

OPTIMAL LOCATION OF CAPACITOR BANK FOR POWER LOSSES
MINIMIZATION

ZIANA BT CHE ROS

A thesis report submitted in fulfillment of the requirement for the award of the Degree of
Master of Electrical Engineering

Faculty of Electrical and Electronics Engineering
Universiti Tun Hussein Onn Malaysia

JULY 2013

ABSTRACT

Power system consist of several components such are generations, transmission lines, distributions and loads. Each part consist of components that might encounter losses during their operations which then, can be divided into two categories: **technical losses** and **non-technical losses**. The main focus of this study is the technical losses that caused by the physical properties of components at transmission lines especially the MW loss and the Mvar loss. This thesis focused on the 9 Bus system analysis. Several studies have been conducted for this system which can be divided into two categories; The original setting (stable system) and the modified circuit for heavy loads setting where the loads capacity are increased to twice the value of the original setting. The purpose is to generate greater value of power losses. Thus, capacitor bank has been introduced to the system to minimize these losses. Several analysis have been done to determine the impact of installing the capacitor. Firstly, by varying the capacitor locations at all the busses in order to find the appropriate location of capacitor that might response to the power losses minimization the most. Record the MW losses and Mvar losses at each Busses and compare to the power losses of the original setting. This finally will show, which bus responses to the installed capacitor the most. Secondly, by varying the capacitor values installed at the effected bus in order to find the optimum range of the capacitor that will reduce Mvar losses the most. This Mvar range also can be calculated theoretically by applying an appropriate formula. The result is depending upon which capacitor value will decrease the power losses greatly. For acknowledgement, all the data and analysis are being done by the Powerworld Simulator Version 14 (student version). Finally, after completing all the analysis, the percentage of power losses reduction also can be determined theoretically . In fact, it can be concluded that many aspects to the capacitor compensation and its effects, depending on where capacitors get to be located, their sizes, and details of the distribution circuit.

ABSTRAK

Sistem kuasa terdiri daripada beberapa komponen asas seperti janakuasa, talian penghantaran, sistem pengagihan dan beban. Setiap satunya terdiri daripada komponen yang mungkin terdedah kepada kesan kehilangan kuasa Terdapat dua jenis kehilangan kuasa iaitu kuasa teknikal dan kuasa bukan teknikal. Fokus utama tesis ini adalah untuk menganalisa kehilangan kuasa teknikal yang terdapat di talian penghantaran umumnya dan kehilangan kuasa MW dan kehilangan kuasa Mvar khususnya pada sistem 9 bus. Pelbagai kajian telah dijalankan terhadap sistem ini yang boleh dikelaskan kepada sistem asal (system yang stabil) dan sistem yang telah diubahsuaikan dimana keperluan Mvar pada bebannya telah ditambah menjadi dua kali ganda daripada beban sistem yang asal. Ini bertujuan untuk menjana kehilangan kuasa yang banyak supaya kesan pemasangan kapasitor pada system dapat dikaji dengan lebih mendalam. Kapasitor telah diperkenalkan untuk mengurangkan kehilangan kuasa kepada system tersebut. Pelbagai analisa juga telah dilakukan untuk mengkaji kesan kapasitor terhadap pengurangan kehilangan kuasa. Pertama, dengan mempelbagaikan lokasi kapasitor keatas setiap bus bagi menentukan bus yang akan memberi tindakbalas yang besar terhadap kapasitor tersebut. Nilai kehilangan kuasa MW dan kehilangan kuasa Mvar direkodkan pada setiap talian penghantaran dan dibandingkan dengan kehilangan kuasa pada sistem yang asal. Kedua, dengan mempelbagaikan nilai kapasitor pada bus yang terkesan demi mencari julat optimum kapasitor yang akan digunakan. Beberapa nilai kapasitor telah digunakan ke atas bus yang dipilih bagi tujuan ini. Nilai kehilangan kuasa MW dan kehilangan kuasa Mvar direkodkan melalui perisian simulasi powerworld versi 14. Di akhir kajian ini, peratusan kadar pengurangan kehilangan kuasa dan julat Mvar yang sesuai juga dapat ditentukan melalui pengiraan berdasarkan penggunaan rumus yang sesuai. Secara keseluruhannya, didapati bahawa kesan kapasitor adalah bergantung kepada lokasinya dalam system kuasa,saiznya dan system pengagihan secara terperinci.

CONTENTS

TITLE	i
DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
ABSTRAK	vi
CONTENTS	vii
LIST OF TABLES	x
LIST OF FIGURES	xii
LIST OF SYMBOLS AND ABBREVIATION	xiii
LIST OF APPENDIX	xiv
 CHAPTER 1 INTRODUCTION	 1
1.1 Overview	2
1.2 Motivation and problem statement	4
1.3 Research objectives	6
1.4 Research scope	6
1.5 Research limitation	7
1.6 Thesis outline	7
 CHAPTER 2 LITERATURE REVIEW	 8
2.1 Introduction	8
2.2 Overview of power losses	8
2.3 Optimal location of capacitor bank	10

2.4	Power factor improvement	12
2.5	Calculation of KVar demand	14

CHAPTER 3 RESEARCH METHODOLOGY **18**

3.1	Introduction	18
3.2	Research methodology	18
3.3	Research flow chart	20

CHAPTER 4 RESULTS AND DISCUSSION **22**

4.1	Introduction	22
4.2	One-line diagram for original setting	22
4.3	Power flow result for original setting	23
4.4	Additional of MVar load demand	25
4.41	Case 1: Adding an extraMvar load deman at Bus no 5	26
4.5	Power flow result for “ Disturbed System “	26
4.6	Capacitor installation at power grid	29
4.7	One-line diagram for capacitor installation	29
4.8	Power flow resulted from capacitor installation	30
4.9	Variation of capacitor location	32
4.10	Power flow data for variation of capacitor location	32
4.11	Summary of power losses minimization at every busses	35
4.12	Variation of capacitor values	35
4.13	One-Line diagram for variation of capacitor values	36
4.14	Power Flow data for varioation of capacitor values	36
4.15	Summary of power flow data for variation of capacitor values	42
4.16	Graphically data presentation of variation of capacitor values	43
4.17	Percentage of power losses reduction	45

4.18	Determination of KVar rating	46
------	------------------------------	----

CHAPTER 5 CONCLUSION AND FUTURE WORK	48
---	-----------

5.1	Introduction	48
-----	--------------	----

5.2	Research conclusion	48
-----	---------------------	----

5.3	Future work	49
-----	-------------	----

REFERENCES	50
-------------------	-----------

APPENDIX A	52
-------------------	-----------



PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF SYMBOLS AND ABBREVIATIONS

V	-	Voltage
I	-	Current
R	-	Resistance
kW	-	Kilo-Watt
S	-	Apparent Power
PF	-	Power Factor
Q	-	Reactive Power
P	-	Active Power
SQRT	-	Square Root
Pmax	-	Maximum Power

