POWER QUALITY AND REACTIVE POWER COMPENSATION STUDY

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Dedicated to my beloved parents, sibling, supervisor and all of you
For giving a constant source of support and encouragement

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Thanks to Allah for giving me this opportunity, the strength and the patience to complete my project finally, after all the challenges and difficulties.

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Hopefully, this final year project will not be the end of my journey in seeking for more knowledge to understand the meaning of life.

ABSTRACT

Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. There are many major cause effected on this quality of power. In this research, power quality and reactive power compensation in electric radial distribution networks will be analyzed using industrial data network and modeled by using DigSILENT *PowerFactory* software as for simulation. This thesis presents an approximate technique of capacitor placement for loss minimization and power quality as well. In order to analyze for this system it suppose to be concern on the sizing and placement of the capacitors. So then, the power loss is minimized and annual savings are maximized.

ABSTRAK

Kualiti tenaga elektrik merupakan isu yang menjadi semakin penting untuk penguna elektrik di semua peringkat pengguna. Terdapat banyak penyebab utama yang menpengaruhi kepada kualiti tenaga elektrik ini. Dalam kajian ini, kualiti tenaga elektrik dan pampasan daya reaktif dalam rangkaian pembahagian tenaga elektrik akan dianalisis menggunakan rangkaian industri data dan dimodelkan dengan menggunakan perisian DigSILENT *PowerFactory*. Dalam kajian ini juga turut menyediakan teknik anggaran penempatan kapasitor untuk meminimumkan kerugian dan kualiti tenaga elektrik. Dalam proses untuk menganalisis sistem ini mengambil kira pada saiz dan penempatan kapasitor. Jadi, kuasa yang hilang dapat di minimalkan dan penjimatan tiap tahun dimaksimalkan.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

KWh	-	Kilo Watt Hour
KW	-	Kilo-Watts
kVA	-	Kilo-Volts Amperes
AC	-	Alternating Current
P	-	Active Power
Q	-	Reactive Power
TNB	-	Tenaga Nasional Berhad

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

The production, transmission and distribution of energy involve important costs such as fixed costs and operating costs. Based on the two types of costs, utility companies have established rate structures that attempt to be as equitable as possible for their customer. The rates are based upon the amount of energy consumed (kWh) and the power factor of the load.

In electrical power consuming, the utility will record energy consumed for billing purpose. If the consumer uses electrical power inefficiently for example used load such as motor, air conditioner and others load which is drawn more current, the power utilities have to supply extra current to make up for the loss caused by poor power factor.

Power factor would be unity, but we have seen in real world, power factor is reducing by highly inductive load to 0.7 or less. This induction is caused by equipment such as lightly loaded electric motors, fluorescent lighting ballasts and welding sets, etc. In Malaysia, the commercial & industrial customers with low power factor below by 0.85 will be charged penalties. Capacitor bank is one of the technique uses for reactive power compensation in the system.

Voltage and Reactive power compensation is an important issue in electric power systems, involving operational , economical and quality of service aspects consumer loads (residential, industrial, service sector, etc.) impose active and reactive power demand, depending on their characteristics. Active power is converted into “useful” energy, such as light or heat. Reactive power must be compensated to guarantee an efficient delivery of active power to loads, thus releasing system capacity, reducing system losses, and improving system power factor and bus voltage profile. The achievement of these aims based on the sizing and allocation of shunt capacitors (sources of reactive power) [2].

Reactive power compensation and voltage regulation are two effective measures to improve the voltage quality. Many works has been done aiming at the optimal compensation on distribution and transmission network. Optimal reactive power compensation (ORPC) models and algorithm research in distribution networks have made numerous progress based on mathematical programming or physical characteristic analysis, Intelligent Search and Heuristic Algorithm [3].

In general, the problem of optimal reactive power planning (ORPP) can be defined as to determine the amount and location of shunt reactive power compensation while keeping an adequate voltage profile.

Quiet sometime ago, evolutionary programming’s (EAs) have been used for optimization; in particular both the genetic algorithm and evolutionary programming have been used in ORPP problem. The EA is a powerful optimization technique analogous to the natural selection process in genetics. Theoretically, this technique converge to the global optimum solution with probability one. Evolutionary algorithm is an inherently parallel process. Recent advances in distributed processing architectures could result in dramatically reduced execution times, and it is now possible to do a large amount of computation in order to obtain the global instead of a local optimal solution [4].

In this study described how to design the capacitor bank in medium voltage system. There have several processes in order to design the capacitor bank, this process involved of determining capacitor size, location and connection type of Wye or Delta. To get the accurate result in capacitor bank design, the optimization capacitor placement should be considered.

In this paper approximate technique will be used in order to analyze the sizing and allocation capacitor bank.

1.2 Project Objectives

The objectives of this project are to:

1. To study a basic design of MV capacitor bank
2. To analyze approximate technique of allocation capacitor bank

1.3 Problems statement

The capacitor placement problem considered in this research is to determine the effect of low power factor, increasing losses in the medium voltage system and thus to avoid power factor penalty.

Power factor is measured of how efficiently or inefficiently that electrical power is used by a customer. It is the ratio between kW (Kilo-Watts) and kVA (Kilo-Volts Amperes) drawn by an electrical load where the kW is the actual (true) load power and the kVA is the apparent load power.

In the effect of low power factor, it has two costly disadvantages for the power user. It can increased the cost incurred by the power company because more current must be transmitted than is actually used perform useful work. This increased cost is passed on to the industrial customer by means of power factor adjustments to rate schedules (Losses, Power Factor Penalty & Loading).

Further, It can reduces the load handling capability of the industrial plants electrical transmission system which that the industrial power user must spend more on transmission lines and transformers to get a given amount of useful power through their plant (Losses and Loading)

1.4 Project scopes

This research will focus on sizing and placement of capacitor bank in distribution network. The research elements would be study on basic design of MV capacitor bank and analyzing an approximate technique to get optimal power factor and also to reduce losses.

The studies for basic design is not involved how to developing the capacitor bank from initial material but only focus to get sizing and placement of the capacitor bank in the distribution system, using two approaches which are doing in practice and also using by simulation. However, dynamic and protection study is not covered in this research study.

Besides, the power quality scope only covers for power factor stability and also for active and reactive power losses. Thus, the studies about the harmonics, sag, swell not cover in these cases of study.

The limitation of getting the real data from utilities for the base case systems have decided to utilise the 43 bus data from industrial network as the test system. The verification will be done by directly applying of approximate techniques and this may not involve in developing those techniques.

Since this research is dealing with real medium voltage system, therefore no testing and live measurement will be done due to safety cautions.

Therefore, the test system will only be simulated by using commercial power system software and depend on its limitation features.

1.5 Thesis outline

This thesis contains of five chapters including Chapter one: Introduction, Chapter two: Literature reviews, Chapter three: Methodology, Chapter four: Result and discussion, Chapter five: Conclusion and Recommendation. Each chapter will contribute to explain different focus and discussion relating with the corresponding chapters heading.

Chapter one is contain introduction which is present about the overviews of the project that is constructed. It consists of project background, objective, problem statement, project scope.

Chapter two is containing literature review which is discussed about the some reference or citation relate to this project title.

Chapter three will discuss about the methodology in this project. This part of methodology is divided by two parts, the first part describes how normally practice does in order to design of capacitor bank and the second one is approximate method which is used in this project.

Chapter four included result and discussion

Chapter five contain conclusion and recommendations for this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Reactive power is a subject of great concern for the operation of alternating current (AC) power systems [5]. It has always been a challenge to obtain the balance between a minimum amount of reactive power flow (to maximize capacity for active power flow) and a sufficient amount of reactive power flow to maintain a proper system voltage profile.

Even though reactive power is not widely understood outside of the power engineering community, it remains one of the most important aspects of AC power system operation. Those involved with maintaining and operating power systems must constantly be concerned with the balance between reactive power supply and demand as much as with active power supply and demand. The reliable and economic use of electric power depends on an availability of sources for leading and lagging reactive power that can be appropriately dispatched to the system.

2.2 Reactive Power Compensation

The earliest distribution systems did not use any form of reactive compensation. Any reactive requirements by the components of the system or by the loads served were supplied by the synchronous generator. This led to very inefficient utilization of the system so utility companies developed rate structures that penalized loads of low power factor.

The first uses of shunt capacitors on power systems was in the 1920s, at large industrial plants where reductions in electric charges justified providing local reactive power compensation. Before capacitors, synchronous motors were (and continue to be) employed in industrial plants on processes requiring large amounts of constant mechanical power.

The synchronous motors could be controlled to provide some amount of reactive supply, often enough to compensate for the reactive consumption of induction machines. Synchronous condensers were used, beginning in the 1930s, on transmission and sub-transmission systems to provide a variable source of reactive power.

In the 1930s, the advantages of series capacitors became apparent and began to find applications in distribution systems and industrial installation [6]. Figure 2.1 shows the Photograph of Synchronous Condenser from Hyundai Ideal Electric Company.

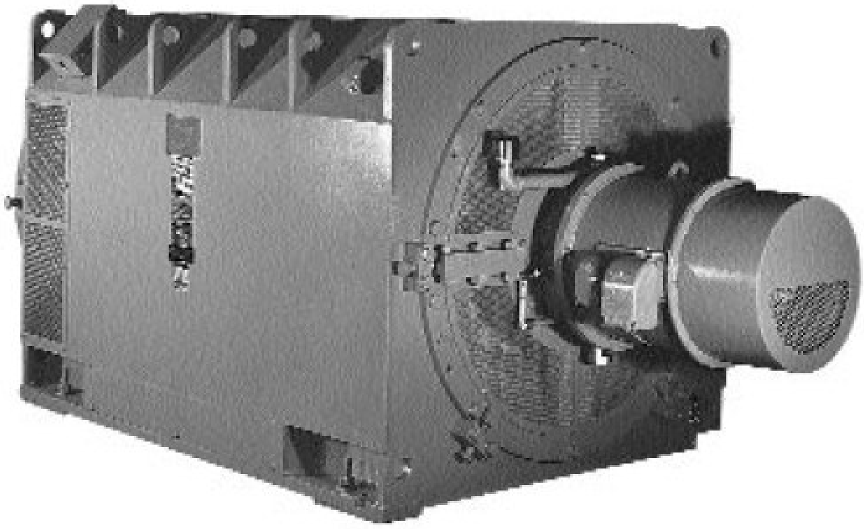


Figure 2.1: Photograph of Synchronous Condenser from Hyundai Ideal Electric Company

2.3 Installation of Capacitor Bank

In electrical power system, capacitors are commonly used to provide reactive power compensation in order to reduce power losses, regulate bus voltage and improve the power factor. The capacitor’s size and allocation should be properly considered, if else they can amplify harmonics currents and voltages due to possible resonance at once or several harmonic frequencies. This condition could lead to potentially dangerous magnitudes of harmonic signals, additional stress on equipment insulation, increased capacitor failure and interference with communication system [5].

2.4 Capacitor Bank Placement

The general problem for capacitor placement is to determine the optimal number, location, sizes and switching times for capacitors to be installed on a distribution feeder to maximize cost savings subjected to operating constraints.

The installed sizes for fixed capacitor banks located on distribution lines are based on matching reactive load to available bank sizes as closely as possible. For capacitor banks installed at substations, the size is chosen to maintain suitable power factor at peak loads, compensate for reactive losses in substation transformers, and release substation capacity. See Figure 2.2 for a photograph of an automatically switched, line-mounted capacitor bank and its components.

