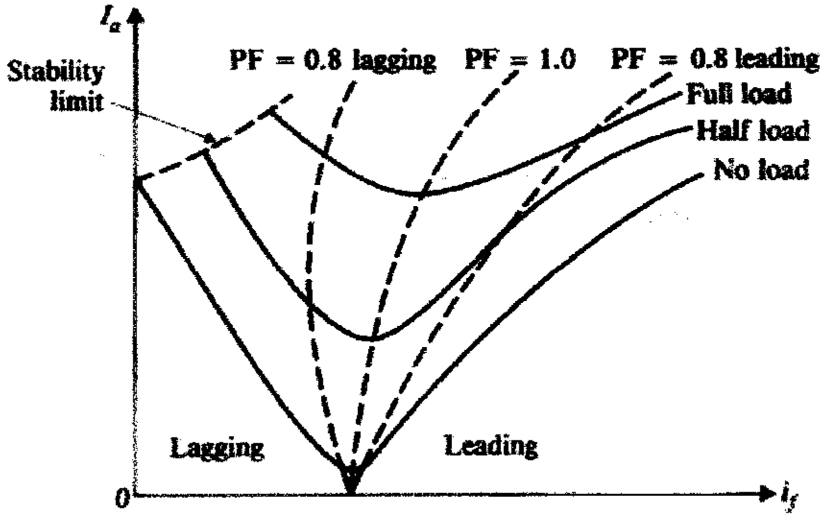


Figure 9: Synchronous motor 'V' curves

2.8 System Harmonics

Power electronics equipment is widely used in the industry as it provides better control of the equipment. This has leads to the concern over the harmonics problem in the power system. Harmonic is defined as a sinusoidal component of a periodic wave or quality having a frequency that is an integral multiple of the fundamental frequency [8]. The harmonics in the power system (h) can be expressed as;

$$h = n \times f$$

Where;

h = harmonic components

n = integer referring to the harmonics order

f = fundamental frequency

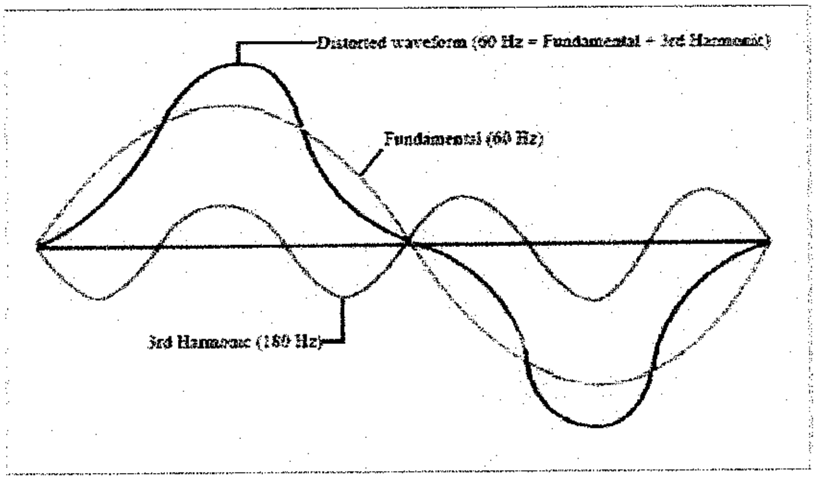


Figure 10: Distorted waveform composed of fundamental and 3rd harmonics

Basically harmonics current is generated as a result of loads that require the current source other than sinusoids. Harmonics in a power system is usually odd order numbered namely 3rd, 5th, 7th and so on. The magnitude of the current harmonics will decrease as the harmonic order increase. That is one of the reason usually our major concern is the third harmonic as this will contribute the most distortion in the system.

Basically the harmonic sources can be divided into two categories namely the saturable sources and power electronic sources [2]. Some of the example saturable devices are discharge devices like fluorescent lamp, magnetic cores like transformer and synchronous machines. Whereas the electronics sources include the adjustable speed drives and switch-mode power supply.

The analysis of the harmonics can be carried out by using the Fourier analysis. The analysis will allow the harmonics to be decomposed to a series of finite frequency components from the first order to the N^{th} order of harmonics. The measurement of harmonics is usually done in terms of the Total Harmonic Distortion (THD) which applies for both current and voltage harmonics [4].

THD is given as follows

$$THD = \frac{\text{rms value of harmonics (current or voltage) components}}{\text{rms value of the fundamental (current or voltage) components}}$$

The presence of harmonics in a power system will result in significant effect to the power system. Some of the problems arises due to harmonics include;

- Malfunctioning of microprocessor-based equipment
- Overheating in neutral conductors, transformers, or induction motors
- Deterioration or failure of power factor correction capacitors
- Additional losses in the system due to the heating and Hysteresis
- Distorted voltage and current waveforms

Besides, it also can cause control and monitoring equipment to register the improperly. Other than that, the harmonics also can lead to voltage distortions which are undesirable in the power system. These voltage distortions may lead to a nuisance tripping especially at the sensitive loads like computer controlled loads. Normally, voltage distortions below 5% are acceptable whereas distortion of larger than 10% can cause a significant and severe impact to the system [2].

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

There are a few stages of the project before its completion. These stages is planned to properly execute the project. The stages can be represented by the flowchart below

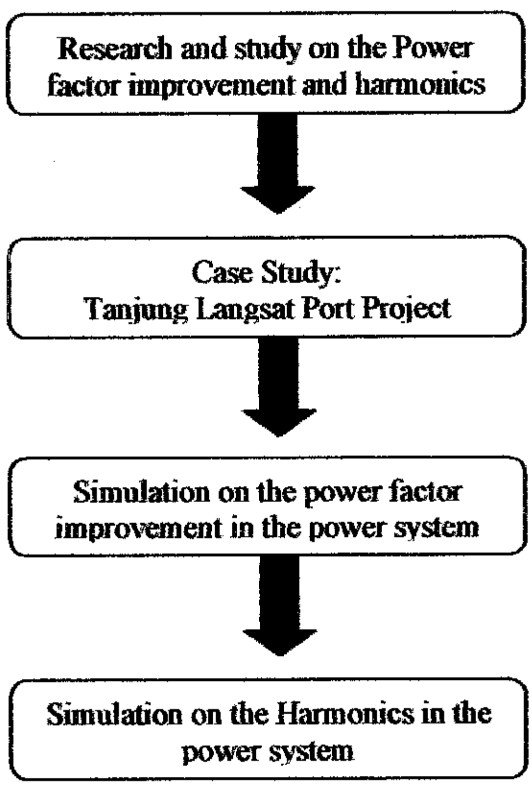


Figure 11: Project flow chart

3.2 Research and study on the power factor improvement and harmonics

Research is an important element in this project. Through a proper research and findings, all the data related to the project will be obtained. These data will further be used in the project as reference project materials. Through the research also, a better understanding of the project shall be obtained.

Research on the power factor improvement involves a few stages. The research is started from the fundamental knowledge on the power components in the AC supply. From this, a better understanding of the power factor before coming to the real subject.

Te next research will be on the power factor improvement in the power system. The power factor improvement is one of the main subjects of the project. This will cover the usage of the capacitor banks to compensate and improve the power factor. There will also be calculations involved to determine the capacitor banks to be installed.

Installation of the power capacitor is normally associated with the harmonic problems. The manner in which the capacitor is installed (both series and parallel) can magnify the harmonic level of the system. Therefore, a study on the harmonic will also be done to complete the project. The research will include the fundamental about the harmonics and how the capacitor contributes to the harmonics in the system.