LIST OF FIGURES

1.1	kW, kVar and kVA Vector	2
1.2	Power triangle	4
2.1	Block diagram of power system	8
2.2	Optimal location of capacitor bank	11
2.3	Improved power factor	13
3.1	Research flow chart	20
4.1	Schematic oneline diagram for the 9 busses	
	Power grid system	22
4.2	Graphical representation of MVAR losses at each busses	25
4.3	Schematic oneline diagram for “ disturbed system”	26
4.4	Graphical representation of the Mvar losses at each busses for case 1	27
4.5	Schematic oneline diagram with the installation of capacitor (243.8 Mvar) parallel to the load at bus no 5	30
4.6	Graphical representation of Mvar losses for the whole system	31
4.7	Graphical representation of Mvar losses for variation of bus location	35
4.8	Schematic oneline diagram for 50 Mvar capacitor at bus 5	36
4.9	Schematic oneline diagram for 100 Mvar capacitor at bus 5	38
4.10	Schematic oneline diagram for 150 Mvar capacitor at bus 5	40
4.11	Schematic oneline diagram for 300 Mvar capacitor at bus 5	41

LIST OF TABLES

2.1	Kvar multiplier	17
4.1	List of component of the original setting	23
4.2	Voltage (p.u) value at each busses	23
4.3	Power Flow (MW & MVAR) value at each busses	24
4.4	MVAR losses at each busses	24
4.5	Power Factor value at each busses	25
4.6	Voltage (p.u) values and the Mvar losses at each busses for case 1	27
4.7	MVA Flow at each busses for case 1	28
4.8	Power Factor at each busses for case 1	28
4.9	Comparison between Load at different MVar	29
4.10	Data for p.u voltage busses and the MVAR losses at each busses With Caps =200 Mvar	31
4.11	Data for Power Factor for the whole system	32
4.12	Mvar losses at each busses without the capacitor	32
4.13	Mvar losses at each busses with the capacitor located at bus 4	33
4.14	Mvar losses at each busses with the capacitor located at bus 5	33
4.15	Mvar losses at each busses with the capacitor located at bus 6	33
4.16	Mvar losses at each busses with the capacitor located at bus 7	34
4.17	Mvar losses at each busses with the capacitor located at bus 8	34
4.18	Mvar losses at each busses with the capacitor located at bus 9	34
4.19	Data for 50 Mvar : voltage (p.u) and Mvar losses at bus 5	37
4.20	Data for 50 Mvar : Power Factor at bus 5	37
4.21	Data for 50 Mvar : MVA flow at bus 5	37
4.22	Data for 100 Mvar : voltage (p.u) and Mvar losses at bus 5	38
4.23	Data for 100 Mvar : Power Factor at bus 5	39
4.24	Data for 100 Mvar: MVA flow at bus 5	39
4.25	Data for 150 Mvar : voltage (p.u) and Mvar losses at bus 5	40
4.26	Data for 150 Mvar: MVA flow at bus 5	40

4.27	Data for 300 Mvar : voltage (p.u) and Mvar losses at bus 5	41
4.28	Data for 300 Mvar : Power Factor at bus 5	42
4.29	Data for 300 Mvar: MVA flow at bus 5	42
4.30	The overall Power Factor data for each capacitor value	43
4.31	The overall Mvar Losses and Voltage (p.u) values each capacitor value	43
4.32	Graphical version for power factor	44
4.33	Graphical version for Mvar Losses	44
4.34	Graphical version for Voltage (p.u)	45
4.35	Power Factor With and Without capacitor installation	46
4.36	Data for Average value	47



CHAPTER 1

INTRODUCTION

1.1 Overview

Due to development of electrical power industry, power plants' planning in a way that they can meet the power network's load demands, is become one of the most essential and important issues in power systems. Calculations and analysis of transmission losses in these networks and efforts in finding methods to reduce losses in the lines are of great importance, since transmission lines connect generation and consumption centres in power networks. Although these calculations and analysis seem to be simple, they are very difficult in practice due to changes in transmitted power, power factors, voltages and resistance of conductors in the lines. Even though transmission losses in high voltage networks (transmission and sub-transmission) are less than low voltage ones (distribution), exact evaluation and proposing methods for loss reduction down to a desired and economic level is a necessary issue. So the loss origins should be identified and a proper model should be derived in order to have calculations' results closer to the real situation in power networks.

Generally, in all industrial electrical distribution systems, the major loads are resistive and inductive. Resistive loads are incandescent lighting and resistance heating. In case of pure resistive loads, the voltage (V), current (I), resistance (R) relations are linearly related, i.e. $V = (I \times R)$ and Power (kW) = $(V \times I)$ [17]. The typical inductive loads are A.C. Motors, induction furnaces, transformers and ballast-type lighting. Commonly, Inductive loads require and active power which is used to perform the work and the other is the reactive power that is used to create and

maintain electro-magnetic fields. Active power is measured in kW (Kilo Watts). Reactive power is measured in kVAR (Kilo Volt-Amperes Reactive). The vector sum of the active power and reactive power make up the total (or apparent) power used. This generated power is being used to perform a given amount of work. Total Power is measured in kVA (Kilo Volts-Amperes). Figure 1.1 shows the vector relationship between the active power and the reactive power which as a resultant will produce the generated apparent power (S) to the power system.

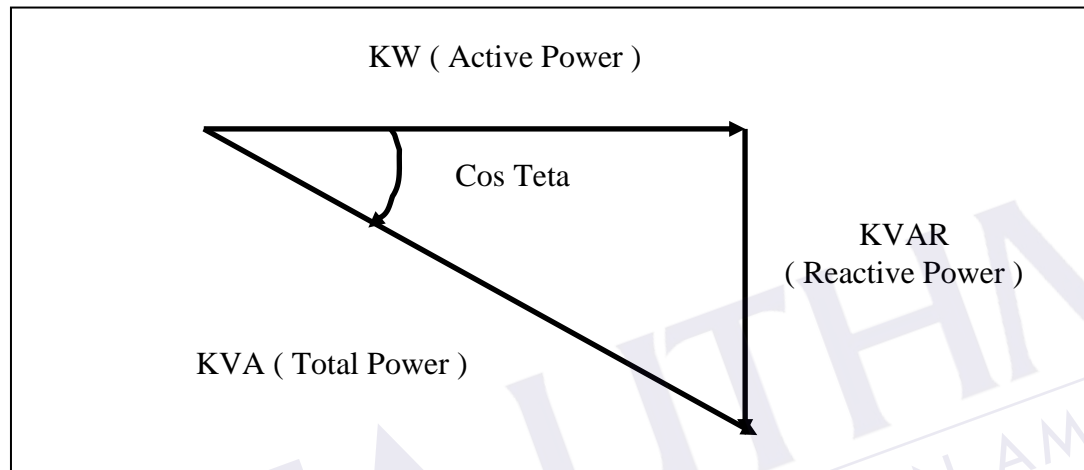


Figure 1.1 : kW, kVAR and kVA Vector

The active power which is the shaft power required or true power required in kW and the reactive power required (kVAR) are 90° apart vectorically in a pure inductive circuit i.e., reactive power kVAR lagging the active kW. The vector sum of the two types of power is called the apparent power (S) denoted as kVA, as illustrated in Figure 1.1. This kVA power reflects the actual electrical load on distribution system. The ratio of kW to kVA is called the power factor (pf), which is always less than or equal to unity. Theoretically, when electric utilities supply power, if all loads have unity power factor, maximum power can be transferred for the same distribution system capacity. However, as the loads are inductive in nature, with the power factor ranging from 0.2 to 0.9, the electrical distribution network is stressed for capacity at low power factors.

Generally, energy loss at transformer and transmission lines can be categorized as resistive loss and reactive loss. The former loss is caused by the resistive component of the load and can't be avoided and the other loss is caused by the reactive component of the load and can be minimized or even avoided. In fact,

this study is more concerned on the reactive loss which come from circuit capacitance and circuit inductance. For example, when a heavy inductive load is connected to the grid, it means that a large positive reactive power component is being added. And thereby increased the observed power (S). Such increased in observed power can lead to several impact to the power system such are ;

- (a) Increases losses due to reactive load current
- (b) Increases in KVA demand
- (c) Increases customer energy consumption
- (d) Degrade voltage profile
- (e) Reduce revenue.