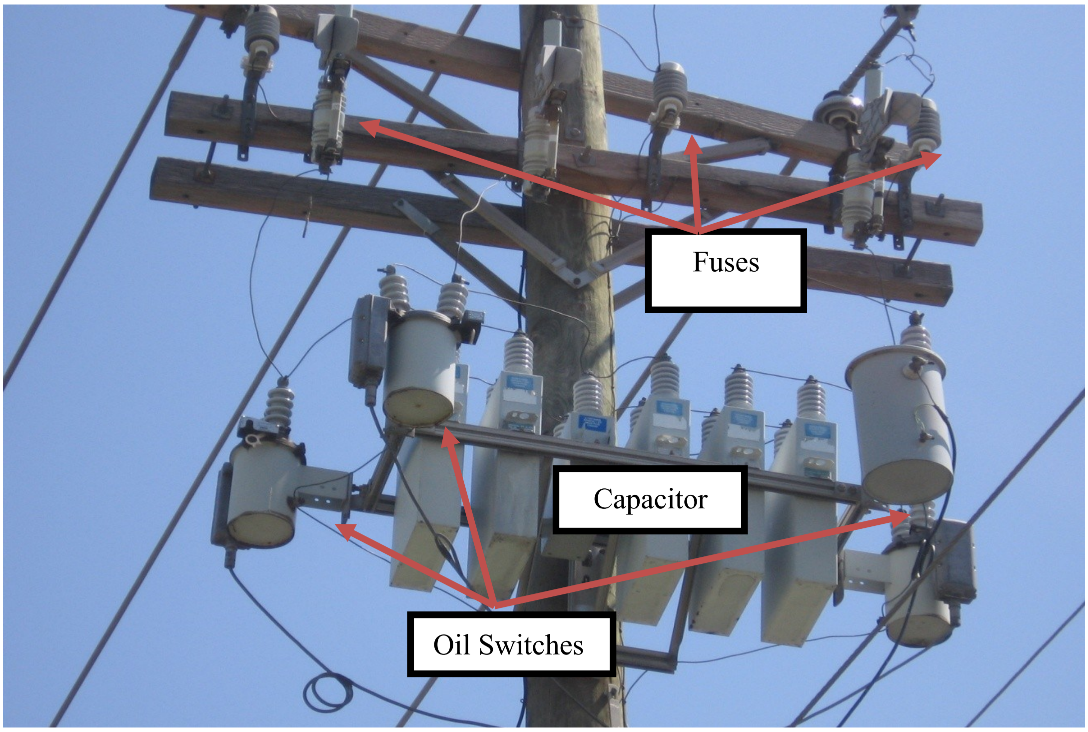
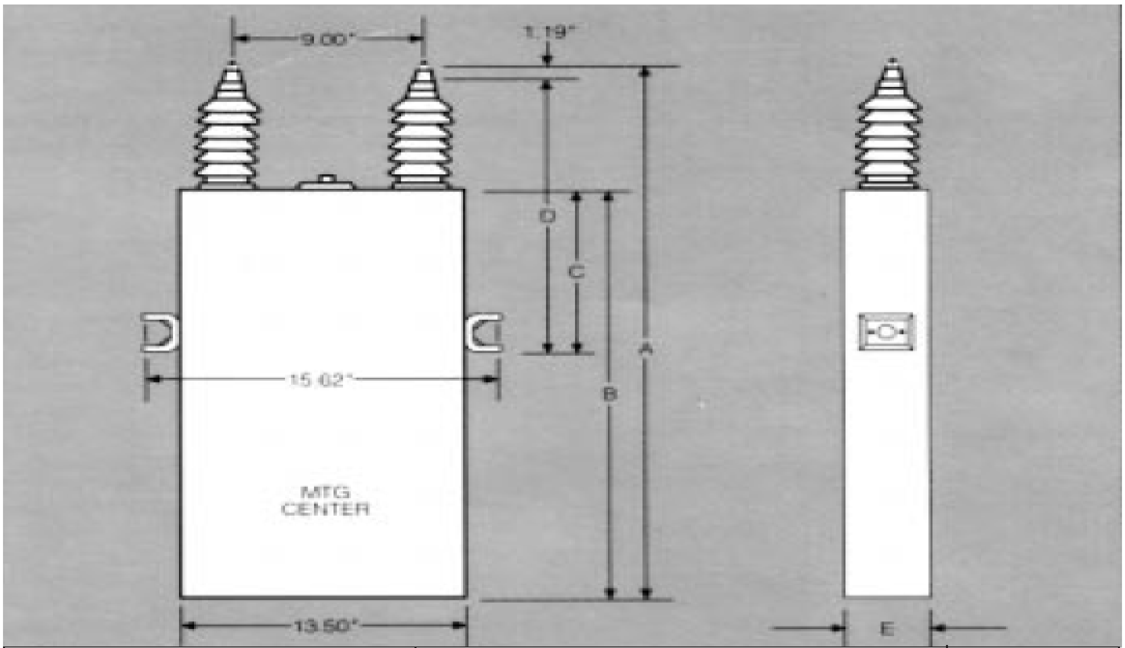


Figure 2.2: Line Mounted Capacitor Bank

Referring to table 2.1, it's showed the dimension and weights of capacitors. This example is taken from Cooper Power System Brochure. Based on this table, noticed that the difference rating of Kvar has their own dimension and weights for capacitors.

Table 2.1: Example of Standard Dimension and Weights of capacitor bank



Ratings			Dimensions					Approx. Net Bushing Capacitor* (lb)
Kvar	Voltage (volts)	BIL (kV)	A	B	C	D	E	
50	2400-4800	75	14.25	6.00	5.88	12.94	4.25	30
	6640-14400	95	14.25	6.00	5.88	12.94	4.25	30
	6640-14400	150	17.87	6.00	5.88	16.56	4.25	34
100	2400-4800	75	18.75	10.50	9.88	12.94	4.25	44
	6640-14400	95	18.75	10.50	9.88	12.94	4.25	44
	6640-24940	150	22.37	10.50	9.88	16.56	4.25	48
150	2400-4800	75	22.50	14.25	9.88	16.94	4.50	58
	6640-14400	95	22.50	14.25	9.88	16.94	4.50	58
	6640-24940	150	26.12	14.25	9.88	20.56	4.50	62
200	2400-4800	75	23.25	15.00	9.88	16.94	5.25	66
	6640-14400	95	23.25	15.00	9.88	16.94	5.25	66
	6640-24940	150	26.87	15.00	9.88	20.56	5.25	70
300	6640-14400	95	31.75	23.50	9.88	16.94	4.50	89
	6640-24940	150	35.38	23.50	9.88	20.56	4.50	93
400	6640-14400	95	31.75	23.50	9.88	16.94	5.75	105
	6640-24940	150	35.38	23.50	9.88	20.56	5.75	109

The allocation of capacitor banks corresponds to one of the most important problems related to the planning of electrical distribution networks. This problem consists of determining, with the smallest possible cost, the placement and the dimension of each capacitor bank to be installed in the electrical distribution grid with the additional objectives of minimizing the voltage deviations and power losses.

As many other problems of planning electrical distribution networks, the allocation of capacitor a bank is characterized by the high complexity in the search of the optimum solution [2].

Optimization of shunt capacitor planning for distribution systems has been implemented effectively by utilities to reduce system loss and improve the electricity service quality for a long time. It consists of determining the locations and sizes of capacitors to be installed in distribution systems so that the objectives of power loss reduction, voltage regulation and system capacity release can be achieved. Up to now, most of the optimal shunt capacitor placement considers fundamental frequency only.

2.5 Methods for Optimal Reactive Power Compensation

There have been some attempts in the past to utilize Optimal Reactive Dispatch (ORD) for system voltage profile correction and reactive power reserve maximization through the redistribution of system reactive power and other reactive power related control actions.

ORD is a special case of the conventional Optimal Power Flow (OPF) problem, whereby all active power related controls are fixed, only reactive power related controls are of interests. Since the first OPF paper was presented in the early 1960s, a lot of effort has been devoted into how to formulate and solve the OPF problem. A survey presented a summary of many different optimization techniques and their popularity based on a compilation of over 300 publications [7].

Several methods have been developed to solve the lack of reactive power problem. A number of these methods use heuristic search methods ref. [8]. It involves a set of possible solutions by examining the solutions at a set of critical nodes named sensitive nodes. This method is suitable for large distribution system and can be useful in online implementation. Some others formulate the problem as a general optimization problem in ref. [2, 5]. The general formulation of this problem is however quite complicated necessitating computationally demanding solutions.

Further, an approximate method to find acceptable location and sizing is describes on reference [8]. In this technique, reactive power of the capacitor bank located in a point is proportional to the reactive power consumption in the point. Therefore reactive power compensation is completely performed and loss minimization is achieved**.**

A genetic algorithm (GA) is proposed to solve the capacitor placement problem in ref. [2]. In this paper the multi-objective optimization problem is treated in details and a typical example concerning the allocation of capacitor banks in a real distribution grid is presented**.** Dynamic programming for the sizing and finally GA for finding the optimum shape of membership functions of bus voltages and line losses. In this context, the GA comes as a viable tool to obtaining practical solutions to this problem. Simulation results obtained with a real electrical distribution grid are presented and demonstrate the effectiveness of the methodology used.

This research work, does not consider the various kinds of optimization technique as stated above. In this research project, the sizing and location of the capacitor bank will be determined by using approximate technique which is used *DigSILENT PowerFactory* software for the simulation process.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This research is focus on examine the design technique of installation capacitor bank on the distribution feeder system. This analysis will divided into two parts of study, firstly for commonly in practice doing the capacitor bank sizing and second part is using Industrial Data Network for the simulation.

The analysis done is to achieve the results for the optimal size and placement of capacitor bank on the test cases with respect to voltage and losses. A technical evaluation will be done to look at the impacts of a change in the location and sizes for capacitors to be installed on a distribution feeder to maximize cost savings subjected to operating constraints.

3.2 Design Technique of Capacitor Banks

To obtain the sizing and location of capacitor bank, commonly have two methods which are:

i. By practice
ii. By simulation

3.3 Practice

Usually, the capacitor bank are placed at the point capacitor coupling (PCC) by measuring voltage, current, kW, kVAr, and kVA on the feeder to determine the maximum and minimum load conditions.

At industrial site, practically they has own method in order to examine on sizing placement technique of installation capacitor bank on the distribution feeder system. Firstly, in order to get the data in term of Active Power (kW), Reactive Power (kVAr) and Apparent Power (kVA) by performing the load profile using Power Quality (PQ) recorder.

PQ recorder is one of equipments used for getting the data at industrial site. Normally, the PQ recorder is tap on secondary side of the main transformer and also at the point capacitor coupling (PCC) to loading bus as shown in figure 3.1.

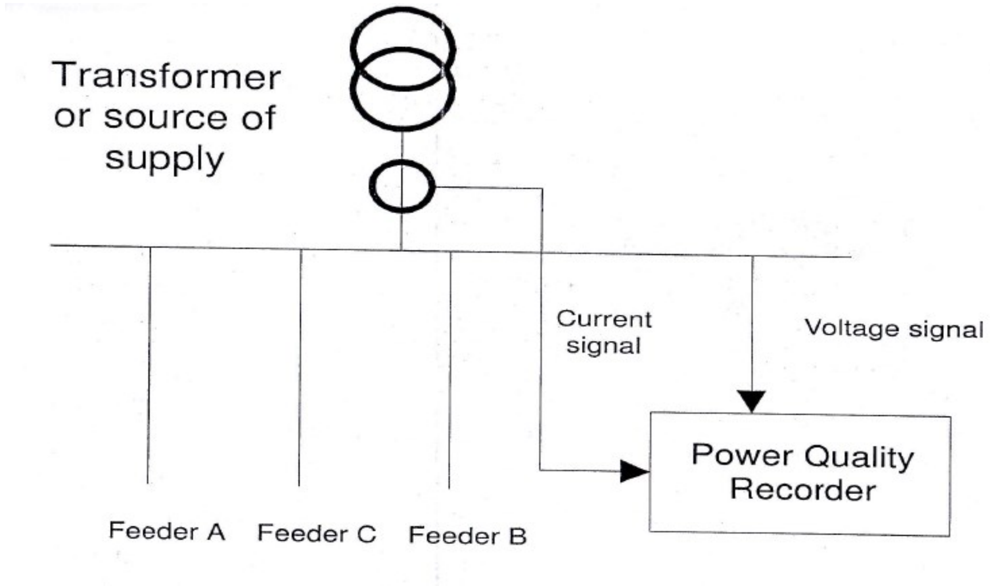


Figure 3.1: Location for load profiling by using Power Quality recorder.

A load profile commonly represent as a graph, these graph contain of variation in electrical load in terms of kW, kVAr and kVA versus time. Referring on figure 3.2 shows the example of load profile graph is taken by one of industrial site.