3.3 Simulation

This project uses ERACS software to simulate and analyze the power system network. ERACS software is provided with simple and easy interface to build the power system (single line diagram). When creating a new network, information of the network shall be filled in the Network properties window. Some basic information like the network name, data state information and other parameters has to be filled (figure 12).

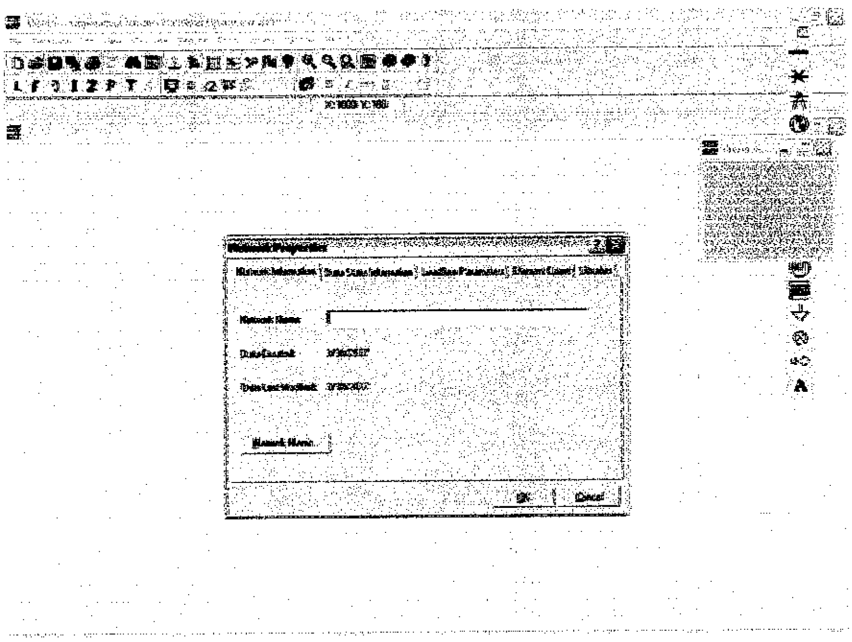


Figure 12 : Eracs New Network Construction Interface

ERACS main window consist of menus and toolbar buttons to provide quick access to the function used and status and progress bar for toolbars to facilitate the simulation.

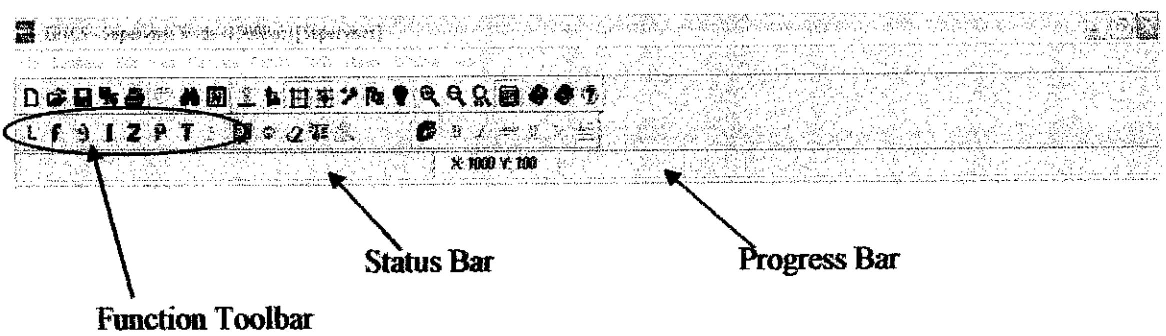


Figure 13: ERACS main window

3.3.1 Adding elements into the network

ERACS features with the element toolbars to facilitate in adding the elements into the network. Element toolbar consist of several power system elements that can be added into the network. Some of element includes busbar, Induction and Synchronous Motor, Shunt element and the switch. Figure below showing the element toolbar in ERACS.

Busbar
Bus Section
Line
Cable
Series Element
Transformer
Tap Changing
Induction Motor
Synchronous Motor
Wind Turbine Generator
Grid Infeed
Shunt Element
Switch / Breaker
Protection Device
Text

Figure 14: ERACS element toolbar

When adding new element, some information about the element has to be filled in the network windows. A popup window will appear when adding new element to the system. Element data like the name (Identifier), voltage rating, power rating and other values need to be filled into the window.

To create e new element, a specific data library must be choose or created for the particular element. Figure 15 shows the popup window to establish the Induction Motor.

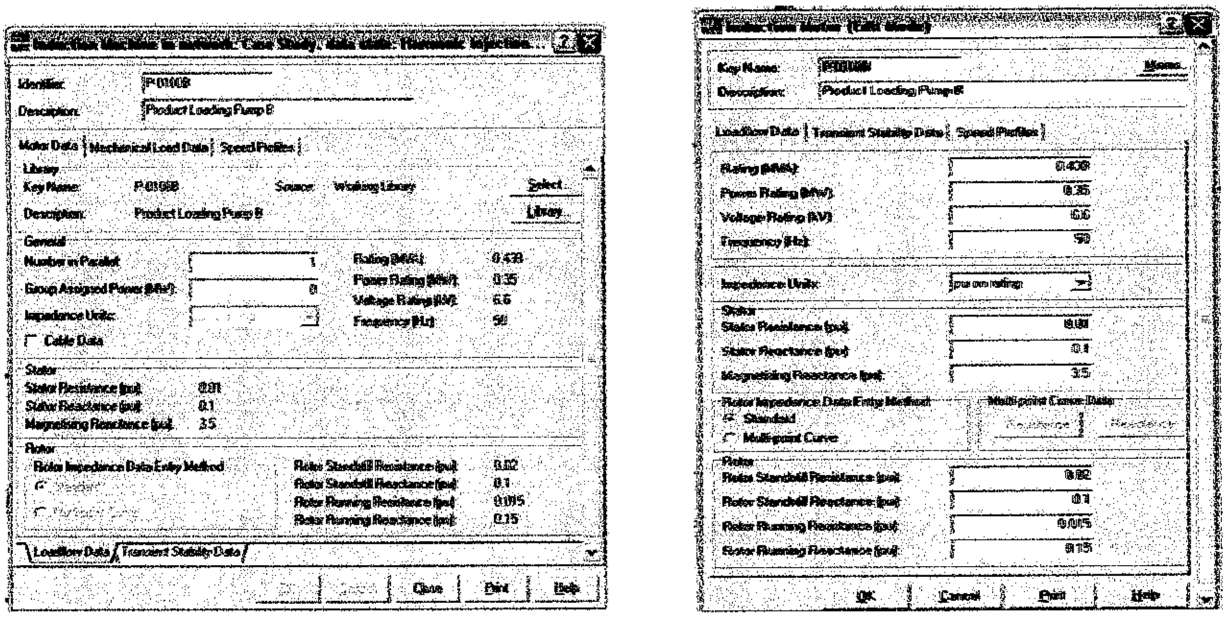


Figure 15 : Library Data Entry

3.3.2 Running the Simulation

The simulation will consist of few parts. The first part will be on the Power factor improvement. The simulation will show the effect of power factor correction by adding the capacitor into the network. Loadflow study was performed and the results were taken to measure the power factor. The Loadflow analysis can be performed by clicking the Loadflow button toolbar. Loadflow study measures the steady state conditions for the power system network. The result from the program will give the network voltage profile, current and the real and reactive power flows in the network. [11]

Harmonics impedance analysis was performed to measure the impedance of each harmonic component. Using Fourier analysis, the current drawn from supply can were split into its fundamental and harmonic components. An injection busbar will be chosen to inject the harmonic current into the network. The result will gives us the impedance value of each harmonic component at the selected injection busbar and also the transfer busbar.