Hence, there are several methods for this losses compensation. For example, by improving power factor, installing capacitor bank , applying material selectivity and FACT Device. In fact, studies have shown that when capacitors of appropriate size are added to the grid at appropriate locations, the above mentioned losses can be minimized by reducing the reactive power component, thereby reducing the observed power demand [6]. Fortunately, the focus of this studies is to locate the optimal location and size of the needed capacitor to be installed in the power grid in order to reduce the unwanted power.

It goes without saying that, the most obvious power dissipated in transmission lines are due to their internal electrical resistance which is called the technical losses [10]. These losses are easy to simulate and calculate. In fact, computation tools for calculating power flow and power losses in power systems have been developed for some time. In this thesis, a simple power flow and power losses calculation is simulated by a very helpful and effective software namely as Power-world Simulator Version 14 (Student Version).

This user-friendly software is implemented and practically used to determine not only the power losses at transmission lines but also to analyse the optimal location of installing the capacitor banks in order to minimize the unwanted losses on the 9 Bus power grid systems. Indeed, the losses are being analyzed by adding capacitor bank to the affected Bus. The impact of adding capacitor bank is then simulated by implementing the tools provided by Power-world simulator software. The results of those simulations are recorded and being discussed in details on the chapter of Data Analysis. By analyzing the gained data, not only , the optimal location and size of the capacitor can be determined in order to minimize the power

losses of the system but also the percentage of power losses reductions can then be calculated. Furthermore, in addition to that, this study also can predict the range of the capacitor values in order to improve the demand power factor.

1.2 Motivation and problem statement

The power triangle and its components can be best illustrated as shown in Figure 1.2.

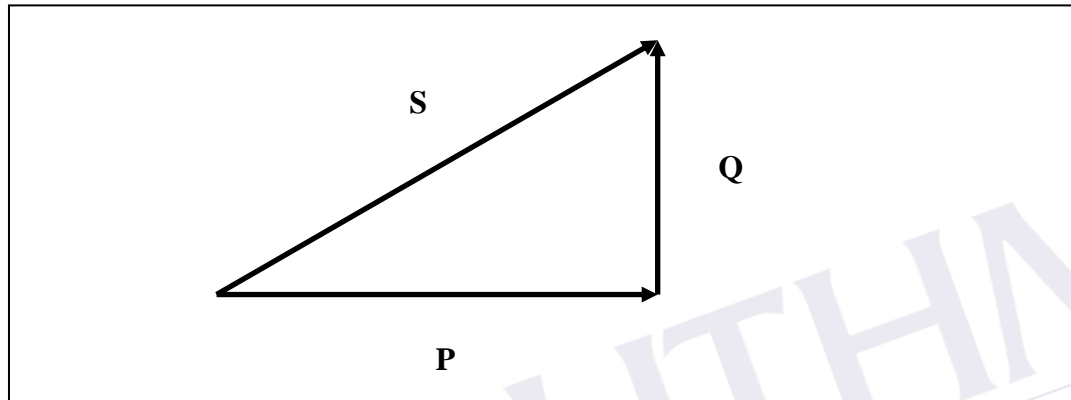


Figure. 1.2 : Power triangle

The Active power (P), also known as working power, is the energy converted into useful work. Apparent power (S), on the other hand, is the total energy consumed by a load or delivered by the utility. The power that is not converted into useful work is called reactive power (Q). However, this power is needed in order to generate the magnetic field in inductors, motors, and transformers. Nevertheless, it's undesirable because it causes a low power factor. A low power factor means a higher apparent power, which translates into excessively high current flows and inefficient use of electrical power. These currents cause elevated losses in transmission lines, excess voltage drop, and poor voltage regulation.

Power factor is given by the proportion of active power (P) to apparent power (S), as shown in Figure 1.2. So power factor is the proportion of power converted into useful work to the total power consumed by the loads or delivered by the power source. Improving power factor can reduce system and conductor losses, boost voltage levels, and free up capacity. However, improper techniques can result in over-correction, under-correction, and/or harmonic resonance, so it can be helpful to understand the process for determining the correct methods of sizing capacitors for

various applications. It's also important for calculating the values of system and conductor losses, power factor improvement, voltage boost, and freed-up system capacity (kVA) you can expect to realize from their installation.

The most common method for improving power factor is to add capacitors banks to the system. Capacitors are attractive because they're economical and easy to maintain. Not only that, they have no moving parts, unlike some other devices used for the same purpose. A power triangle as shown in Figure 1.2 is used to represent the proportion and calculate the reactive power, using the Pythagorean Theorem as stated in the equation (1.1) .

$$S^2 = P^2 + Q^2 \quad (1.1)$$

For example, suppose you have a load with a power factor of 0.95. What does this mean? Basically, it means that the load consumes 95% of the apparent power and converts it into work. But how much is reactive power? The answer is , by using the power triangle and the Pythagorean Theorem stated in equation (1.1), the value can be determined as follows:

$$Q = \sqrt{S^2 - P^2} \quad (1.2)$$

$$Q = \sqrt{100^2 - 95^2} = 31.225$$

If power factor (PF) is corrected to 1.0, then reactive power=0 and apparent power = $\sqrt{95^2 + 0^2} = 95$. This demonstrates an actual reduction of energy consumption and peak demand of 5% (100kVA-95kVA= 5kVA). An ideal power factor is unity (1.00), which means that the load is using 100% of the power to perform actual work. However, power losses is inevitable and increases at transmission lines. These increases losses are due to reactive load current. In order to minimize such losses, adding the capacitor bank with appropriate value and size at an appropriate location is tremendously will cause the percentage of power losses reductions become higher.

In this study, the one-line diagrams of 9 Bus systems provided by the tools are being altered technically such as varying the loads capacities of the systems and the value of capacitor bank used at various location. All the data required for analysing all the losses are being recorded in tabulated form. Then, by implementing Power-world simulator tool , recalculate the losses for each modification that have

been done to the system in order to study the impact of adding the capacitor banks to the power grid. The power flow and power losses calculation are recorded. The analysis are done by considering the losses before installing the capacitor and after installing the required capacitor to the grid. Technically, all the calculation and analysis of power losses of the system will be done by using Power-world simulator tool version 14 (student version).

1.3 Research objectives

There are several objectives that need to be completed at the end of this project.

- (a) To determine the optimal location of Capacitor Banks in minimizing power losses.
- (b) To determine the appropriate size of the capacitor banks.
- (c) To calculate the percentage of power losses reduction of the selected system.
- (d) To estimate the suitable value of Kvar in order to get the desired power factor.
- (e) To configure all the calculation in minimizing the power losses by applying the tools that are provided by Power-world Version 14 (Student version) software.

1.4 Research scopes

This study will focus on the 9 Bus power grid system offered by the simulator tool. The systems then, will be disturbed by introducing the heavy inductive load Kvar demand by doubling the size of the loads capacity at the selected Bus. The study will concentrate on the MW and Mvar Power Losses created at transmission lines. Basically, power losses are caused by several effects such as copper loss, reactive loss and dielectric loss. Hence, in this studies, such losses can only be minimized by power factor correction and by installing the capacitor bank at various size and location to the power grid system. All calculations and analysis are being practically done by implementing the Power-world simulator tool version 14 (student Version).