Actually the load profile characteristic will vary depend on customer type of load, such as for residential, commercial or in industrial site which have different of type of load usage. These load profile characteristic are essential data for future upgrading system, for example to calculating and evaluating equipments needs, maintenance and other related work.

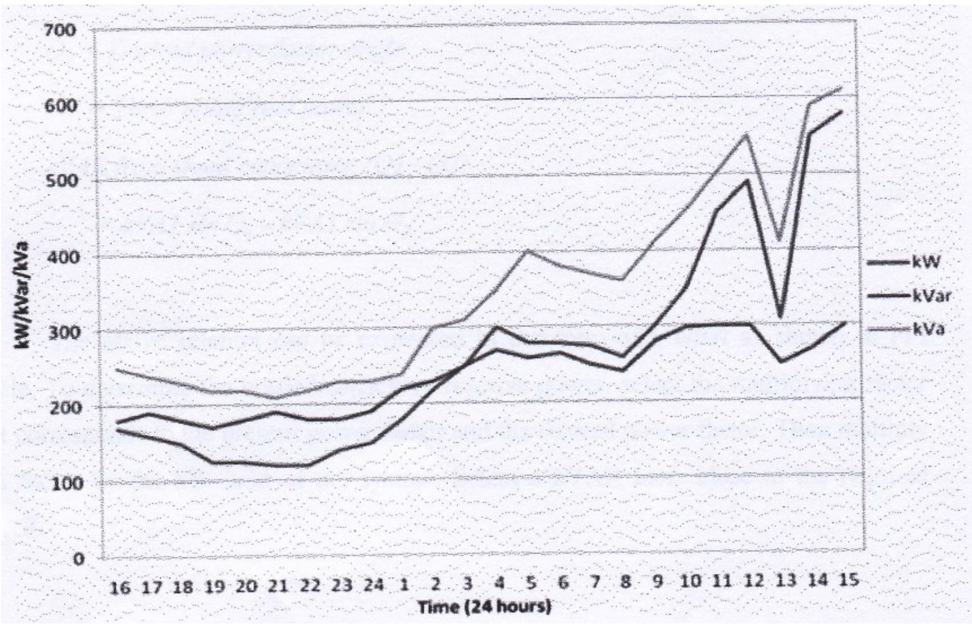


Figure 3.2: Example of load profile graph contain of kW, kVAr and kVA versus time

In order to design of capacitor bank, there have two types of connections which are for delta connection and Wye connection. Both of this connection have their own characteristic to be determined before proceed to choose either for Delta or Wye connection. Referring figure, figure 3.3(a) is for Delta connection and figure 3.3(b) is for Wye connection.

Normally, the capacitor bank at 4.16 kV and rated capacity less than and equal to 1 MVAR are connected in delta, meanwhile capacitor bank has rating more than 4.16 kV and less than 1 MVAR are advisable to be connected in Wye.

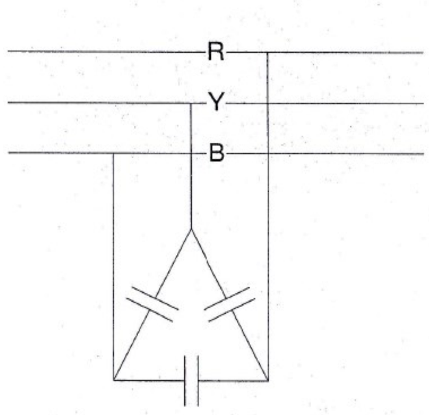


Figure 3.3(a): Delta connection

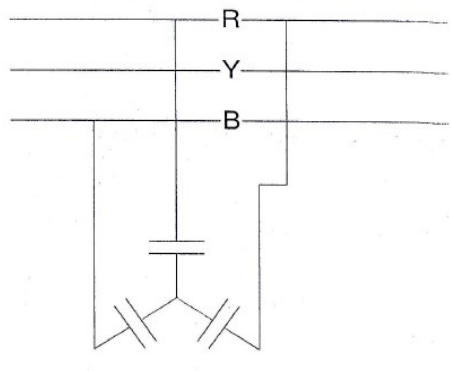


Figure 3.3(b): Wye connection

The power factor has leading and lagging sign. If a unity power factor is achieved during a peak load, them there would be leading kVAr on the line during off-peak condition, resulting in an over-corrected condition. Over-correction of power factor can produce excess loss in the system, similar to the lagging power factor condition. Overvoltage condition may occur during leading power factor condition causing damage to the equipments.

Therefore, a leading power factor is not an advantageous condition. In order to handle such conditions, fixed capacitors are used to supply the constant kVAr and meanwhile the switched capacitors are used for supplying the kVAr for the peak load conditions. Thus, this fixed and switched capacitor will prevent for over-corrected of kVAr. Figure 3.4 shows the example Wye-connection with fixed and switched capacitors are installed.

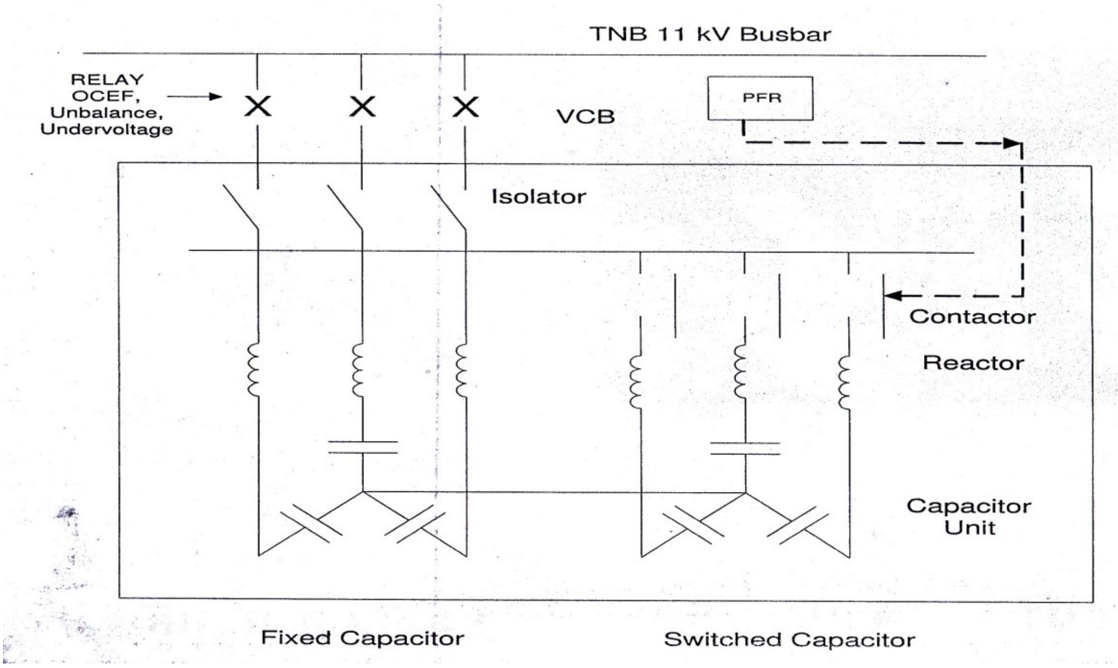


Figure 3.4: Wye-connection with fixed and switched capacitors are installed

In this research, delta and Wye connection are not covered for the analysis in this project. Besides, switched capacitors also not are considered in this research. These research project only cover on fixed capacitors were injected for this system.

3.3.1 Location of capacitor banks

Depending upon specific factors such as cost, requirement of area for installation and load, the location of capacitor banks is divided into two types. They are;

i. Central compensation

ii. Local Compensation

i) CENTRAL COMPENSATION

When the main purpose is to reduce reactive power purchase due to power supplier tariffs, central compensation is preferable. Reactive loading conditions within a plant are not affected if compensation made on the high voltage side. When made the low voltage side the transformer is relieved. Cost of installation on the high voltage and low voltage sides respectively determine where to install the capacitor. Referring the figure 3.5 shows the example of Central Compensation in the distribution network.

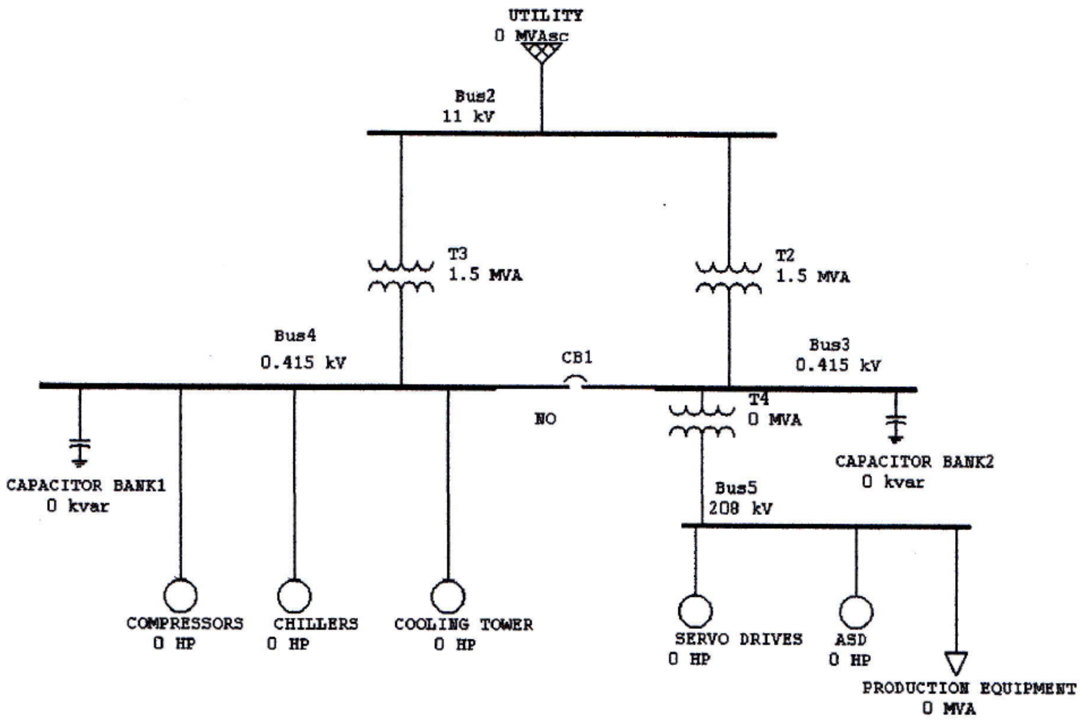


Figure 3.5: Example of Central Compensation

ii) LOCAL COMPENSATION

In this installation, the placement of the capacitor is direct to the load such as induction motor loads. The figure 3.6 shows the example of local compensation.

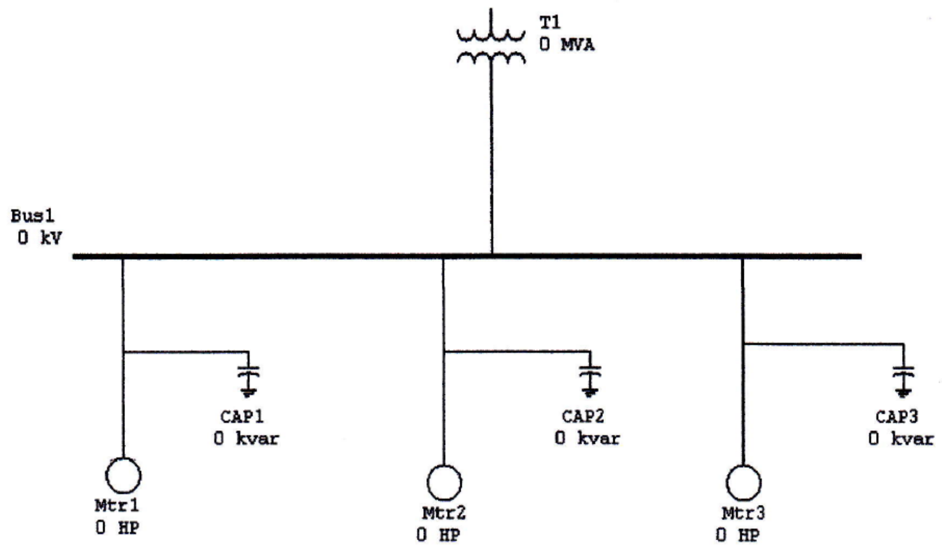


Figure 3.6: Example of Local Compensation

From the figure 3.7(a) and figure 3.7(b) shows the flow of current in term of active and reactive current for installed of capacitor bank and without installed of capacitor bank. Figure 3.7(a) showed the total of active and reactive current will flow through the induction motor loads. But for figure 3.7(b) only the active current is flow through the induction motor loads and for the reactive current is supplied by the installed capacitor bank.