Harmonic injection analysis was performed to investigate the Total Harmonic Distortions (THD) of the power system at each busbar and other equipment. The simulation will make use of the adjustable speed drives which is used to control the motor as the source of harmonics. The effect of source harmonic location in the power system will be investigated. The result from the simulation will indicates the current of each individual harmonic in the power system as well as the total distortion.

3.4 Case Study: Tanjung Langsat Port Oil Terminal

Tanjung Langsat Port Sdn Bhd has planned to build a new Oil Terminal near the existing Tanjung Langsat Port. The Oil Terminal is designed to receive FOUR types of Gasoline Blending Components delivered by Ships through the existing Port jetty with twine Berth 1 & 2. The Components are to be pumped using the on board pumps through dedicated shore Pipelines to be constructed from the jetty to the terminal to a distance of 1.5 km. The Gasoline components are received at the terminal and channeled into the designated Storage tanks depending on the particular components being received.

The power system in Tanjung Langsat is having low power factor than the requirement set by the Tenaga Nasional berhad (TNB). Therefore, a power factor correction shall be implemented to the system to correct the power factor. The capacitor banks are installed in both medium Voltage (MV) and also Low Voltage (LV) system. [10]

A proper study on the power factor improvement in the project will be done for the project. This project will investigate the harmonic effects in the system due to the capacitor banks installed. The system parameters are depicted as in table 1,

Table 1: System parameter and specification

Tag Name	Description
Busbar 1	22 kV busbar
Busbar 2	11 kV busbar
Busbar 3	450 V busbar
Transformer 1	22/6.6 (4 MVA)
Transformer 2	22/0.415 (1.6 MVA)

Refer Appendix C for the list of total loads connected to the system

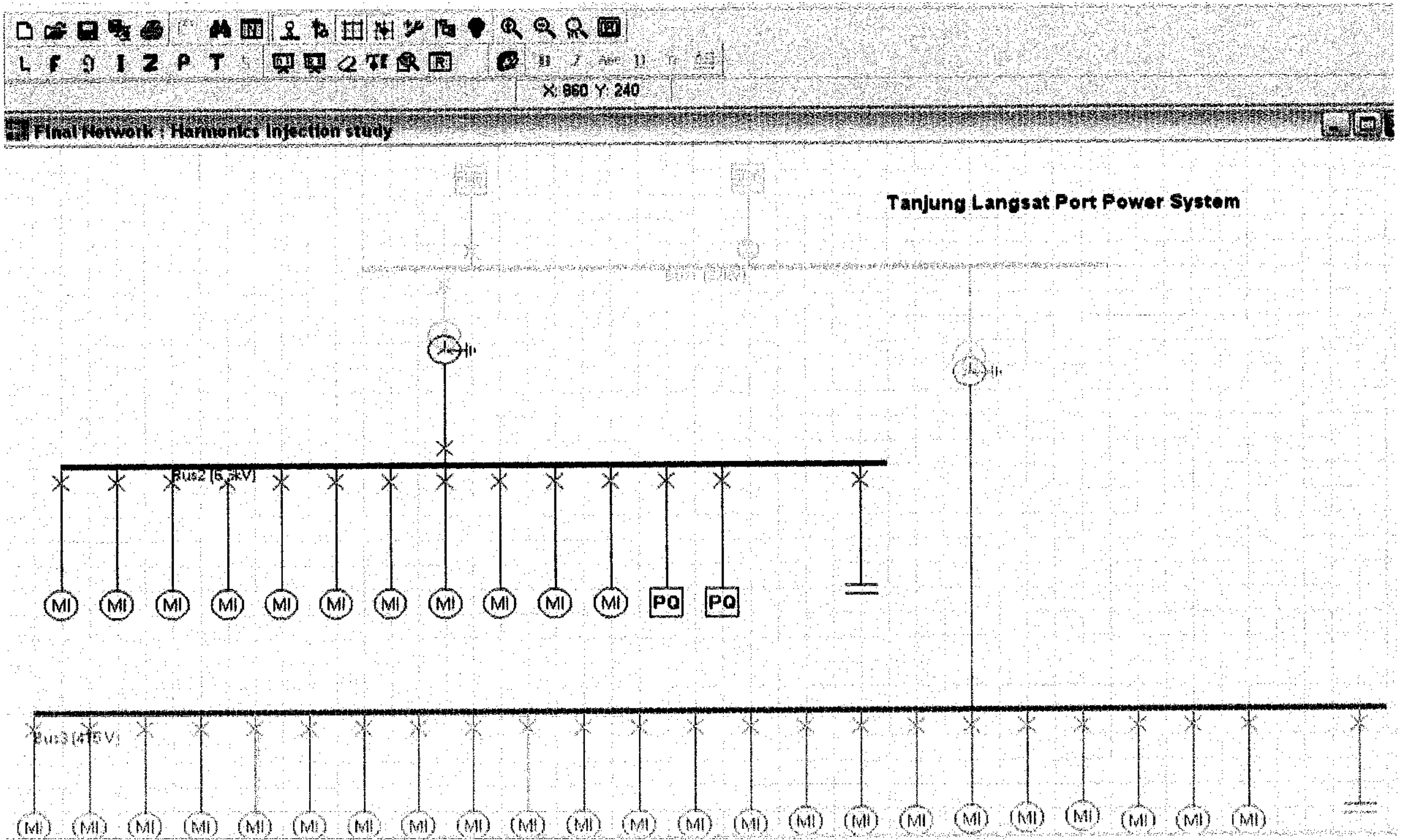


Figure 16 : Tanjung Langsat Port Single Line Diagram

CHAPTER 4

RESULT AND DISCUSSION

4.1 Power Factor Improvement

Loadflow analysis is used to see the effect of power factor improvement in the power system. To perform the analysis, the capacitor bank is initially disconnected to the system to determine the load power factor before compensation. The load power factor can be calculated using the following formulae:

$$\text{Cos } \theta = \frac{\text{Active power}}{\text{Apparent power}}$$

Where θ is given by;

$$\theta \quad = \quad \text{Tan}^{-1} \left(\frac{\text{Reactive power}}{\text{Active power}} \right)$$

After performing the Loadflow analysis it is found out that the initial power factor of the system load is 0.5153. The capacitor bank is then switched on to compensate for the low power factor of the system. The capacitor banks are located at bus 2 (6.6 kV) and also bus 3 (0.415 kV). The initial parameters of the capacitors are as follow;

Table 2: Initial rating of capacitor

	Capacitor 1	Capacitor 2
Rating	4 MVA	1.6 MVA
kVAR Rating	400 kVAR	382 kVAR

The total kVAR value is found by adding the kVAR supplied by both capacitors. Initial total kVAR supplied to the system is 782 kVAR. The kVAR rating of the capacitor is then increase gradually to see the effect of compensation. This is done by adjusting the value of the sequence susceptance and the change in the load power factor is observed. The result of the analysis is summarized in table below.

Before compensation

Active power, P : 2.005 MW

Reactive Power, Q : 3.335 MVAR

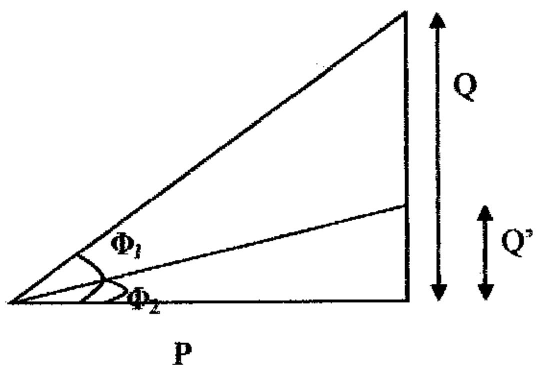
Power Factor, PF : 0.5153

System Losses : 0.005 p.u.