1.5 Research limitation

The following assumptions will be taken into account during simulation :

- (a) The simulations experiment assumed perfect simulation
- (b) Outside interference from other technologies are negligence.
- (c) The values of the capacitor are randomly selected.
- (d) The chosen bus to install the capacitor is based on the greatest losses shown by the power world simulator.

1.6 Thesis outlines

This report is structured into five chapters.

Chapter 1 discusses the background of the research, the objectives of the studies, the problem statements, the scope and limitation of the research and also the expected outcomes gained from the studies.

Chapter 2 consists of the literature review of the previous researches and findings related to the power losses minimization by capacitor installation.

Chapter 3 consists of all the research methodology that will be carried out throughout the studies.

Chapter 4 consists of all data, analysis of the research and discussion of thesis findings.

Chapter 5 consists of the conclusion and future work for the related studies.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes some overview of power losses at power grid system. Many researchers have done several studies regarding this power losses issues. In fact, these issue will be discussed in detail in the following sub topics.

2.2 Overview of power losses

Power distribution from electric power plants to ultimate consumers is accomplished via the transmission sub transmission, and distribution lines. Figure 2.1 illustrates the basic elements of a power system block diagram.

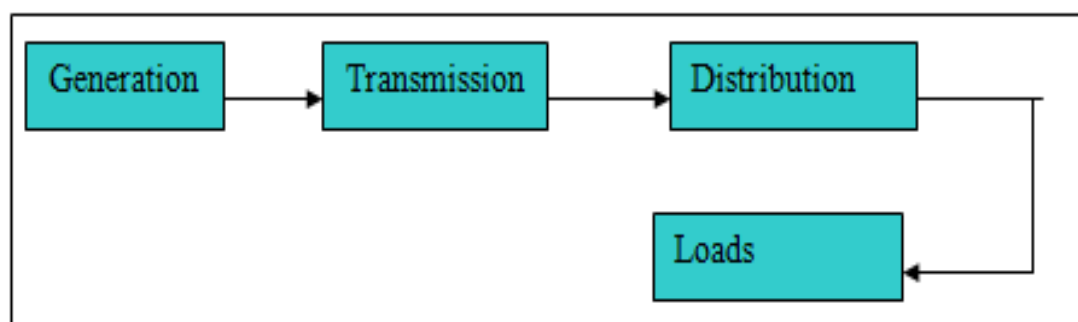


Figure 2.1: Block diagram of power system

The transmission and distribution system delivers electricity from the generating site (electric power plant) to residential, commercial, and industrial facilities. These distribution networks comprise overhead lines, cables, transformers, switchgear and other equipment to facilitate the transfer of electricity. However, power losses are inevitable in power system analysis. According to a “Consultation Document (2003) entitle “ Electricity Distribution loss “, on the average, around 7 percent of electricity transported across local distribution systems is reported as electrical losses. In fact, the level of reported losses in any given year will be influenced by a number of factors , both technical and operational. Hence, these losses will creates several consequences such as the following listed details [5];

- (a) Less electricity being transmitted to the loads
- (b) Generation parts has to generate more power which then causes another type of losses- require more financial & equipment support.
- (c) Reducing energy consumption in the residential and commercial sectors
- (d) Limits the transfer capability of a system - become less efficient.
- (e) No maximum power transfer due to the losses created.
- (f) Power Factor decreases which then create more losses .
- (g) Increases losses due to reactive load current thus, increases kVA demand, increases customer energy consumption, usually degrades voltage profiles, and reduces revenue.

In fact, studies have indicated that as much as 13% of total power generated is consumed as RI^2 losses at the distribution level.[1] The RI^2 losses can be separated to active and reactive component of branch current, where the losses produced by reactive current can be reduced by the installation of shunt capacitors. It goes without saying, that many researchers also interested in finding the practical method to minimize power losses. By referring to Gustavo Brunello, Dr Bogdan Kasztenny & Craig Wester (2003), shunt capacitor banks are used to improve the quality of the electrical supply and the efficient operation of the power system.

2.3 Optimal location of capacitor bank

Commonly, the shunt capacitors are used to supply a capacitive type-Leading VAR reactive power to the AC Power system at the point of connection for several advantages such are ;

- (a) To reduce the lagging component of the circuit current
- (b) To increase the voltage of the load bus
- (c) To improve bus-voltage regulation and /or power factor
- (d) To reduce transmission losses and
- (e) To reduce Electricity Billing cost based on KVA Demand [1].

In addition to that, capacitors are widely used in distribution systems to reduce energy and peak demand losses, release the KVA capacities of distribution apparatus and to maintain a voltage profile within permissible limits. The power capacitor can be considered to be a VAR-GEN (reactive power Source), since it actually supplies needed-magnetizing current requirements for inductive loads.[3] The fundamental function of power capacitor is to provide needed reactive power compensation. Furthermore, the objective of optimal capacitor placement problem is to determine the size, type, and location of capacitor banks to be installed on radial distribution feeders to achieve positive economic response. The economic benefits obtained from the loss reduction weighted against capacitors costs while keeping the operational and power quality constraints within required limits.

The capacitor location or placement for low voltage systems determines capacitor type, size, location and control schemes. The optimal capacitor placement is generally a hard combinatorial optimization problem that can be formulated as a nonlinear/search minimization problem.[6] Almost all the methods to solve capacitor placement problems are based on the historical data of the load models and associated cost of the energy and the cost of capacitor banks. The cost \$/Kvar for power savings and losses (power losses/energy losses) . However, historical data and load models are uncertain and may change in reality. In general, capacitor placement problems can be solved in two steps.[8] The first step is the use of load flow model and find the V,P,Q at all the buses and also the feeder losses . The second step is to minimize the cost function-Jo-min - subject to constraints, like practical limits of voltage and capacitor size.

Many of the previous strategies for capacitor allocation in the literature are also limited for the application to planning, expansion or operation of distribution systems.[6] Very few of these capacitor allocation techniques have the flexibility of being applicable to more than one of the above problems. Hence, this paper presents a powerWorld simulation approach to determine the suitable locations for capacitor placement and the sizing of the capacitor. This approach has the versatility of being applied to the planning, expansion, and operation studies of distribution systems. The proposed method was tested on electrical distribution systems consisting of 9 buses power grid system.

Theoretically, in the case of concentrated industrial loads, there should be a bank, sized to almost equal the reactive load current, located as close to each load as possible.[6] Figure. 2.2 shows the block diagram of the best location of capacitor proposed for losses minimization.