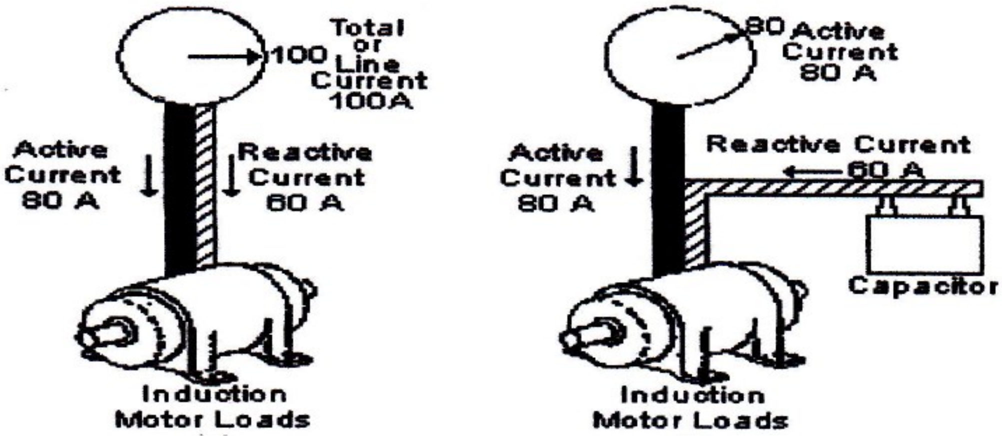


Figure 3.7 (a): Without installed of capacitor bank; Figure 3.7 (b): Installed with capacitor bank

3.4 Simulation

3.4.1 DigSILENT *PowerFactory* software

In DigSILENT *PowerFactory* software, there have the ability to take a solved load flow study and store all the necessary data including the solution in a file created on computer disk. This will allow for future change or to perform any correction on that system file.

In this software, single line diagram which is displays the base case load flow in graphical form. It shows the voltage at all busses and flows on all lines. The system configuration is shown clearly all busses are supplied to each feeder, loads and transformers also.

Besides, it more concise because all required parameters needed in order to presenting load flow is provided to fill up and also to display them graphically on the system single line diagram. System flows can be quickly analyzed from this visual presentation that relates system configuration, operating conditions and equipments parameters.

Furthermore, load flow output result provides an excellent opportunity to documents study results. It may be desirable to list corrective action taken for the next load flow run, which hopefully can improve the system operation.

3.4.2 Power Flow Study

Power flow studies, commonly known as *load flow*, form an important part of power system analysis. They are necessary for planning, economic scheduling, and control of an existing system as well as planning its future expansion.

The two most commonly used methods for calculating load flow are Gauss Seidel and Newton-Raphson. In DigSILENT *PowerFactory* software, they used Newton-Raphson in order to running the system load flow.

Because of its quadratic convergence, Newton's method is mathematically superior to the Gauss Seidel method and is less prone to divergence with ill-conditioned problems. For large systems, the Newton-Raphson method is found to be more efficient and practical. The number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required for each iteration.

3.4.3 Step for Capacitor Bank Design Using Simulation

In process to designing of capacitor bank, first of all the industrial data network systems will be used as a test system. For this study, 43-bus data network system will be used. Then, this system will be modelled by using DigSILENT *PowerFactory* software represents into single line diagram.

Thus, after completed of fill up all the data needed, the load flow analysis will be run. When the system is already run for load flow, the power factor, active and reactive power losses will be recorded and analyzed.

The second step, approximate technique will be used in order to get the sizing and placement for the capacitor bank which is has two cases, firstly we determine the placement of capacitor banks and secondly we determine for the size of capacitor banks to be installed. The capacitors were placed at all the busses in this system network and the size of the capacitor are defined based on their level of busses.

Further, the same step will be used for the rest of 43 bus data in this system network. In the table result, we identify the power factor and see the Active Power Losses (MW) and Reactive Power Losses (Mvar) for all injected buses. In detail, see the figure 3.8 for all research flow as describing above.

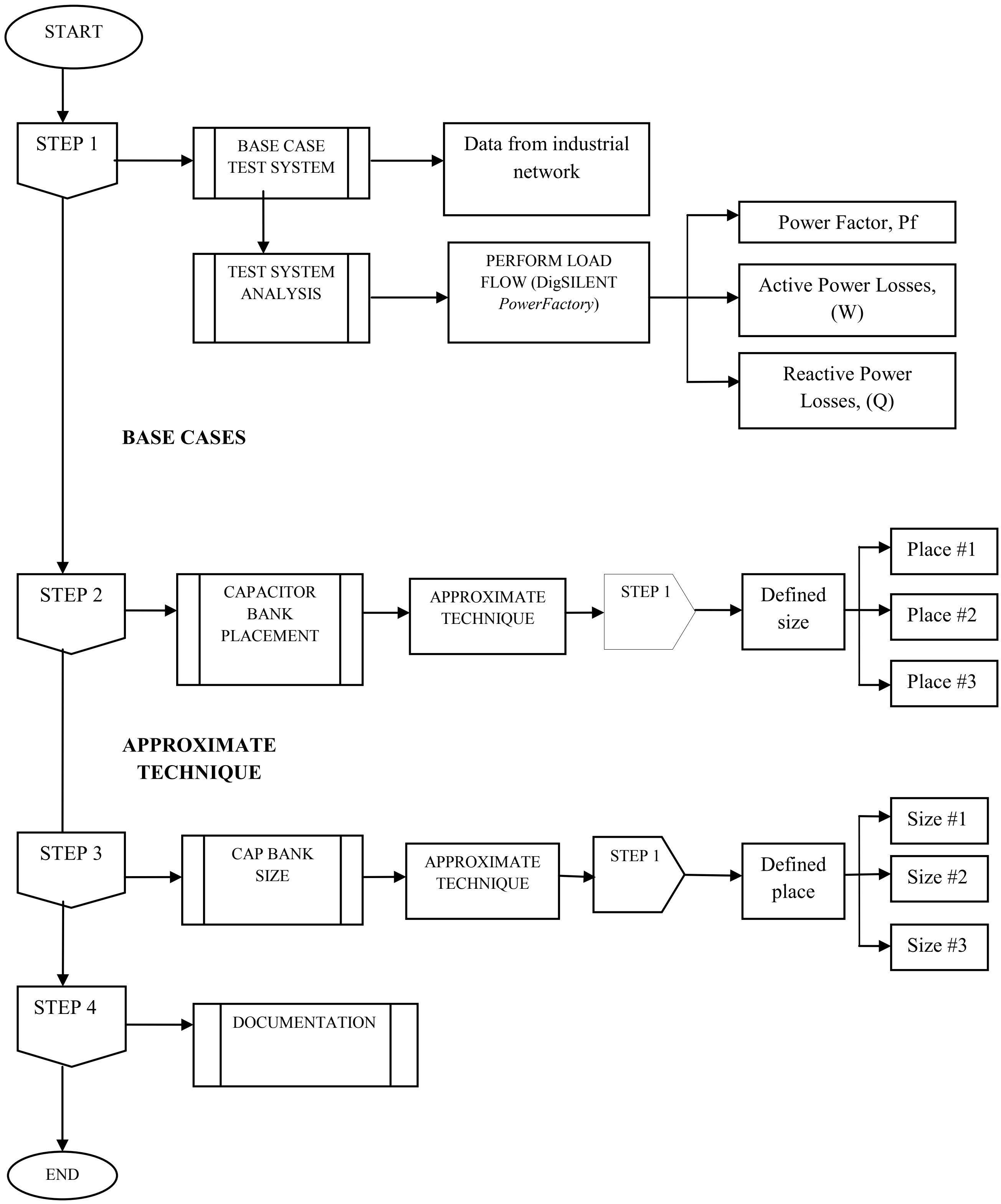


Figure 3.8: Research Flow

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

For this project, industrial data network has been modelled by using DigSILENT *PowerFactory* software. From this base case system, it has been modified the system with injected of capacitor bank in order to identify the optimal power factor and see their calculated system losses in term of Active Power Losses (MW) and Reactive Power Losses (Mvar).

4.2 Industrial Data Network

To illustrate the use of a load flow program, a typical plant will be studies by using this system.

In general, A distribution system comprises of network operating at medium (MW) and low (LV) voltage levels that obtain power from the transmission network or the grid. Most customers are connected to distribution network at MV or LV voltage levels.

4.2.1 Connection to the Grid and Power Transformers

The main step down substation (in Malaysia normally called as main intake substation; PMU) is connected to the grid at nominal voltage of 33kV as the source for this system network.

The 33 kV is stepped down to 11kV using 2 X 31500KVA transformers, whose parameters are also indicated in figure 4.1 has been modelled by using DigSILENT *PowerFactory* software.

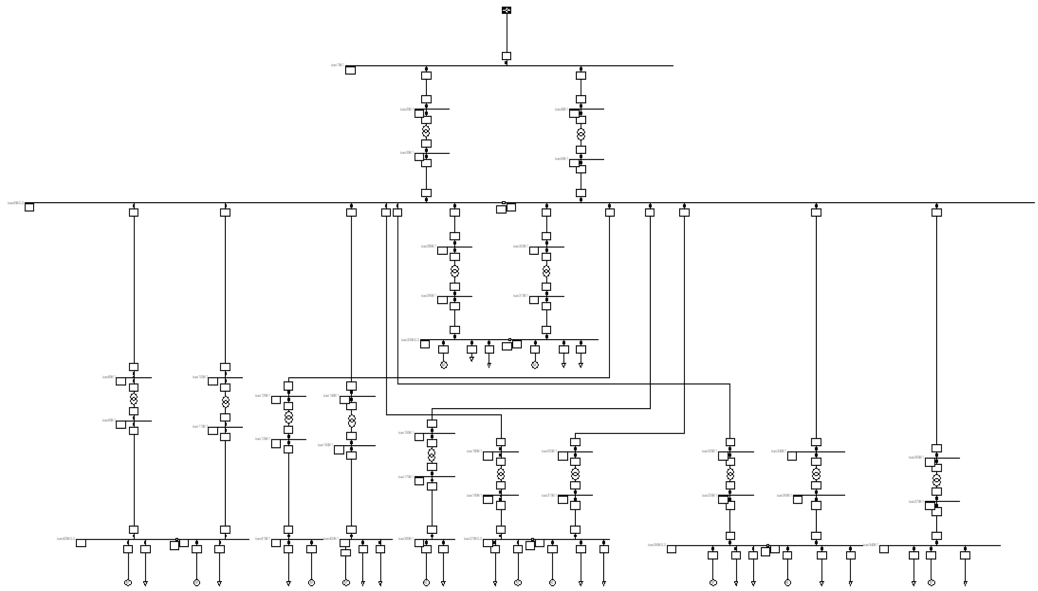


Figure 4.1: 43-bus Industrial Data Network has been modelled by using DigSILENT *PowerFactory* software

4.2.2 Feeder and Substations

On the 11kV side of the main intake substation, there are 2 x incoming feeders (Bus no. 3 and 5) from two power transformers and 12 x 11kV outgoing feeders.

Typically an 11/0.433kV substation comprises of switches for incoming and outgoing feeders as well as for distribution transformer feeders.

4.3 Analysis of system

From the result, parts of analysis will be divided into two parts, which are result for doing in practice and second part by using the simulation.

4.3.1 Results for Using Practice Methods

The data from load profile will be analysis to get the propose size which is has the minimum and the maximum size of capacitor bank. Figure 4.2 shows the example for load profile data is taken by one industry. Commonly, the data of load profile is taken for each three week in order to make sure the system always in stable and good condition.