Table 3 : Table showing the effect of compensation by increasing the capacitor kVAR value

	CAP 1	CAP 2	Total	Seq. Susc	P (MW)	Q (MVAR)	PF	Losses pu
	(MVAR)	(MVAR)	kVAR					
case 1	0.399	0.382	781	0.004	2.005	2.555	0.6173	0.005
case 2	0.499	0.477	976	0.005	2.005	2.36	0.6475	0.005
case 3	0.599	0.572	1171	0.006	2.005	2.165	0.6795	0.004
case 4	0.698	0.668	1366	0.007	2.005	1.97	0.7133	0.004
case 5	0.798	0.763	1561	0.008	2.005	1.774	0.7489	0.003
case 6	0.898	0.859	1757	0.009	2.005	1.579	0.7856	0.003
case 7	0.998	0.954	1952	0.01	2.005	1.384	0.8230	0.003
case 8	1.098	1.05	2148	0.011	2.005	1.189	0.8601	0.003

Power factor improvement calculations



Initial power factor = 0.5153

To improve power factor to = 0.86

$= \cos^{-1} 0.86$

$= 30.6834$

$Q' = 1.1897$

$Qc = Q - Q'$

$= 3.335 - 1.1897$

= 2.1453 MVAR

Additional of 2.1453 MVAR from capacitor is required as shown in the result of simulation.

As the value of the power kVAR rating is increased from 781 to 2148, it is found out that the power factor of the system is improved from 0.5153 to 0.8601 which has reach the acceptable value. It is also observed that the active power value of capacitor and also system does not vary as the value of the kVAR value of the capacitor is varied. This is in line with the power triangle representation of power factor improvement where the insertion of the capacitor banks will only compensate and improve for the reactive power and not the active power component.

Another observation from the analysis is the power system losses. Initially, as the power capacitor is inserted in the system the losses are about 0.005 MVAR. As the kVAR value of capacitor is increased, the system losses decrease to 0.003 MVAR. This indicates that as the power factor is improved the power transmission is delivered more efficient thus reducing the losses.

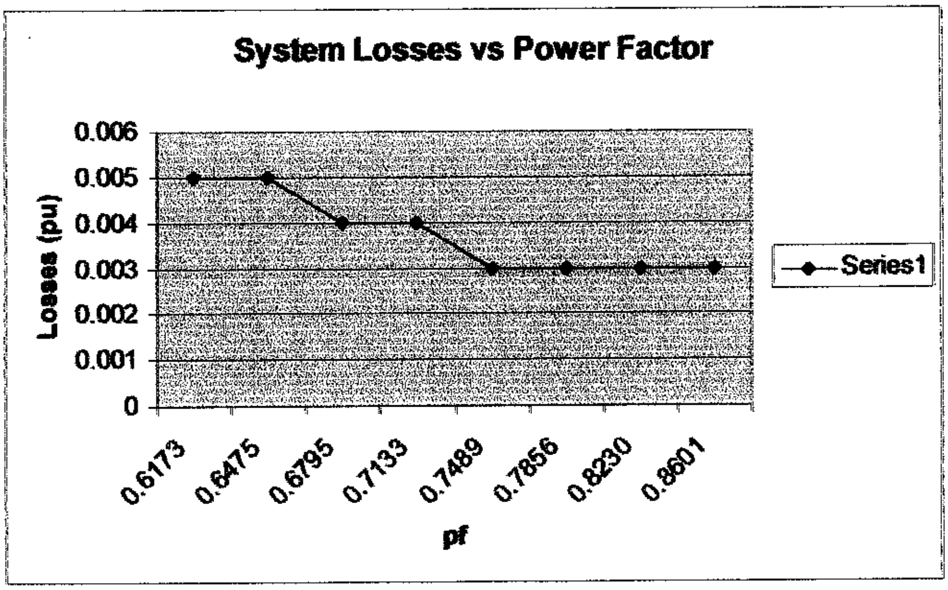


Figure 17: System losses versus power factor

4.2 Harmonics problem with capacitor banks

Before the insertion of the power capacitor, the system impedance does not experience any resonance in the circuit. Figure below shows the response of the system impedance with increasing harmonic order. The magnitude of the impedance seen by the harmonics currents will increase linearly as the order of harmonic increases. The system impedance is inductive in nature and causes voltage drops to occur following current flow.

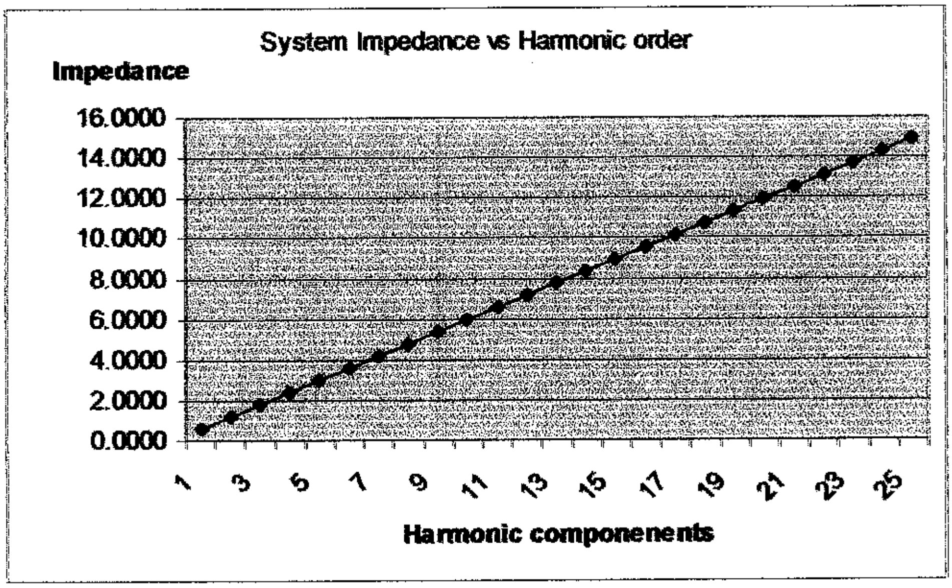


Figure 18: Harmonic impedance versus harmonic components without capacitor

As discussed earlier, the system impedance is directly proportional to the harmonics components. On the other hand, the capacitor has impedance which is reduces with frequency. The combined effect of the two is the following:

- At low frequency, the system impedance of the system in determined by the low inductive impedance of the power system and the transmission lines
- At high frequencies, the system impedance is determined by the capacitive impedance of the capacitor banks

- Resonance condition may occur where intermediate range of frequency where capacitive and inductive effects to give high impedance [10]

The presence of power factor correction capacitors, the total impedance seen by the harmonic currents is the parallel combination of the normal system impedance. [10] Harmonic resonance occurs when both the capacitive and inductive reactance are equal. The capacitive and inductive reactance will cancel each other and network will be purely resistive in resonance condition. During this condition, voltage and current will be dominated by the resonant frequency and can be highly distorted. At this condition, a small harmonic current within this frequency range will contribute to high harmonic voltages. This will lead to a high voltage distortion in the loads particularly in the nonlinear loads. Figure below shows the harmonic impedance versus the harmonic components in the system.