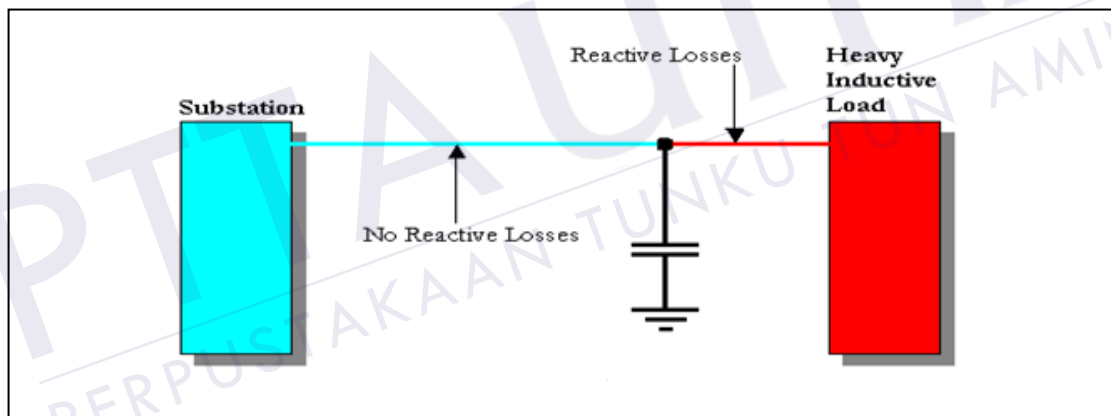


Figure 2.2 : Optimal location of capacitor bank (H.N.Ng.M.M.A.Salama ,1995)

When capacitors of appropriate size are added to the grid at appropriate locations, the power losses can then be minimized by reducing the reactive power component in , thereby reducing the observed power demand. [8]Indeed, there are many aspects to this compensation and its effects, depending on where capacitors get to be located, what are the optimal sizes , and the details of the distribution circuit. Obviously properly switched capacitors located at appropriate locations along distribution feeders provide great financial benefits to the utility[12]. In addition, if there is to be only one capacitor bank on a uniformly loaded feeder, the usual two-thirds, two-thirds rule gives optimum loss and demand reduction [19]. This means

that the bank kVAr size should be two-thirds of the heavy load kVAr as measured at the substation, and the bank should be located two-thirds the length of the feeder from the substation. If the objective is voltage control the bank should be farther from the substation. With several banks on a uniformly loaded feeder, the total capacitor kVAr can more closely match the total load kVAr. Depending on the type of the switching control used, multiple banks on a feeder can lead to 'pumping' as the controls affect the operating points of each other[10]. Usually no more than three or four banks are used per feeder. In fact, in the case of concentrated industrial loads, there should be a bank, sized to almost equal the reactive load current, located as close to each load as possible.[6]

2.4 Power factor improvement

The importance of installing the capacitor is also to improve the power factor. The solution to improve the power factor is to add power factor correction capacitors to the plant power distribution system. They act as reactive power generators, and provide the needed reactive power to accomplish kW of work. This reduces the amount of reactive power, and thus total power, generated by the utilities.[4]

For example: A chemical industry had installed a 1500 kVA transformer. The initial demand of the plant was 1160 kVA with power factor of 0.70. The % loading of transformer was about 78% ($1160/1500 = 77.3\%$). To improve the power factor and to avoid the penalty, the unit had added about 410 kVAr in motor load end. This improved the power factor to 0.89, and reduced the required kVA to 913, which is the vector sum of kW and kVAr . Figure 2.3 shows the mathematical representation on how to calculate the improved power factor.

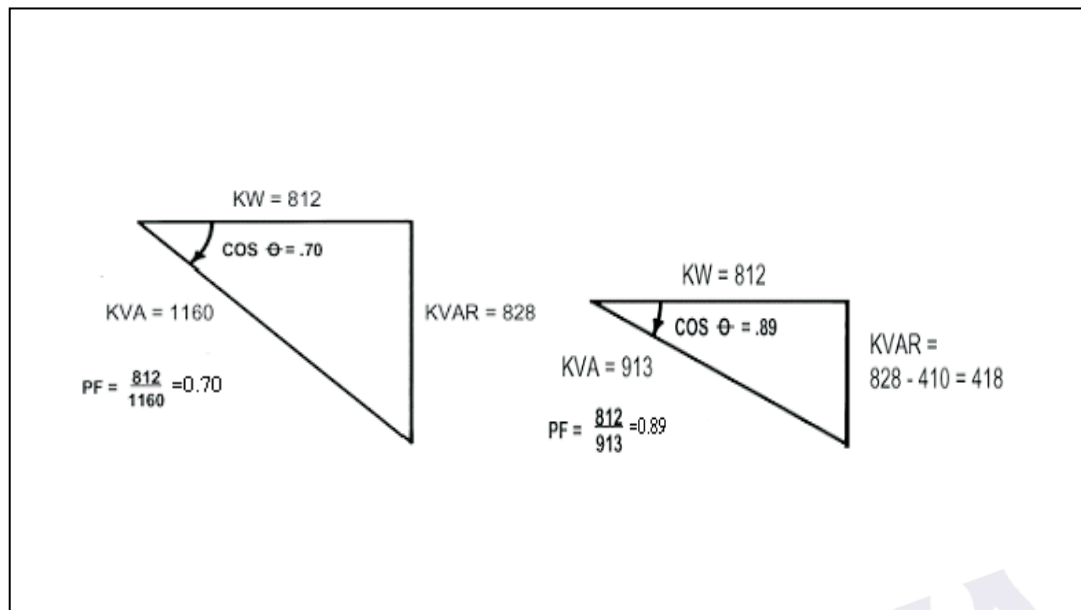


Figure 2.3: Improved power factor (Dr. G. Thomas Bellarmine ,1997)

There are several advantages of PF improvement by capacitor addition as listed below: [3]

- (a) The reactive component of the network is reduced and so also the total current in the system from the source end.
- (b) The I^2R power losses are reduced in the system because of reduction in current.
- (c) The voltage level at the load end is increased.
- (d) The kVA loading on the source generators as also on the transformers and lines up to the capacitors reduces giving capacity relief.

Indeed, a high power factor can help in utilising the full capacity of your electrical system. Installing capacitors at appropriate location will help to reduce loss reduction within the plants distribution network as well and directly benefit the user by reduced consumption. Reduction in the distribution loss % in kWh when tail end power factor is raised from PF1 to a new power factor PF2, will be proportional to the below stated equation (2.1) .[18]

$$\left[1 - \left(\frac{PF_1}{PF_2} \right)^2 \right] \times 100 \quad (2.1)$$

2.5 Calculation of KVar demand

Determining the capacitor kVAR requirement is also vital in this studies in order to ensure that power system is operating at optimal efficiency. Generally, to calculate the capacity, in kVAR or MVAR of the capacitor bank needed to improve power factor from pf_1 (actual power factor) to pf_2 (target power factor) can be done by using the following equation (2.2).[18]

$$Q_{cap} = P \times [(\sqrt{1 - pf_1^2})/pf_1 - (\sqrt{1 - pf_2^2})/pf_2] \quad (2.2)$$

The above mentioned formula can only be used if the active power is constant. But when active power isn't constant, you must consider other factors. You should consider the average value of the active power (P) as well as the average power factor in the facility[18]. Using these two values, you can calculate the capacitor bank for the average operating condition. You should also consider the worst case operating conditions (highest active power and lowest power factor). All the three mentioned methods are being discussed in detail as the following .

a) Calculating the kVAR requirement based on maximum active power.

Looking at the preceding equation, you can see that either of two factors can cause the calculated value of reactive power of the capacitor bank to be less than the value required: The active power (P) is higher than the average value used in equation (2.2). The power factor (pf_1) is lower than the average value used in the given equation (2.2). Taking this into account, you need to re-calculate the reactive power requirement of the capacitor bank using the maximum active power in the system and the power factor measured under this operating condition. Equation (2.2) can now be expressed as:

$$Q_{cap} = P_{max} [(\sqrt{1 - pf_1^2 - P_{max}})/pf_{1-P_{max}} - (\sqrt{1 - pf_2^2})/pf_2] \quad (2.3)$$

where P_{max} is the maximum active power in the facility and $pf_{1-P_{max}}$ is the power factor in the facility when the active power is P_{max} [18] . If the reactive power

requirement for the capacitor bank, as calculated using equation (2.3), is greater than the average value previously calculated using equation 1, then the capacitor bank sized for the average value won't be sufficient for compensating the reactive power of the load when the active power reaches its maximum value.[6] As a result, the power factor in the facility won't reach the target value. In this case, you should select the capacitor based on the maximum active power and the actual power factor under that operating condition

b) Calculating the kVAR requirement based on minimum power factor.