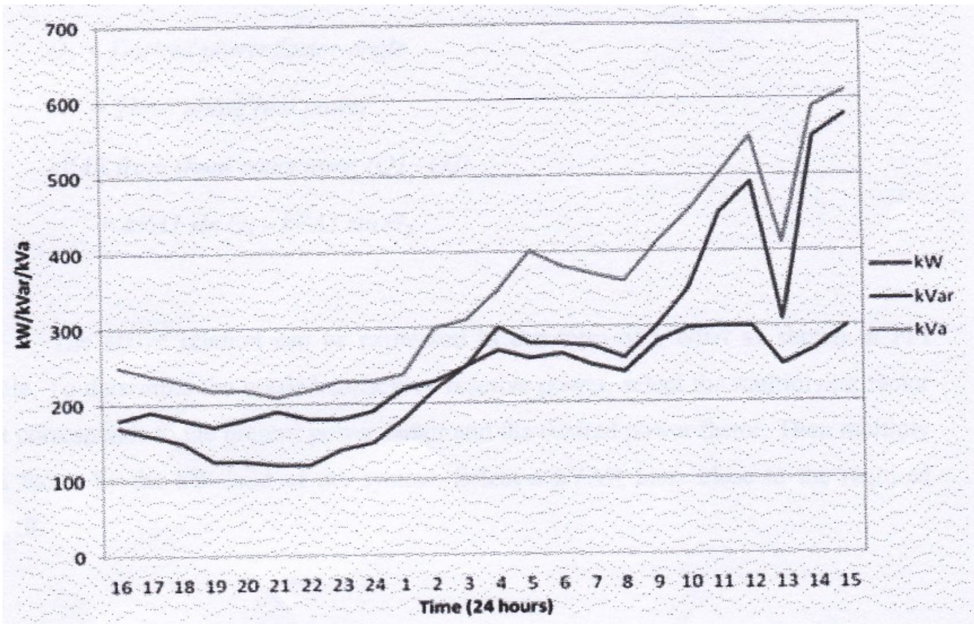


Figure 4.2: Example of load profile

From figure 4.2 above shows that the variable data contain value of kW, kVAr and kVA in duration of 24 hours. From the graph, noted that the maximum data is 300 kVAr and minimum data is 150 kVAr. Thus, the propose size for this maximum and minimum size of capacitor bank is, 2 x 150 kVAr is equal to 300 kVAr. In these cases, 300kVAr will selected as the suitable size to be installed.

4.3.2 Results for Simulation Methods

After load flow run for the base condition, shows that this system not so stable and some correction must be done in order to improve its operation. In this analysis, there has three parts will be discussed which are:

i. Standard system voltage
ii. Power Factor
iii. System losses

Referring on table 2, showed the result for injected of capacitors at 43 buses in this system network. Difference rating of kVAr was injected at difference voltage level.

For the injected of capacitors is referring to example budgetary cost used by Northeast Power Systems, Inc (NEPSI) for medium (MV) and low (LV) voltage levels in (Appendix A3). The capacitors placement used is different based on the level of busses.

For the analysis, Power Factor, Active Power Losses (MW) and Reactive Power Losses (Mvar) will be recorded in table 4.1.

Table 4.1: Result for injection of capacitor bank

				System Losses	
Bus Location	Rating Voltage (kV)	Injected of Capacitor (kVAr)	Power Factor	Active Power (MW)	Reactive Power (Mvar)
Base Case		***0***	***0.62***	***0.26***	***1.06***
Bus 1	33	2000	0.7	0.26	1.06
		3000	0.74	0.26	1.06
		4500	0.81	0.26	1.06
Bus 2	33	2000	0.7	0.26	1.06
		3000	0.74	0.26	1.06
		4500	0.81	0.26	1.06
Bus 3	11	1500	0.68	0.26	1.02
		3000	0.75	0.25	0.98
		4500	0.82	0.25	0.72
Bus 4	33	2000	0.7	0.26	1.06
		3000	0.74	0.26	1.06
		4500	0.82	0.26	1.06
Bus 5	11	1500	0.68	0.26	1.01
		3500	0.77	0.25	0.96
		4500	0.75	0.25	0.98
Bus 6	11	1500	0.68	0.26	1.02
		3500	0.77	0.25	0.97
		4500	0.82	0.25	0.97
Bus 7	11	1500	0.68	0.26	1.01
		3500	0.77	0.25	0.96
		4500	0.82	0.25	0.95
Bus 8	11	1500	0.68	0.26	1.02
		3500	0.77	0.25	0.98
		4500	0.82	0.25	0.97
Bus 9	0.433	1000	0.66	0.26	1.02
		1500	0.68	0.26	1.03
		1900	0.7	0.26	1.03
Bus 10	11	1500	0.68	0.26	1.01
		3500	0.77	0.25	0.98
		4500	0.82	0.25	0.97
Bus 11	0.433	1000	0.66	0.25	1
		1500	0.68	0.25	0.98
		1900	0.7	0.25	0.99
Bus 12	11	1500	0.68	0.26	1.01
		3500	0.77	0.25	0.96
		4500	0.82	0.25	0.95
Bus 13	0.433	1000	0.66	0.25	1.01

		1500	0.68	0.26	1.01
		1900	0.7	0.26	1.03
Bus 14	11	1500	0.68	0.26	1.02
		3500	0.77	0.25	0.98
		4500	0.82	0.25	0.97
Bus 15	0.433	1000	0.66	0.26	1.03
		1500	0.68	0.26	1.04
		1800	0.7	0.26	1.06
Bus 16	11	1500	0.68	0.26	1.01
		3500	0.77	0.25	0.96
		4500	0.82	0.25	0.95
Bus 17	0.433	1000	0.66	0.26	1.03
		1500	0.68	0.26	1.04
		1900	0.7	0.26	1.06
Bus 18	11	1500	0.68	0.26	1.02
		3500	0.77	0.25	0.98
		4500	0.82	0.25	0.97
Bus 19	0.433	1000	0.66	0.26	1.04
		1500	0.67	0.26	1.04
		1900	0.7	0.26	1.08
Bus 20	11	1500	0.68	0.26	1.01
		3500	0.77	0.25	0.96
		4500	0.82	0.25	0.95
Bus 21	0.433	1000	0.66	0.26	1.02
		1500	0.68	0.26	1.03
		1900	0.7	0.26	1.06
Bus 22	11	1500	0.68	0.26	1.02
		3500	0.77	0.25	0.98
		4500	0.82	0.25	0.97
Bus 23	0.433	1000	0.66	0.26	1.04
		1500	0.68	0.26	1.05
		1800	0.7	0.26	1.07
Bus 24	11	1500	0.68	0.26	1.01
		3500	0.77	0.25	0.96
		4500	0.82	0.25	0.95
Bus 25	0.433	1000	0.66	0.26	1.02
		1500	0.68	0.26	1.03
		1900	0.7	0.26	1.05
Bus 26	11	1500	0.68	0.26	1.01
		3500	0.77	0.25	0.96
		4500	0.82	0.26	0.96
Bus 27	0.433	1000	0.66	0.25	1
		1500	0.68	0.25	1
		1900	0.7	0.26	1.02

Bus 28	11	1500	0.68	0.26	1.02
		3500	0.77	0.25	0.97
		4500	0.82	0.25	0.97
Bus 29	3.45	2000	0.7	0.25	0.96
		3000	0.75	0.25	0.95
		4000	0.8	0.25	0.97
Bus 30	11	1500	0.68	0.26	1.01
		3500	0.77	0.25	0.96
		4500	0.82	0.25	0.95
Bus 31	3.45	2000	0.71	0.25	0.94
		3000	0.76	0.25	0.91
		4000	0.8	0.25	0.92
Bus 32	3.3	1200	0.67	0.23	0.94
		2200	0.72	0.22	0.9
		2500	0.74	0.23	0.91
Bus 33	3.3	1200	0.67	0.24	0.94
		2200	0.72	0.23	0.89
		2500	0.74	0.23	0.88
Bus 34	0.415	300	0.63	0.25	1.02
		600	0.64	0.24	0.99
		900	0.66	0.25	0.98
Bus 35	0.415	300	0.63	0.25	1.02
		600	0.64	0.25	1.01
		900	0.66	0.26	1.03
Bus 36	0.415	300	0.63	0.25	1.04
		600	0.65	0.26	1.03
		900	0.66	0.26	1.03
Bus 37	0.415	300	0.63	0.25	1.03
		600	0.64	0.25	1.02
		900	0.66	0.26	1.04
Bus 38	0.415	300	0.63	0.25	1.03
		600	0.65	0.26	1.05
		900	0.66	0.29	1.12
Bus 39	0.415	300	0.63	0.25	1.03
		600	0.65	0.25	1.03
		900	0.66	0.27	1.06
Bus 40	0.415	300	0.63	0.25	1.03
		600	0.64	0.25	1.02
		900	0.66	0.26	1.04
Bus 41	0.415	300	0.63	0.25	1.03
		600	0.64	0.25	1
		900	0.66	0.25	0.99
Bus 42	0.415	300	0.64	0.25	1.02
		600	0.64	0.24	0.99

		900	0.66	0.24	0.97
Bus 43	0.415	300	0.64	0.25	1.03
		600	0.64	0.25	1.02
		800	0.66	0.25	1.02

4.3.2.1 Standard System Voltage

For standard system voltage, we have set up in the Colour Representation of Graphic (Low and High Voltage Loading) which is the Lower Limit of Allowed Voltage is (0.95 pu), Higher Limit of Allowed Voltage is (1.05 pu) and the last for Maximum of Loading Voltage is (100%).

Referring on figure 4.3 shows the example of setting for low and high voltage loading in DigSILENT *PowerFactory* software. Here, the voltage profile at the acceptable range which is (0.95 to 1.05 p.u),

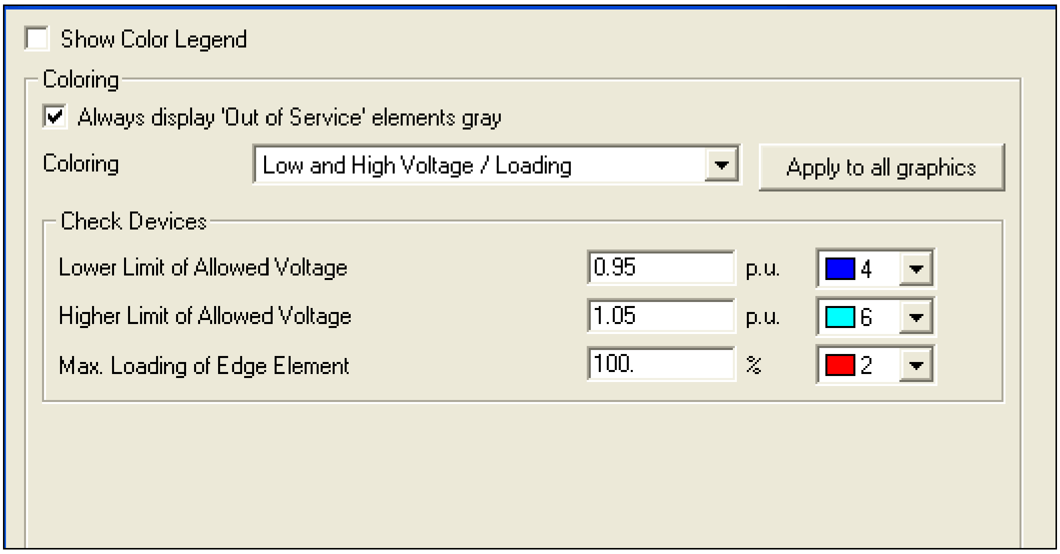


Figure 4.3: Example of setting for low and high voltage loading

4.3.2.2 Power Factor

After load flow run for the base condition, shows that this system is not so stable and the power factor at the base case is 0.62. Referring table 4.1, increasing the value of the capacitor size (kVAr), the power factor becoming more stable is 0.8 and above. Reactive power caused by inductance always acts at 90 degree angle to real power. Therefore, by injecting the capacitance to the bus, reactive power can be compensated. Thus, it will correct the power factor close to power factor 1.