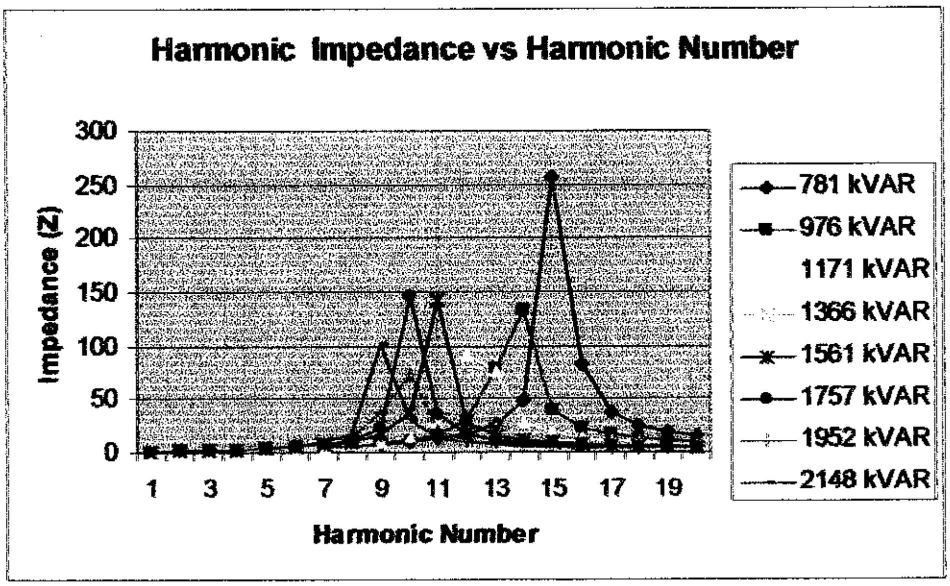


Figure 19: Harmonic impedance versus the harmonic components at injection busbar

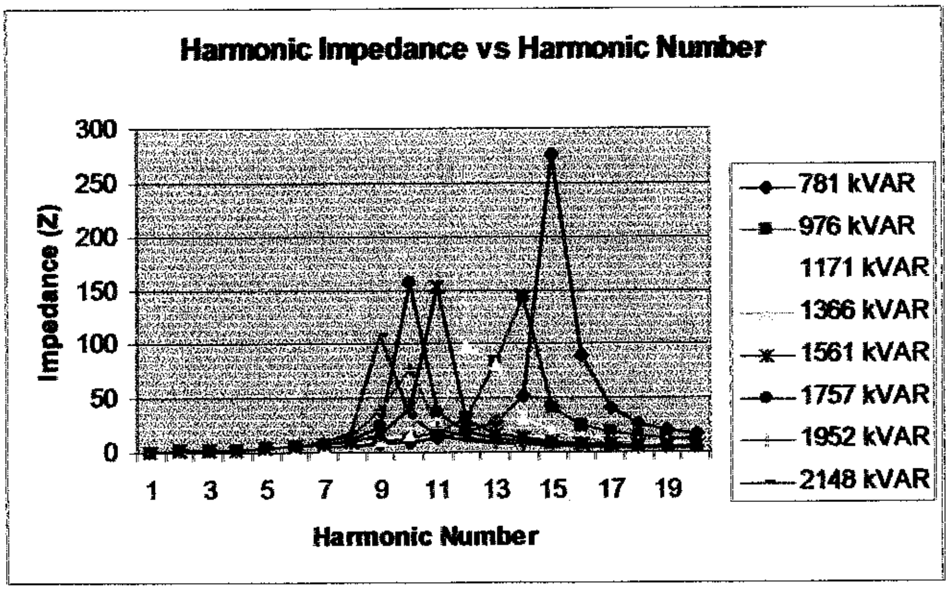


Figure 20: Harmonic impedance versus the harmonic components at transfer busbar

Result is obtained by gradually increasing the kVAR value of the capacitor. From the graph we can see that resonance occurs when adding the capacitor bank into the network. As we in increase the kVAR rating of the capacitor, the resonance is shifted to the lower frequency. Harmonic impedance will interact with the injected current and produces the high harmonic voltages.

When there is no capacitor in installed, the system impedance is linearly proportional with the frequency. This cause the harmonics current difficult to propagate in the system network as the harmonic order increases. However, this is not the case when the capacitor bank is installed as the capacitor impedance is inversely proportional to the frequency. Thus, power factor correction which initially draws 50 Hz currents will have lower impedances and resulting the harmonic currents easily flow into the capacitor. This will further cause an overloading of the capacitor and worse will damage the capacitor [10].

From the analysis, it is also found out that increasing the value of capacitor will lower the resonance frequency. The risk of this resonance is if the harmonic order is present in the harmonics load. It will further interact with the loads and causing high harmonics distortions. For example, if the harmonics resonance occurs at 15^{th} order, this may coincide with the harmonics order produced by several types of loads. Therefore there will be high risk of resonance in any distorting loads.

To avoid this, one solution is to reduce adjust the value of capacitor so that it will not produce harmonics resonance close to the harmonic present in the harmonics load. With that, loads will not much affected by the harmonics produced in the system. Another solution is to detuning the capacitor so that the lowest order load current harmonics sees very small impedance. This can be done by adding inductor in series with the capacitor [10].

A thorough study shall be done prior to the installation of the capacitor banks is needed to ensure that there is no major harmonics current producing loads in the premises. This will reduce or avoid any unwanted effect due to the harmonics in the system.

4.3 Harmonic injection analysis

Harmonic injection analysis will investigate the Total Harmonic Distortion (THD) for different busbar injection. The first case will consider harmonic sources from bus 3 and thus harmonics will be injected from connected load at bus 3. The same analysis will be done for bus 2 and for both bus 2 and 3. The results will give us clearer picture of THD impact at different harmonic source location.

The summary results of harmonic injection analysis are as follows:

Table 4: THD results at each bus when harmonics injected at bus 2

	NC	781	976	1171	1366	1561	1757	1952	2148
BUS 1	0.08496	0.87403	2.12392	1.37889	2.12116	2.06457	0.79507	0.57452	0.51293
BUS 2	0.08404	0.89803	2.18554	1.41521	2.18184	2.11756	0.8138	0.58849	0.52658
BUS 3	0.09101	0.90306	2.19055	1.426	2.18861	2.13633	0.825	0.59632	0.53156

Table 5: THD results at each bus when harmonics injected at bus 3

	NC	781	976	1171	1366	1561	1757	1952	2148
BUS 1	0.08496	0.13611	0.25768	0.24494	0.25942	0.46254	0.1356	0.09216	0.07973
BUS 2	0.08404	0.13991	0.26379	0.25198	0.26586	0.47567	0.14015	0.09541	0.0824
BUS 3	0.09101	0.14063	0.26719	0.25276	0.26872	0.47737	0.13946	0.09486	0.08235

Table 6: THD results at each bus when harmonics injected at bus 2 and 3

	NC	781	976	1171	1366	1561	1757	1952	2148
BUS 1	0.08496	0.87403	2.12392	1.37889	2.12116	2.06457	0.79507	0.57452	0.51293
BUS 2	0.08404	0.89803	2.18554	1.41521	2.18184	2.11756	0.8138	0.58849	0.52658
BUS 3	0.09101	0.90306	2.19055	1.426	2.18861	2.13633	0.825	0.59632	0.53156