The next consideration is to calculate the capacitor bank needed when the power factor is minimum. The calculation can be done by using the following equation (2.4).

$$Q_{cap} = P_{pf1min} [(sq\ rt\ (1 - pf_1^2)_{min})/pf_{1min}) - (sq\ rt\ (1 - pf_2^2)/pf_2)] \quad (2.4)$$

where pf_{1min} is the minimum power factor measured in the facility and P_{pf1min} is the active power when the power factor is pf_{1min} . If the two previously calculated values (average and maximum active power conditions) are less than the value calculated using equation (2.3), the capacitor bank kVAR previously determined using equation (2.1) or equation (2.2) won't be sufficient to compensate for the reactive power of the load when the power factor reaches its minimum value, and the power factor in the facility won't reach the target value. In this case, you should select the capacitor based on the minimum power factor as calculated in equation (2.4). Generally, the best value of capacitance will be the greater of all calculations above, because the capacitor bank will have the capacity for compensating for the maximum active power condition as well as minimum power factor condition. Automatic capacitor banks can ensure high power factor under widely varying operating conditions.[3]

c) Direct relation for capacitor sizing.

equation (2.5) states the formula of the kVAr Rating is equal to :

$$\text{kVAR rating} = \text{kW} [\tan \phi_1 - \tan \phi_2] \quad (2.5)$$

Where kVAR rating is the size of the capacitor needed, kW is the average power drawn, $\tan \phi_1$ is the trigonometric ratio for the present power factor, and $\tan \phi_2$ is the trigonometric ratio for the desired PF. Equation (2.6) illustrates the meaning of all the angles.[3]

$$\phi_1 = \text{Existing (Cos-1 PF1)} \text{ and } \phi_2 = \text{Improved (Cos-1 PF2)} \quad (2.6)$$

d) Alternatively the table 2.1 can be used for capacitor sizing.

The tabulated data shown in Table 2.1 are the multiplication factors which are to be multiplied with the input power (kW) to give the kVAR of capacitance required to improve present power factor to a new desired power factor.[3]. Generally, the procedure of using Table 2.1 are as follows:[22]

- (a) Locate 0.72 (original power factor) in column (1).
- (b) Read across desired power factor to 0.95 column. We find 0.635 multiplier
- (c) Multiply 627 (average kW) by 0.635 = 398 kVAR.
- (d) Install 400 kVAR to improve power factor to 95%.

TABLE 1: MULTIPLIERS TO DETERMINE CAPACITOR KVAR REQUIRED FOR POWER FACTOR CORRECTION

Original Power Factor	Desired Power Factor																				
	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.0
0.50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.589	1.732
0.51	0.937	0.962	0.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1.544	1.687
0.52	0.893	0.919	0.945	0.971	0.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	0.850	0.876	0.902	0.928	0.954	0.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.457	1.600
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1.416	1.559
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.093	1.124	1.156	1.190	1.227	1.268	1.316	1.376	1.517
0.56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.054	1.085	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.619	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.006	1.040	1.077	1.118	1.166	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.938	0.970	1.004	1.041	1.082	1.130	1.190	1.333
0.61	0.549	0.575	0.601	0.627	0.653	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.646	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.807	0.838	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.474	0.503	0.529	0.555	0.581	0.608	0.634	0.661	0.689	0.717	0.745	0.775	0.806	0.838	0.872	0.909	0.950	0.998	1.068	1.211
0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.966	1.026	1.169
0.66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.626	0.654	0.682	0.712	0.743	0.775	0.809	0.846	0.887	0.935	0.995	1.138
0.67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.965	1.108
0.68	0.328	0.354	0.380	0.406	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.786	0.827	0.875	0.935	1.078
0.69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.906	1.049
0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.371	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	0.936
0.74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.578	0.626	0.685	0.829
0.78	0.052	0.078	0.104	0.130	0.156	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
0.80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.609	0.750
0.81	0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724	
0.82	0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.555	0.698		
0.83	0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.529	0.672			
0.84	0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646				
0.85	0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620					
0.86	0.000	0.026	0.053	0.081	0.109	0.137	0.167	0.198	0.230	0.264	0.301	0.342	0.390	0.450	0.593						
0.87	0.000	0.027	0.055	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567							
0.88	0.000	0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540								
0.89	0.000	0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512									
0.90	0.000	0.028	0.058	0.089	0.121	0.155	0.192	0.233	0.281	0.341	0.484										
0.91	0.000	0.030	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456											
0.92	0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426												
0.93	0.000	0.032	0.066	0.103	0.144	0.192	0.252	0.395													
0.94	0.000	0.034	0.071	0.112	0.160	0.220	0.363														
0.95	0.000	0.037	0.079	0.126	0.186	0.329															
0.96	0.000	0.041	0.089	0.149	0.292																
0.97	0.000	0.048	0.108	0.251																	
0.98	0.000	0.060	0.203																		
0.99	0.000	0.143																			
	0.000																				

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The chapter focuses on how to analyse power losses by using powerworld simulator. It also describes general step by step methodology , designing stage , important parameters and assumptions that are considered. The research methodology of this studies can be illustrated as shown in Figure 3.1

3.2 Research Methodology

The project started with the initiative in drawing one-line diagram of 9 buses power grid system with certain rated value of components needed as suggested by the simulator tool. It consists of three units of generator and four units of load busses. All the drawings are being done by applying the Powerworld tools. Upon completion, record all the data regarding the Voltage (pu), Mvar losses , MW and MVA at each busses by using Powerworld simulator version 14 .Then calculate theoretically, the value of power factor of each busses for the whole system. As a result , the bus that shows the greatest Mvar losses can be determined. In other words, these are the results for the system that are originally in stable condition. The project also being further analysed by categorizing the analysis by cases.

For case 1, the value of the load Mvar demand at the selected bus resulted from the previous findings is double the original size. This is to show more convincing result or Mvar losses at the bus. Again, record all the data regarding the Voltage (pu), Mvar losses, MW and MVA at each busses. Then calculate the value of power factor of each busses for the whole system. Determine the bus that shows the greatest Mvar Losses.

After determining the effected bus, install capacitor parallel to the load at the selected bus. Record all the data regarding the Voltage (pu), Mvar losses, MW and MVA at each bus with capacitor installation by using Powerworld simulator version 14. Then calculate the value of Power Factor for the whole system.

For case 2, varies the location of capacitor at each busses in order to indicate the optimal location for power losses minimization. Record all the MVar losses for each location of capacitor installation. Compare all the Mvar losses values for each installation. The best location of capacitor is based on the busses that shows the reduction of Mvar losses the most.

For case 3, the capacitor values are varies at selected bus. This is to estimate the capacitor range needed for power losses minimization technique. The purpose of variation of the capacitor value at selected bus is to find the optimal rating and size of the capacitor installed. Then, record all the data regarding the Voltage (pu), Mvar losses, MW and MVA for each Mvar variations. Variation of capacitor values are chosen from 50 MVar ~ 300 Mvar.