According to the power factor standard from Tenaga Nasional Berhad (TNB), the power factor used must be 0.85 and above. So, if the power factor used is below than 0.85, TNB will charge penalty because more current must be transmitted than it usually used to perform work. Normally TNB will check their consumer consumption in secondary side of main transformer to loading bus.

4.3.2.3 System losses

In these system losses, result will be analyzed at each level of buses. In this system network we have six differences of voltage level which is at 33kV, 11kV, 3.45kV, 3.3kV, 0.433kV and also at the bus load is 0.415kV.

Based on the result in table 4.1, difference injected of kVAr will give difference value for system losses. After load flow run for the base condition, the active and reactive power losses is 0.26MW and 1.26Mvar respectively. In detail, the graph below will show the result for every of buses level.

i) Result for bus at 33kV

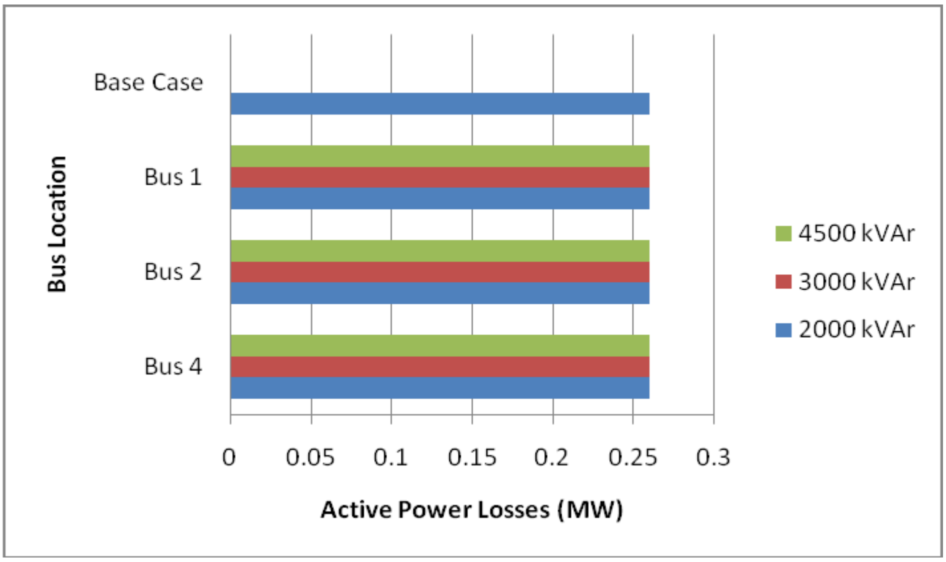


Figure 4.4(a): Active Power Losses (MW)

Note that;

X Axis: Active Power Losses (MW)

Y Axis: Bus Location

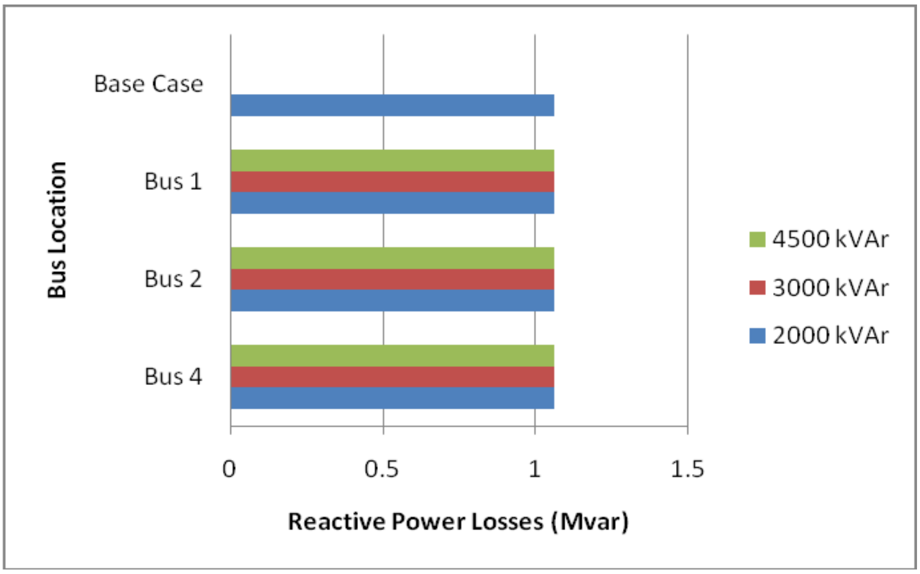


Figure 4.4(b): Reactive Power Losses (Mvar)

Note that;

X Axis: Reactive Power Losses (Mvar)

Y Axis: Bus Location

Based on the graph, injected of kVAr at buses 1, 2 and 4 not affected on the system losses. The active and reactive power losses are not be change, respectively is 0.26MW and 1.06Mvar same as the losses at the base case.

This is happen because the reactive loading conditions within a plant are not affected if compensation made on the high voltage side but when made the low voltage side the transformer is relieved, so the losses will be affected as well.

ii) Result for bus at 11kV

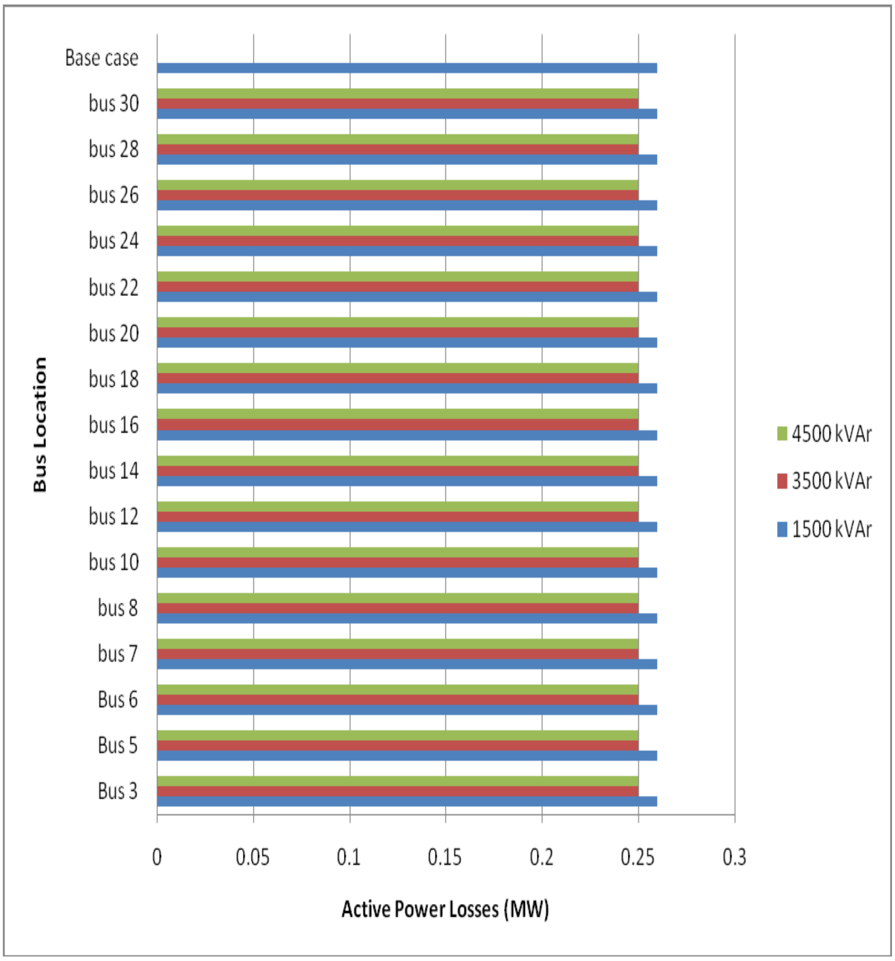


Figure 4.5(a): Active Power Losses (MW)

Note that;

X Axis: Active Power Losses (MW)

Y Axis: Bus Location

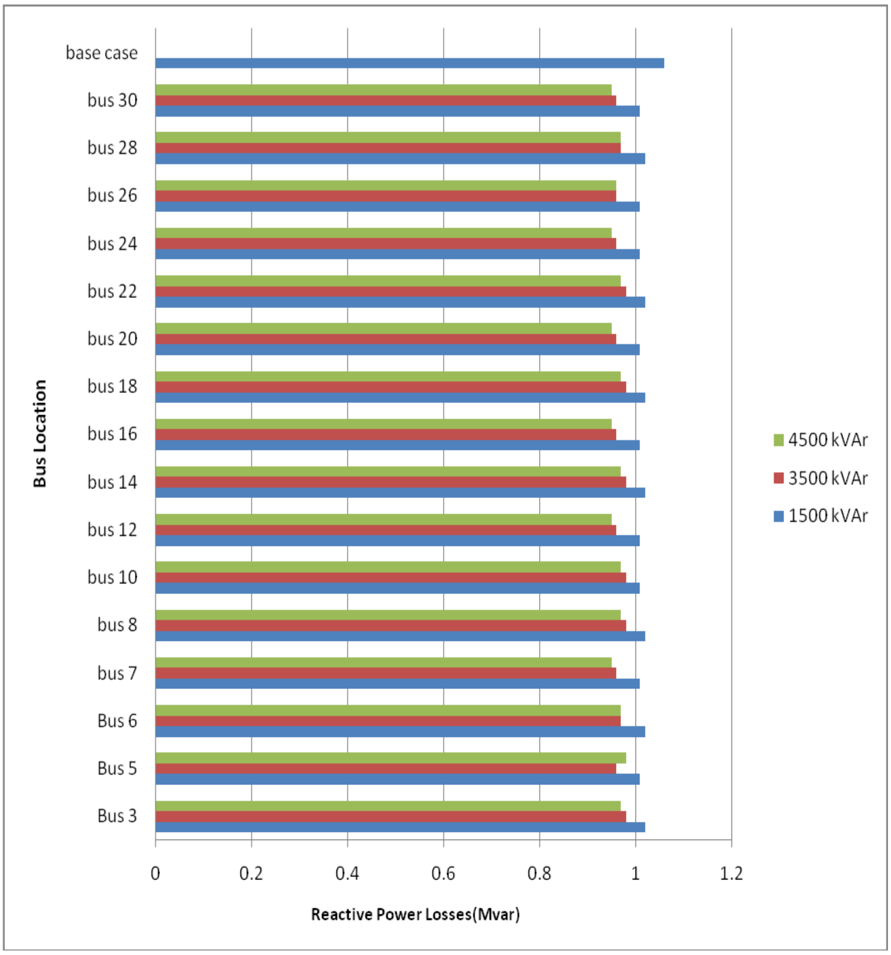


Figure 4.5(b): Reactive Power Losses (Mvar)

Note that;

X Axis: Reactive Power Losses (Mvar)

Y Axis: Bus Location

Based on the graph, noted that the active and reactive power losses is decreased with injected of kVAr. But for the active power losses in figure 4.5(a), shows that the capacitor rated 1500kVAr have same losses with the base case is 0.26MW. For other buses, shows the reduced of losses is 0.25 MW.