****Note*** – NC (No Capacitor Connected)

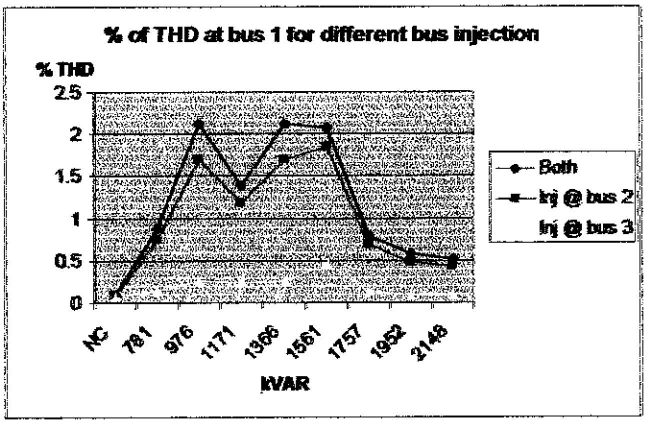


Figure 21: THD at bus 1 for different location of harmonic source injection

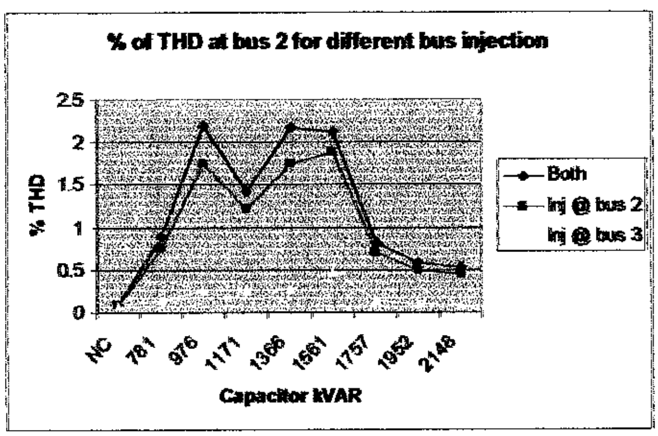


Figure 22: THD at bus 2 for different location of harmonic source injection

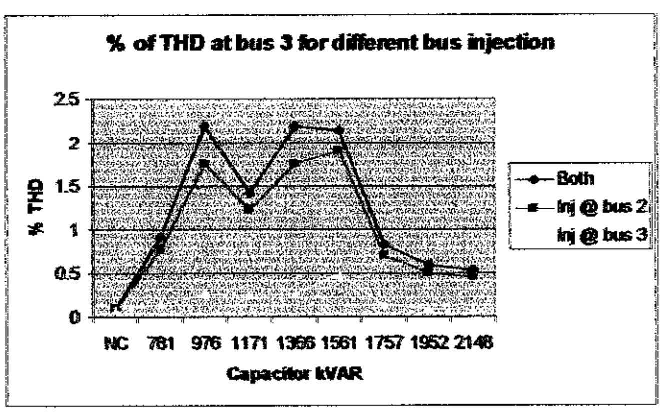


Figure 23: THD at bus 3 for different location of harmonic source injection

Figure 21-23 shows the result for harmonic distortion at bus 1, 2 and 3 for different location of the harmonic sources. From the results, it is found that the distortion is small when there is no capacitor connected to the system which is about 0.1%. The distortion increases significantly as we insert the capacitor to the system.

The distortion is less prominent when the harmonic source is injected from bus 3(LV bus). The graph shows that the harmonic distortion is highest when the injection source is from both bus 2 and bus 3. However, we can also notice that when the injection in placed at bus 2, the distortion increases significantly. This is because of the load capacity of the machine connected to the HV bus has a greater magnitude and thus contributing to a higher distortion as compared to the injection from bus 3 (LV bus).

Another observation that can bee seen from the result is that for several location of harmonic injection the THD for each condition is highest at bus number 3. For example if we refer to injection from bus 2, the results shows that the THD is highest at bus no 3, followed by bus 2 and bus 1 (refer table 5 for full result). However the difference is not so significant for each bus.

From the result, we can conclude that the THD will be affected by the location of the source of harmonic in the network. Harmonic sources located at the higher voltage busbar will contribute to a greater distortion. This is due to the high load capacity connected to bus 2 and resulting to greater current distortions. Thus, the location of the harmonic sources shall be considered before installing the capacitor bank. The harmonic sources shall be placed at the lower voltage busbar to reduce the distortions.

CHAPTER 5

5.1 CONCLUSION

This report presents the study and also the findings of the project. The study on the power factor and the harmonic relationship is beneficial as it is very closely related to the power system. It will help in better understanding the power system problems particularly the power factor problems and the concerns over the harmonics.

The project focuses on the power factor correction of the power system using capacitor banks. The effect of adding the capacitor banks is thoroughly analysed. It is observed that the insertion of capacitor banks will further improve the reactive power and thus compensating for the low power factor. The insertion of the capacitor also will reduce the system losses. This indicates that the power can be transferred efficiently to the system.

Harmonic response of the system when inserting the capacitor is also analysed. Harmonic resonance occurs when capacitor is added into the system. Current and voltage will be dominant at the resonant frequency during resonance. This will lead to a high current and voltage rise in the network. By increasing the capacitor kVAR value, it is also noted that the resonance is shifted to the lower frequency

The distortions results indicate that harmonic sources located at high voltage busbar will result in greater THD. This is due to the load capacity bigger machine rating are connected to the bus. Thus, harmonics load location shall be considered before the insertion of the capacitor bank.

5.2 Recommendations

From this project, it is found out that the insertion of capacitor into the network will compensate for the low power factor of the system. However, it leads to the harmonics problem in the network. The resonance condition due to capacitor shall be properly treated to reduce the impact.

A proper study shall be done prior to installing the capacitor bank in the system. This will help in reducing the harmonics effect due to the insertion of the capacitor. Capacitors may need to be detuned to avoid the resonance at frequency which is close to a frequency of harmonic current of distorting load. Harmonic filter can also be used in reducing the harmonic effect in the system. Several factors need to be considered before installation of the capacitor like the location of the capacitor itself and also the location of the harmonics load in the network. This will help in avoiding the unwanted impact of harmonics to the system.

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[9] P-5135-EL-RP-0011- Power Capacitor Sizing Report

[10] www.elec.uow.edu.au/iepqrc/files/technote3.pdf

[11] ERACS - Technical Manual for Power System Analysis Software

APPENDIX

Project Title : Study and analysis of Realtionship Between Power Factor Improvement and Harmonic Distortion

EE Area : Power Engineering

PROJECT ACTIVITIES	WEEK NO / DATE														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. FYP title finalization	■	■													
2. Study on the Power components		■	■	■	■	■	■	■	■	■	■				
3. Study on the Power Factor		■	■	■	■	■	■	■	■	■	■	■			
4. Study on the Harmonic Distortion				■	■	■	■	■	■	■	■	■			
5. To learn on the SKM Software				■	■										
6. To learn on the Matlab (PSAT) Software					■	■									
7. To finalize which software to be used						●									
8. To gather data from the Tanjung Langsat					■	■	■	■	■	■					
9. Simulation on the Tanjung Langsat Project							■	■	■	■	■	■			
10.Problem Troubleshooting							■	■	■	■	■	■	■		
11.Report submission & presentation															
a. Preliminary report submission				●											
b. Progress report submission							●								
c. Draft report submission												●			
d. Interim report submission														●	
e. Final Presentation															●

■ Process
● Suggested milestone

....
FYP Supervisor's Signature
Name: Ms. Khairul Nisak Bt. Md. Hasan
Designation:Lecturer of Electrical & Electronics Department

Student's Name: **MOHD PURYADIN BIN SUDIRMAN**
Student's ID No. : **4086**

APPENDIX A : GANTT CHART SHOWING PROGRESS OF THE PROJECT FOR FYP 1

APPENDIX B: kVAR TABLE FOR POWER FACTOR IMPROVEMENT

RAKO

Determination of required capacitor rating

able 2: Factor *f* ($f = \tan\varphi_{actual} - \tan\varphi_{desired}$)