Finally, do all the analysis required to find the optimal capacitor location in order to minimize power losses, determine the appropriate size and rating for the above capacitor, calculate the % of power losses reduction for the power system and calculate the KVar rating for the desired Power Factor. In general, all the above mentioned procedure can be best illustrated by the following flow chart drawn in Figure 3.1.

3.3 Research Flow Chart

Figure 3.1 shows the overall process flow of this studies.

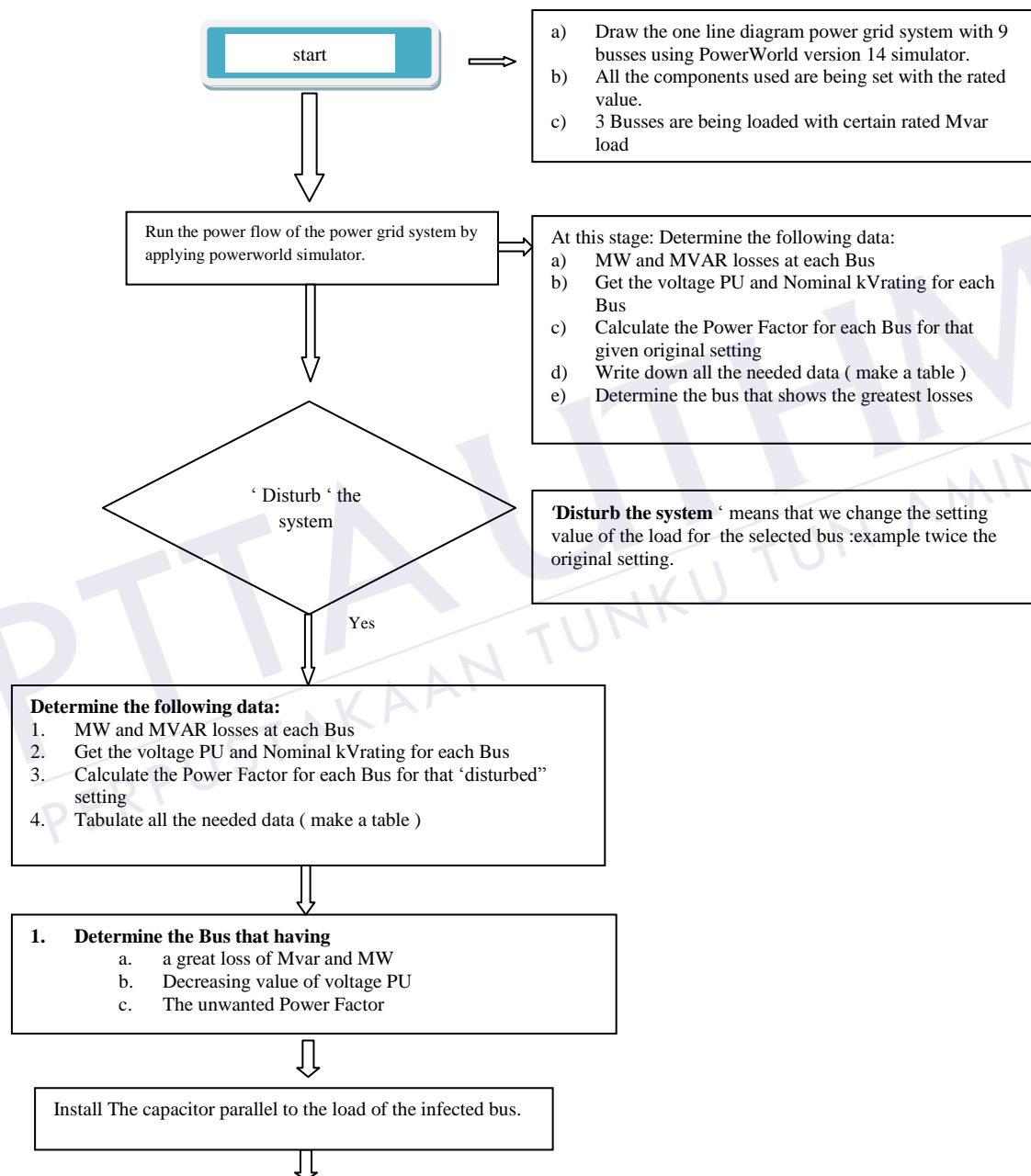


Figure 3.1 : Research Methodology Flow Chart

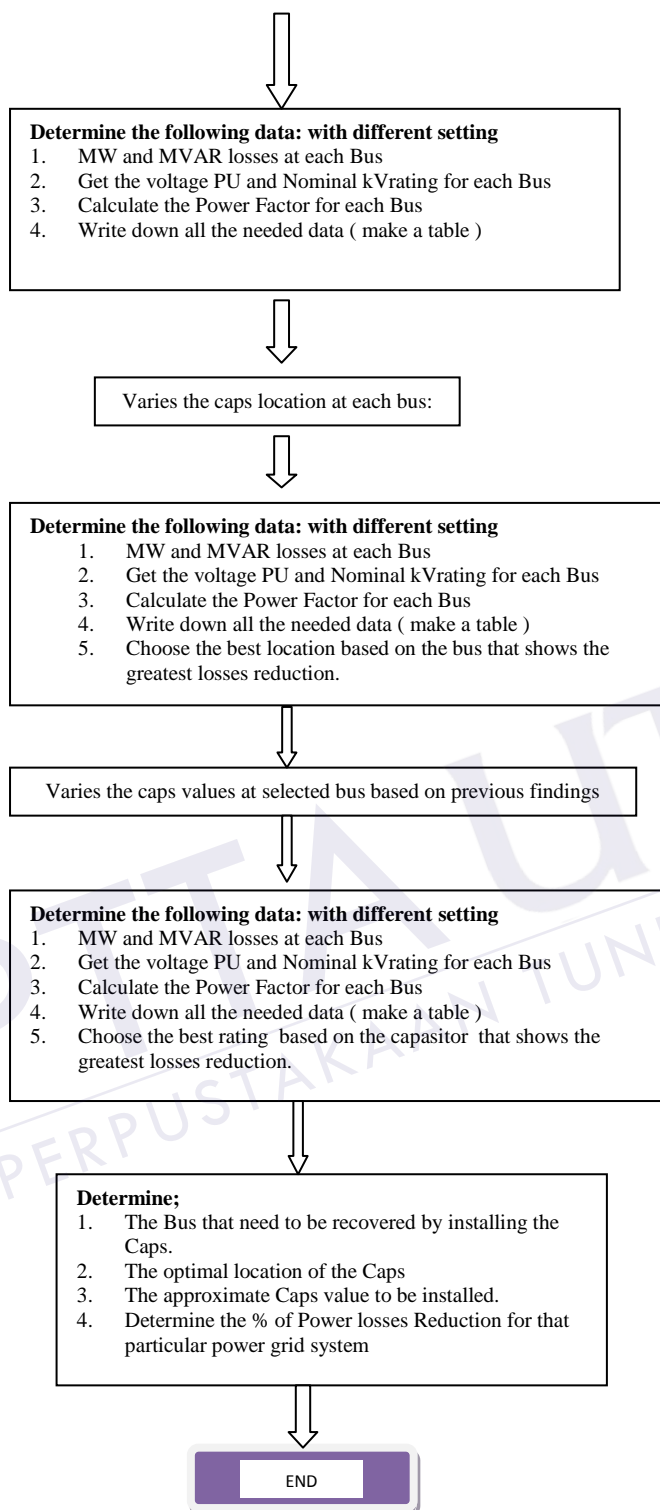


Figure 3.1 : Research Methodology Flow Chart (continued)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter describes in details what are the findings outlined for this project. It also discusses thoroughly the meaning of all the findings.