Referring on figure 4.5(b), decreasing of reactive power losses is mostly same for each the buses.

iii) Result for bus at 3.45kV

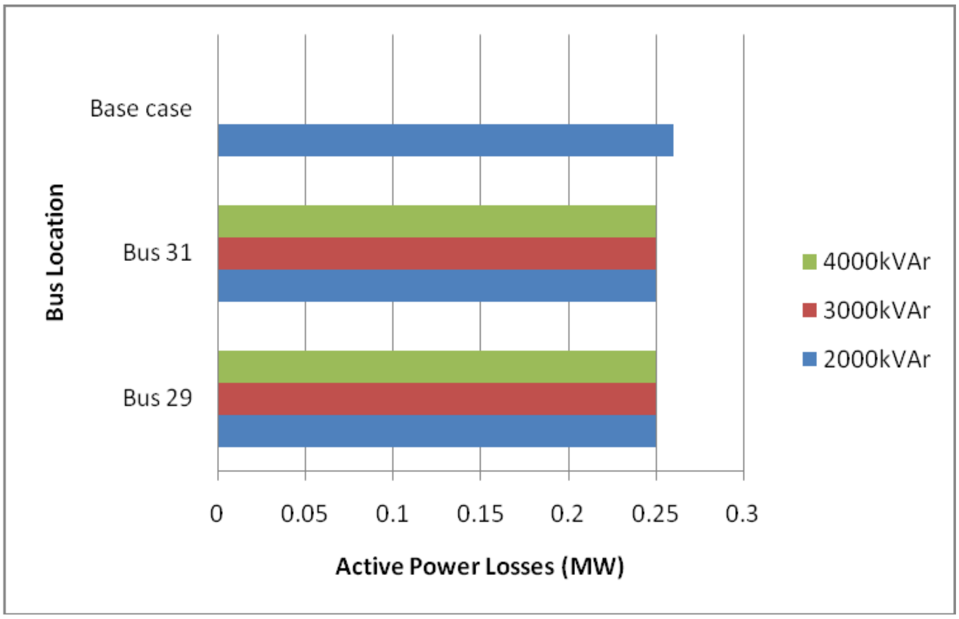


Figure 4.6(a): Active Power Losses (MW)

Note that;

X Axis: Active Power Losses (MW)

Y Axis: Bus Location

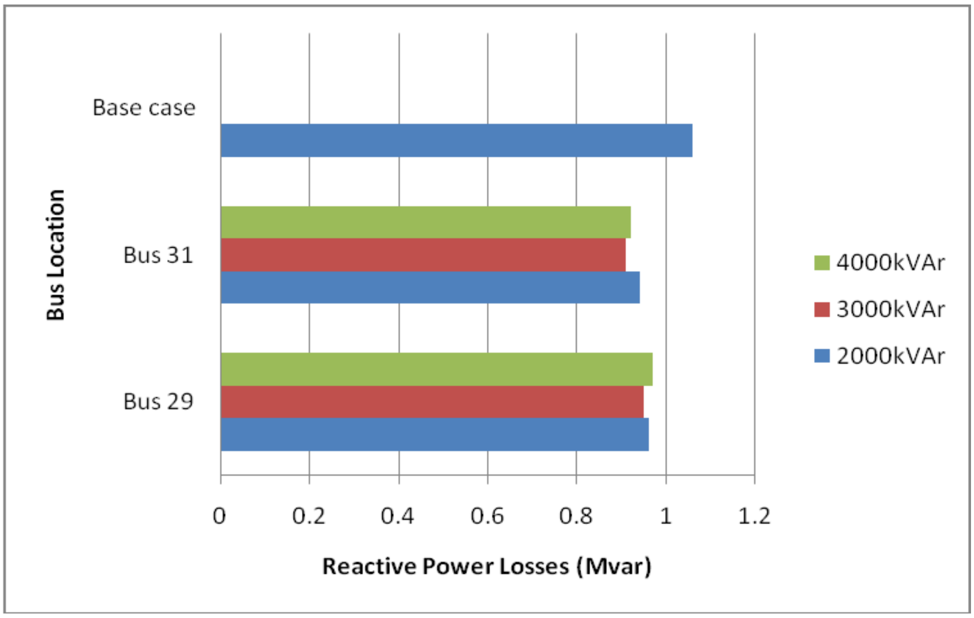


Figure 4.6(b): Reactive Power Losses (Mvar)

Note that;

X Axis: Reactive Power Losses (Mvar)

Y Axis: Bus Location

Based on the graph, noted that the active and reactive power losses is decreased with injected of kVAr. Referring on figure 4.6(a), the active power loss decreased by 0.25MW from the base case is 0.26MW, respectively at buses 29 and 31.

As for reactive power losses, the figure 4.6(b) shows that the lower value of reactive power losses is due to placement of capacitor rated 3000kVAr at bus 31.

iv) Result for bus at 3.3kV

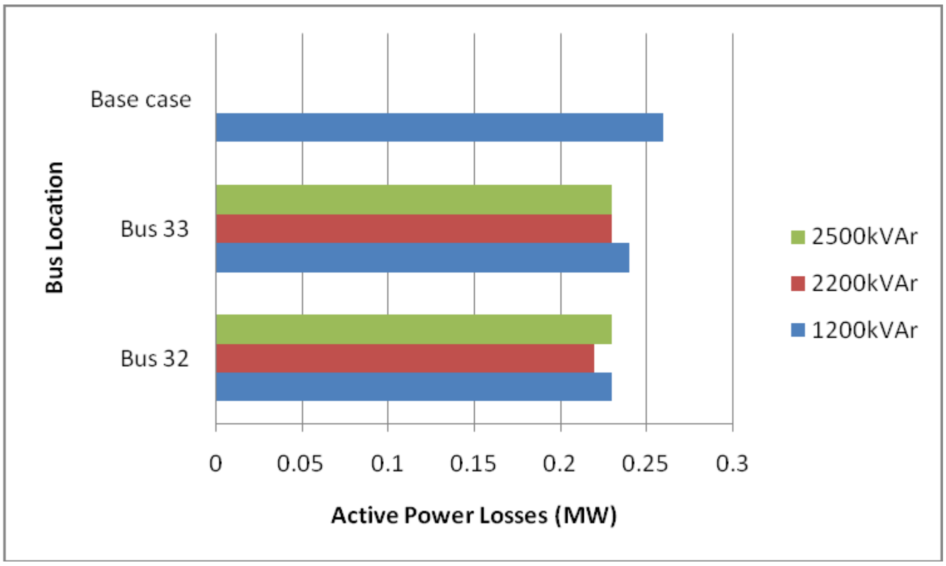


Figure 4.7(a): Active Power Losses (MW)

Note that;

X Axis: Active Power Losses (MW)

Y Axis: Bus Location

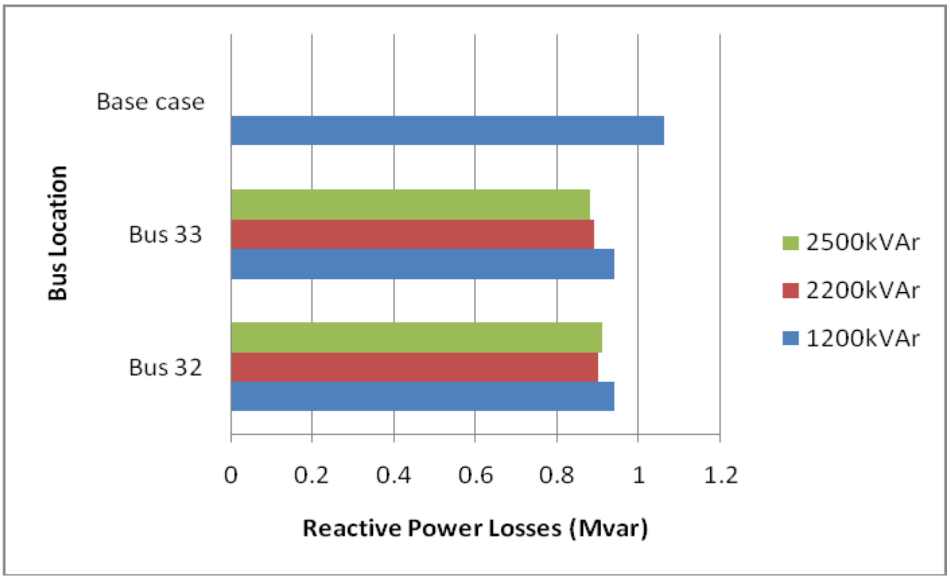


Figure 4.7(b): Reactive Power Losses (Mvar)

Note that;

X Axis: Reactive Power Losses (Mvar)

Y Axis: Bus Location

Based on the graph, noted that the active and reactive power losses is decreased with injected of kVAr. Referring on figure 4.7(a), the lower value of active power loss is due to placement at bus 32 with capacitor rated 2200kVAr.

As for the reactive power losses, figure 4.7(b) shows that the lower of reactive system loss is achieved when the placement is made at bus 33 with capacitor rated 2500kVAr.

v) Result for bus at 0.433kV

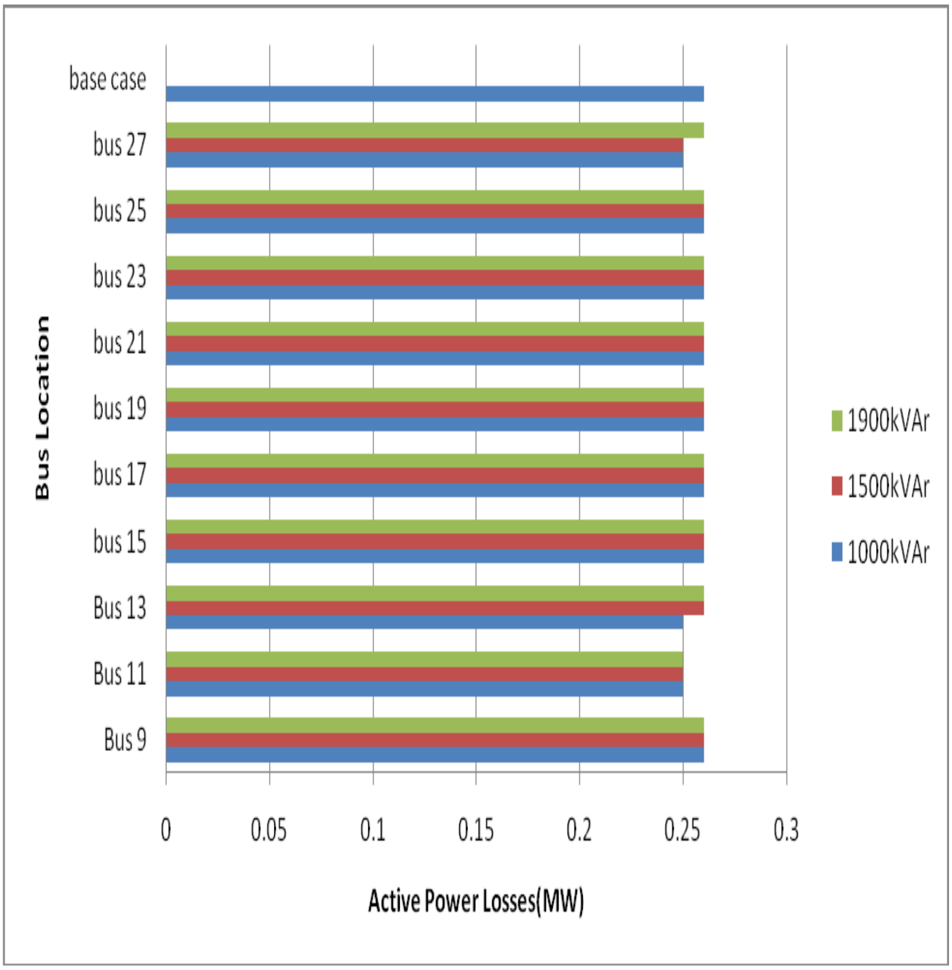


Figure 4.8(a): Active Power Losses (MW)

Note that;

X Axis: Active Power Losses (MW)