Uncorrected		Desired cos φ						
tan φ	cos φ	0,80	0,85	0,90	0,92	0,95	0,98	1,00
3.18	0.30	2.43	2.56	2.70	2.75	2.85	2.98	3.18
2.96	0.32	2.21	2.34	2.48	2.53	2.63	2.76	2.96
2.77	0.34	2.02	2.15	2.28	2.34	2.44	2.56	2.77
2.59	0.36	1.84	1.97	2.10	2.17	2.26	2.39	2.59
2.43	0.38	1.68	1.81	1.95	2.01	2.11	2.23	2.43
2.29	0.40	1.54	1.67	1.81	1.87	1.96	2.09	2.29
2.16	0.42	1.41	1.54	1.68	1.73	1.83	1.96	2.16
2.04	0.44	1.29	1.42	1.56	1.61	1.71	1.84	2.04
1.93	0.46	1.18	1.31	1.45	1.50	1.60	1.73	1.93
1.83	0.48	1.08	1.21	1.34	1.40	1.50	1.62	1.83
1.73	0.50	0.98	1.11	1.25	1.31	1.40	1.53	1.73
1.64	0.52	0.89	1.02	1.16	1.22	1.31	1.44	1.64
1.56	0.54	0.81	0.94	1.07	1.13	1.23	1.36	1.56
1.48	0.56	0.73	0.86	1.00	1.05	1.15	1.28	1.48
1.40	0.58	0.65	0.78	0.92	0.98	1.08	1.20	1.40
1.33	0.60	0.58	0.71	0.85	0.91	1.00	1.13	1.33
1.30	0.61	0.55	0.68	0.81	0.87	0.97	1.10	1.30
1.27	0.62	0.52	0.65	0.78	0.84	0.94	1.06	1.27
1.23	0.63	0.48	0.61	0.75	0.81	0.90	1.03	1.23
1.20	0.64	0.45	0.58	0.72	0.77	0.87	1.00	1.20
1.11	0.67	0.36	0.49	0.63	0.68	0.78	0.90	1.11
1.08	0.68	0.33	0.46	0.59	0.65	0.75	0.88	1.08
1.05	0.69	0.30	0.43	0.56	0.62	0.72	0.85	1.05
1.02	0.70	0.27	0.40	0.54	0.59	0.69	0.82	1.02
0.99	0.71	0.24	0.37	0.51	0.57	0.66	0.79	0.99
0.96	0.72	0.21	0.34	0.48	0.54	0.64	0.76	0.96
0.94	0.73	0.19	0.32	0.45	0.51	0.61	0.73	0.94
0.91	0.74	0.16	0.29	0.42	0.48	0.58	0.71	0.91
0.88	0.75	0.13	0.26	0.40	0.46	0.55	0.68	0.88
0.86	0.76	0.11	0.24	0.37	0.43	0.53	0.65	0.86
0.83	0.77	0.08	0.21	0.34	0.40	0.50	0.63	0.83
0.80	0.78	0.05	0.18	0.32	0.38	0.47	0.60	0.80
0.78	0.79	0.03	0.16	0.29	0.35	0.45	0.57	0.78
0.75	0.80	-	0.13	0.27	0.32	0.42	0.55	0.75
0.72	0.81	-	0.10	0.24	0.30	0.40	0.52	0.72
0.70	0.82	-	0.08	0.21	0.27	0.37	0.49	0.70
0.67	0.83	-	0.05	0.19	0.25	0.34	0.47	0.67
0.65	0.84	-	0.03	0.16	0.22	0.32	0.44	0.65
0.62	0.85	-	-	0.14	0.19	0.29	0.42	0.62
0.59	0.86	-	-	0.11	0.17	0.26	0.39	0.59
0.57	0.87	-	-	0.08	0.14	0.24	0.36	0.57
0.54	0.88	-	-	0.06	0.11	0.21	0.34	0.54
0.51	0.89	-	-	0.03	0.09	0.18	0.31	0.51
0.48	0.90	-	-	-	0.06	0.16	0.28	0.48
0.46	0.91	-	-	-	0.03	0.13	0.25	0.46
0.43	0.92	-	-	-	-	0.10	0.22	0.43
0.40	0.93	-	-	-	-	0.07	0.19	0.40
0.36	0.94	-	-	-	-	0.03	0.16	0.36
0.33	0.95	-	-	-	-	-	0.13	0.33
0.29	0.96	-	-	-	-	-	0.09	0.29

APPENDIX C: CONNECTED LOAD TO THE SYSTEM

BUS-2 (6.6 kV)

	TAG NUMBER		RATING	
			(kW)	(kVA)
1	P-100A	Product Loading Pump A	350	437.5
2	P-100B	Product Loading Pump B	350	437.5
3	P-100C	Product Loading Pump C	350	437.5
4	P-300A	Reformate Blending Pump	210	262.5
5	P-300B	Light Naphta Blending Pump	220	275
6	P-300C	Light Naphta Blending Pump	250	312.5
7	P-500A	Blend Compressor Loading Pump	360	450
8	P-500B	Blend Compressor Loading Pump	360	450
9	P-1000A	Primary Firewater Pump A	560	700
10	P-3010	Pigging Water Supply Pump	400	500
11	P-3020	Pigging Water Supply Pump	400	500
	Total		**3810**	**4762.5**

BUS-3 (0.415 kV)

	TAG NUMBER		RATING	
			(kW)	(kVA)
1	P-0100D	Product Stripping Pump	110	137.50
2	P-0300D	Blending Stripping Pump	90	112.50
3	P-0400A	MTBE Blending Pump	110	137.50
4	P-0400B	MTBE Blending Pump	110	137.50
5	P-0500C	Blend Component Loading Stripping Pump	110	137.50
6	P-0600	MTBE Loading Pump	75	93.75
7	P-2060A	Additive Injection Pump	2.5	3.13
8	P-2060B	Additive Injection Pump	2.5	3.13
9	P-2070A	Additive Injection Pump	2.5	3.13
10	P-2070B	Additive Injection Pump	2.5	3.13
11	P-0200A	Circulation Pump	55	68.75
12	P-0200B	Circulation Pump	55	68.75
13	P-0200C	Circulation Pump	55	68.75
14	P-2090	Slop Oil Tranfer Pump	1.5	1.88
15	P-2080	Slop Oil Tranfer Pump	1.5	1.88
16	P-1010A	Jockey Pump	1.5	1.88
17	P-1010B	Jockey Pump	30	37.50
18	K-1000A	Air Compressor	132	165.00
19	E1001A	Cooler Fan	6	7.50
20	K-1000B	Air Compressor	132	165.00
21	E-1001B	Cooler Fan	6	7.50
22	P-1250	CPI Transfer Pump	1.1	1.38
23	P-1260	Holding Basin Sump Transfer Pump	1.1	1.38
	Total		**1092.7**	**1365.88**

INJECTION BUSBAR (415 V)
VOLTAGE MAGNITUDE

BUS 3 (Injection Busbar)

H. No	NC	**0.004**	**0.005**	**0.006**	**0.007**	**0.008**	**0.009**	**0.01**	**0.011**
1	0.602	0.603	0.603	0.603	0.603	0.603	0.603	0.603	0.603
2	1.194	1.21	1.214	1.218	1.222	1.226	1.23	1.234	1.238
3	1.786	1.848	1.865	1.881	1.898	1.915	1.933	1.951	1.969
4	2.377	2.538	2.582	2.627	2.674	2.723	2.773	2.826	2.88
5	2.97	3.304	3.4	3.501	3.61	3.725	3.849	3.981	4.123
6	3.562	4.178	4.368	4.577	4.808	5.063	5.348	5.668	6.029
7	4.155	5.209	5.566	5.976	6.454	7.016	7.689	8.507	9.524
8	4.747	6.47	7.123	7.928	8.943	10.263	12.05	14.605	18.556
9	5.34	8.076	9.283	10.925	13.291	16.991	23.599	38.716	**106.123**
10	5.933	10.235	12.553	16.264	23.159	40.388	**153.444**	**76.804**	31.44
11	6.526	13.346	18.211	28.806	69.474	**148.15**	36.624	20.701	14.377
12	7.119	18.3	30.666	**96.016**	**80.121**	28.379	17.138	12.23	9.48
13	7.712	27.587	82.035	79.933	26.843	16.021	11.367	8.778	7.128
14	8.305	51.761	**139.455**	29.631	16.423	11.297	8.573	6.882	5.731
15	8.898	**269.826**	39.898	18.495	11.952	8.781	6.908	5.672	4.794
16	9.491	86.626	23.672	13.572	9.446	7.203	5.792	4.822	4.115
17	10.084	38.876	17.001	10.777	7.831	6.112	4.985	4.188	3.595
18	10.677	25.393	13.344	8.962	6.694	5.306	4.368	3.691	3.18
19	11.27	19.006	11.021	7.681	5.845	4.682	3.878	3.289	2.838
20	11.863	15.261	9.404	6.722	5.181	4.18	3.476	2.953	2.548

APPENDIX D: IMPEDANCE RESULT FOR EACH HARMONIC COMPONENTS

INJECTION BUSBAR (415 V)
VOLTAGE MAGNITUDE

BUS 1 (Transfer Busbar)

H. No	NC	**0.004**	**0.005**	**0.006**	**0.007**	**0.008**	**0.009**	**0.01**	**0.011**
1	0.556	0.557	0.557	0.557	0.557	0.557	0.557	0.557	0.557
2	1.102	1.117	1.121	1.125	1.128	1.132	1.136	1.14	1.144
3	1.648	1.707	1.723	1.739	1.755	1.771	1.788	1.805	1.823
4	2.194	2.347	2.388	2.431	2.476	2.523	2.571	2.621	2.673
5	2.74	3.058	3.15	3.247	3.351	3.461	3.579	3.705	3.84
6	3.287	3.874	4.056	4.255	4.475	4.719	4.991	5.296	5.641
7	3.833	4.84	5.18	5.572	6.028	6.565	7.207	7.989	8.96
8	4.38	6.024	6.648	7.417	8.386	9.647	11.354	13.795	17.571
9	4.927	7.54	8.692	10.261	12.521	16.057	22.371	36.817	**101.242**
10	5.474	9.583	11.797	15.343	21.932	38.397	**146.46**	**73.603**	30.251
11	6.021	12.535	17.185	27.31	66.18	**141.81**	35.229	20.011	13.969
12	6.568	17.25	29.069	**91.533**	**76.823**	27.372	16.629	11.939	9.312
13	7.115	26.106	78.151	76.668	25.926	15.583	11.137	8.664	7.089
14	7.662	49.193	**133.581**	28.612	15.989	11.092	8.49	6.877	5.778
15	8.209	**257.64**	38.446	17.991	11.739	8.711	6.923	5.744	4.908
16	8.756	83.133	22.96	13.309	9.368	7.227	5.882	4.959	4.285
17	9.303	37.513	16.607	10.66	7.848	6.209	5.136	4.379	3.816
18	9.85	24.648	13.134	8.95	6.787	5.465	4.573	3.932	3.447
19	10.397	18.565	10.937	7.75	6.001	4.895	4.132	3.575	3.15
20	10.945	15.009	9.417	6.859	5.393	4.442	3.776	3.284	2.904

APPENDIX D: IMPEDANCE RESULT FOR EACH HARMONIC COMPONENTS

INJECTION BUSBAR (415 V)
VOLTAGE MAGNITUDE

BUS 2 (Transfer Busbar)

H. No	NC	0.004	0.005	0.006	0.007	0.008	0.009	0.01	0.011
1	0.575	0.576	0.576	0.576	0.576	0.576	0.576	0.576	0.576
2	1.139	1.155	1.159	1.163	1.167	1.171	1.176	1.18	1.184
3	1.702	1.766	1.783	1.8	1.817	1.835	1.853	1.872	1.89
4	2.266	2.43	2.475	2.521	2.569	2.619	2.671	2.725	2.78
5	2.83	3.172	3.27	3.374	3.485	3.603	3.73	3.865	4.01
6	3.395	4.025	4.219	4.433	4.669	4.93	5.222	5.55	5.92
7	3.959	5.038	5.403	5.823	6.312	6.888	7.576	8.414	9.457
8	4.524	6.286	6.955	7.779	8.818	10.17	12.001	14.619	18.668
9	5.089	7.889	9.124	10.806	13.229	17.021	23.792	39.286	**108.388**
10	5.654	10.057	12.431	16.232	23.298	40.955	**156.855**	**79.151**	32.666
11	6.219	13.2	18.184	29.042	70.723	**152.298**	38.024	21.707	15.229
12	6.784	18.232	30.904	**97.884**	**82.64**	29.62	18.103	13.076	10.26
13	7.349	27.705	83.509	82.493	28.091	17.003	12.238	9.589	7.902
14	7.914	52.435	**143.53**	30.992	17.461	12.213	9.426	7.698	6.523
15	8.479	**275.922**	41.557	19.629	12.929	9.685	7.772	6.511	5.618
16	9.044	89.486	24.977	14.634	10.413	8.121	6.683	5.697	4.979
17	9.609	40.6	18.191	11.82	8.81	7.057	5.911	5.104	4.506
18	10.174	26.831	14.493	10.013	7.699	6.287	5.337	4.655	4.142
19	10.739	20.335	12.163	8.753	6.884	5.705	4.895	4.305	3.857
20	11.304	16.548	10.56	7.825	6.261	5.251	4.545	4.025	3.627

APPENDIX D: IMPEDANCE RESULT FOR EACH HARMONIC COMPONENTS

Injection at bus 2 & 3

THD SUMMARY FOR EACH BUSBAR

	NC	781	976	1171	1366	1561	1757	1952	2148
BUS 1	0.08496	0.87403	2.12392	1.37889	2.12118	2.06457	0.79507	0.57452	0.51293
BUS 2	0.08404	0.89803	2.16554	1.41521	2.18184	2.11756	0.8138	0.58849	0.52658
BUS 3	0.09101	0.90308	2.19055	1.426	2.18861	2.13633	0.825	0.59632	0.53156

Injection at bus 2 (HV)

THD SUMMARY FOR EACH BUSBAR

	NC	781	976	1171	1366	1561	1757	1952	2148
BUS 1	0.08496	0.73579	1.69789	1.1856	1.69744	1.84503	0.68078	0.48665	0.43199
BUS 2	0.08404	0.75611	1.74895	1.2164	1.74738	1.89153	0.69591	0.4981	0.44369
BUS 3	0.09101	0.76042	1.74951	1.22675	1.75026	1.91019	0.70797	0.50656	0.44878

Injection at bus 3 (LV)

THD SUMMARY FOR EACH BUSBAR

	NC	781	976	1171	1366	1561	1757	1952	2148
BUS 1	0.08496	0.13611	0.25768	0.24494	0.25942	0.46254	0.1356	0.09216	0.07973
BUS 2	0.08404	0.13991	0.26379	0.25198	0.26586	0.47567	0.14015	0.09541	0.0824
BUS 3	0.09101	0.14063	0.26719	0.25276	0.26872	0.47737	0.13946	0.09486	0.08235

APPENDIX E : THD RESULT OF EACH BUS FOR DIFFERENT INJECTION SOURCE