Y Axis: Bus Location

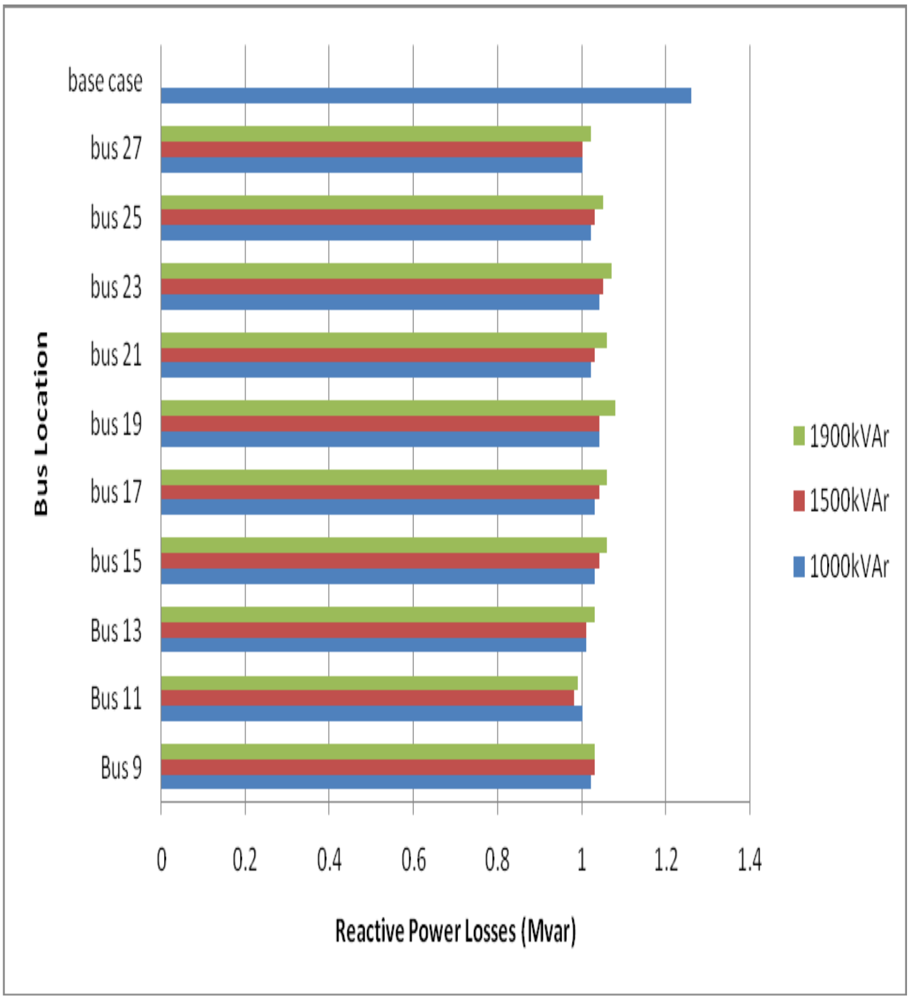


Figure 4.8(b): Reactive Power Losses (Mvar)

Note that;

X Axis: Reactive Power Losses (Mvar)

Y Axis: Bus Location

Referring on figure 4.8(a), only at buses 11, 13 and 27 shows the decreasing of the active power loss. For other buses, the total losses are same as the base case is 0.26 MW.

As for reactive power losses, figure 4.9(b) shows that the lower of reactive power loss is achieved when placement made at the bus 11 with capacitor rated is 1500kVAr.

vi) Result for bus at 0.415kV

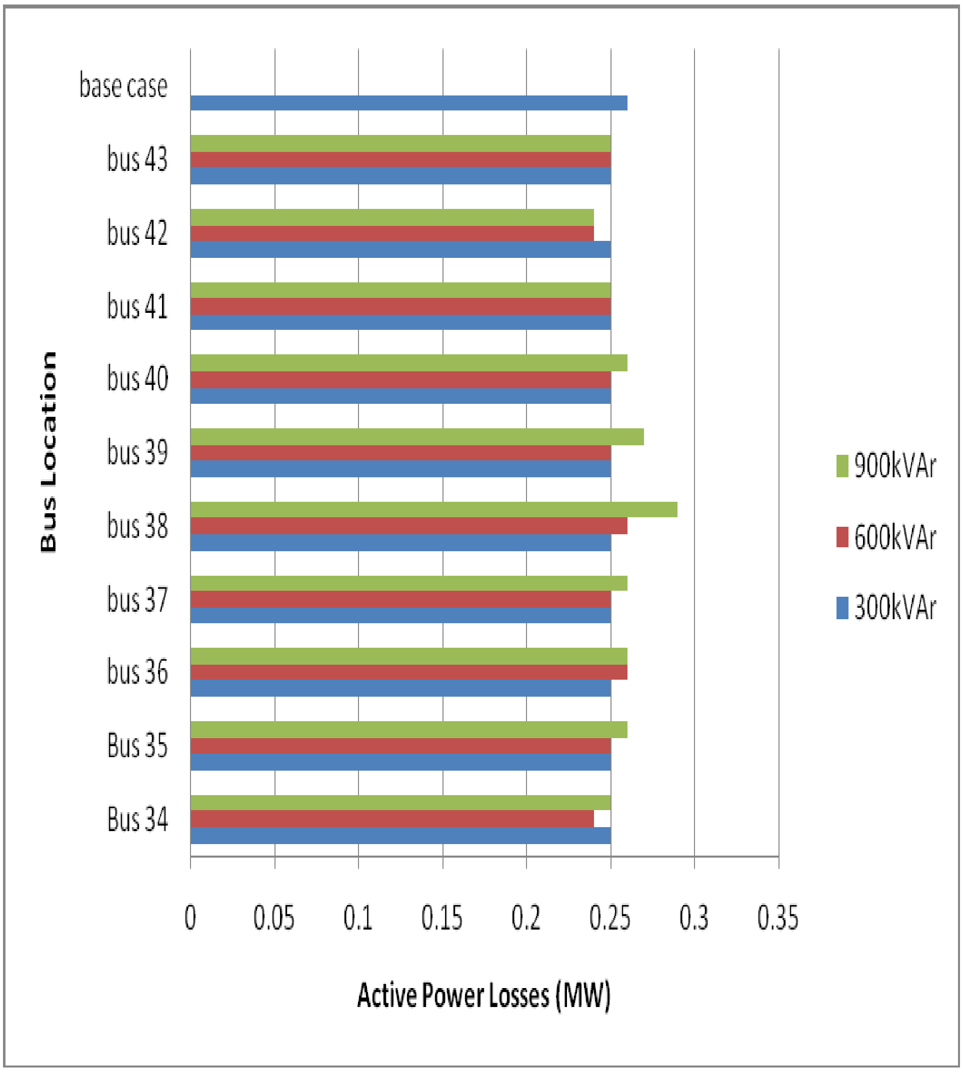


Figure 4.9(a): Active Power Losses (MW)

Note that;

X Axis: Active Power Losses (MW)

Y Axis: Bus Location

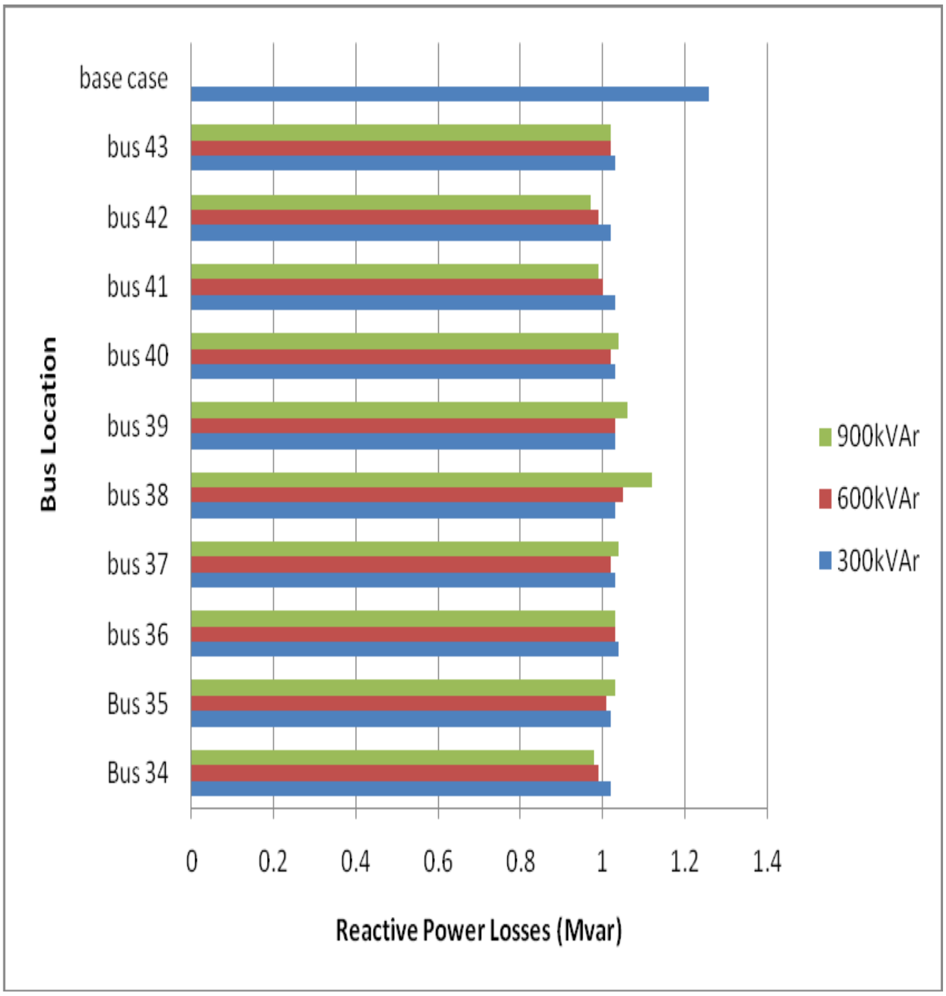


Figure 4.9(b): Reactive Power Losses (Mvar)

Note that;

X Axis: Reactive Power Losses (Mvar)

Y Axis: Bus Location

Based on the graph above, noted that the active and reactive power losses is decreased with injected of kVAr. But for the active power losses, the figure 4.9(a) shows increasing of the losses compared to the base case is 0.26MW respectively is 0.29MW and 0.27MW at the bus 38 and 39. This occurrence because of leading kVAr or called as over-corrected condition.

As for reactive power losses, figure 4.9(b) shows the lower of reactive power loss due to placement at bus 34 and 42, respectively is 0.98Mvar and 0.97Mvar compared to the base case is 1.26Mvar.

Based on the analysis above, noted that the decreasing and increasing of losses depend on the total of kVAr were injected to the system. Based on the voltage level at this system network, the load bus is suitable for capacitor placed compared to high voltage side. If we referring to the total losses at the 33kV and also at the load bus 0.415 kV, the load bus will give larger decreasing losses compared than the high voltage side.

Besides, the costing also must be taken into consideration in order to choose the capacitors to be placed. This costing included for the capacitors itself, also additional costing such as for maintenance and others.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

Many economic and operational benefits can be achieved by finding the optimal location and compensation levels of installation of capacitor bank in distribution systems. These benefits include reducing power losses and improving the power factor and voltage profile in addition to release of KVA. The capacitor location and compensation level problem was solved by using the optimal reduction of peak power losses.

The work thesis presented two approaches to determine the optimal location and compensation of capacitor banks based on two objectives. The first objective was to study the basic design of MV capacitor bank and the second is to analyze the approximation technique of allocation the capacitor bank. The two approaches will be used are practice and simulation technique to determine the suitable sizing for the allocation of the capacitor bank in the electrical network.

Based on the practice technique, they had analyzed voltage profile in order to get suitable size of the capacitor bank. The voltage profile will show the maximum and minimum value for the kVAr data respectively. Based on this data, then the capacitor bank will be designed with proper ways. This technique will save time compare doing in simulation.

Based on the simulation results, it can be concludes that the installation of capacitor bank at some potential locations will improved the power factor, which is 0.8 and above. Besides, this will reduce the total active and reactive system losses significantly. Also, the voltage drop constraints on the distribution feeder are keeping within permissible limit.

The installed capacitors support the voltage profile along the line during the peak hours, and then voltage reduction does not affected to the quality of the customer supply. The approximate method is capable of determining the proper placement and sizing of capacitor banks. However, it requires more computing time.

5.2 Recommendation

During this research, the optimal sizing and location of capacitor bank, improving power factor, reducing active and reactive system losses were investigated in this system. On the other hand, there are some recommended points that appeared as a result of this research, they are as follows:

1. The research was done by using only one technique which is approximate technique. A future work need to be carried out to find optimal sizing and location of capacitors using more developed methods compared to the existing technique.

2. Fixed capacitors were considered in this research. Switched capacitors could be studied in future work.

3. The static compensation applies for these cases of these studies, for the future work the dynamic compensation can be used as well.

4. In this studies only used one of the software, in future can be used other software in order to make comparison result between other software for more accuracy.

5. The various analyses can be done in future such as harmonics, short circuit and others in order to get detail analyze for the system.

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