4.2 One-line diagram for original setting

Figure 4.1 shows the schematic one-line diagram for the original setting of the 9 busses power grid system drawn by using the powerWorld simulator tools.

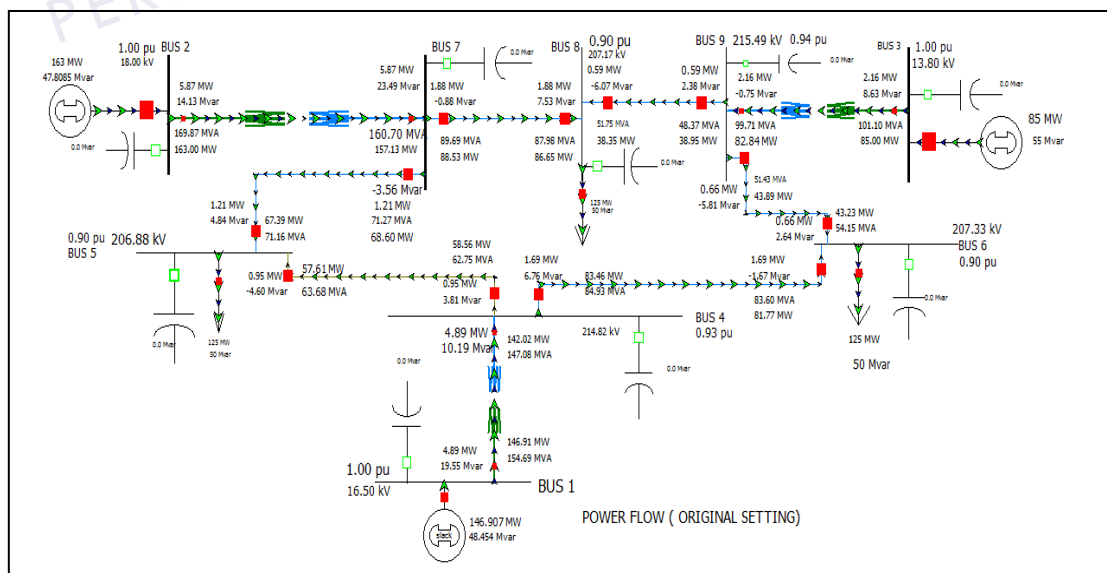


Figure 4.1: Schematic one-line diagram for the 9 Busses power grid system.

All the component values are set by the tools according to the IEEE one-line diagram provided. Table 4.1 shows all the components value for the original setting in tabulated form.

Table 4.1 : List of component of the original setting

Original setting			Original setting				Original setting			
Component	MW output	Mvar output	Bus No	Nominal Voltage (kV)	Bus p.u	angle	Line	line voltage (kV)	R (p.u)	X (p.u)
Generator 1	147.89	0	1	16.5	1.000	0.000	1 to 4	16.5 - 230	0.02	0.08
Generator 2	163	0	2	18.0	1.000	0.663	4 to 6	230 - 230	0.02	0.08
Generator 3	85	0	3	13.8	1.000	-5.348	4 to 5	230 - 230	0.02	0.08
			4	230.0	0.974	-6.927	5 to 7	230 - 230	0.02	0.08
			5	230.0	0.896	-9.397	6 to 9	230 - 230	0.02	0.08
			6	230.0	0.962	-11.033	9 to 3	230 - 13.8	0.02	0.08
			7	230.0	1.009	-7.219	9 to 8	230 - 230	0.02	0.08
			8	230.0	1.068	-12.066	8 to 7	230 - 230	0.02	0.08
			9	230.0	1.013	-9.579	7 to 2	230 - 18	0.02	0.08

4.3 Power flow results for original setting

After simulating the original setting for the power grid system, all the data gained regarding the Voltage (pu), MW and MVA and Mvar losses at each busses are recorded in tabulated forms. Then, the value of power factor of each busses for the whole system are also calculated theoretically. The following Table 4.2, Table 4.3, Table 4.4 and Table 4.5 show all the data obtained by powerworld simulator tool respectively.

Table 4.2: Voltage (p.u) value at each busses

PU VALUE VOLTAGE BUS		
BUS NO	PU	KV
1	1.000	16.500
2	1.000	18.000
3	1.000	13.800
4	0.930	214.820
5	0.900	206.880
6	0.900	207.330
7	0.930	214.560
8	0.900	207.170
9	0.940	215.490

Table 4.3: Power flow (MW & MVAR) value at each busses

DATA FOR: MW FLOW							
BUS NO	MW IN	MW IN	T.MW IN	MW OUT	MW OUT	T.MW OUT	NET POWER FLOW
1	146.91	0.00	146.91	146.91	0.00	146.91	0.00
2	163.00	0.00	163.00	163.00	0.00	163.00	0.00
3	85.00	0.00	85.00	85.00	0.00	85.00	0.00
4	142.00	0.00	142.00	83.46	58.56	142.02	-0.02
5	57.61	67.39	125.00	125.00	0.00	125.00	0.00
6	43.23	83.60	126.83	125.00	0.00	125.00	1.83
7	157.13	0.00	157.13	88.53	68.60	157.13	0.00
8	86.65	38.35	125.00	125.00	0.00	125.00	0.00

DATA FOR: MVA FLOW							
BUS NO	MVA IN	MVA IN	T.MVA IN	MVA OUT	MVA OUT	T.MVA OUT	NET POWER FLOW
1	0.00	0.00	0.00	154.69	0.00	154.69	-154.69
2	0.00	0.00	0.00	169.87	0.00	169.87	-169.87
3	0.00	0.00	0.00	101.10	0.00	101.10	-101.10
4	147.08	0.00	147.08	84.93	62.75	147.68	-0.60
5	71.16	63.68	134.84	0.00	0.00	0.00	134.84
6	54.15	83.60	137.75	0.00	0.00	0.00	137.75
7	160.70	0.00	160.70	89.69	71.27	160.96	-0.26
8	87.98	51.75	139.73	0.00	0.00	0.00	139.73
9	99.71	0.00	99.71	48.37	51.43	99.80	-0.09

Table 4.4: MVAR losses at each busses

DATA FOR : MVAR LOSSES AT EACH BUS							
BUS NO	MVAR IN	MVAR IN	T.MVAR IN	MVAR OUT	MVAR OUT	T.MVAR OUT	MVAR LOSS
1	48.454	0	48.454	19.55	0	19.55	28.90
2	47.8085	0	47.8085	14.13	0	14.13	33.68
3	55	0	55	8.63	0	8.63	46.37
4	10.19	0	10.19	3.81	6.76	10.57	-0.38
5	4.84	-4.6	0.24	50	0	50	-49.76
6	-1.67	2.64	0.97	50	0	50	-49.03
7	23.49		23.49	-0.88	-3.56	-4.44	27.93
8	7.53	-6.07	1.46	50	0	50	-48.54
9	-0.75	0	-0.75	2.38	-5.81	-3.43	2.68

REFERENCES

- [1] IEEE standards (2002). *IEEE Standard for Shunt Power Capacitor*. 18.
- [2] M.H.Shwehdi and M.R.Sultan. Power Factor Correction Capacitors; Essentials and Cautions. *IEEE Power Engineering Society Summer Meeting* 2000, Vol.3, pp.1317-1322.
- [3] S.W.Cichanowaki & G.R. Newcomb.(1991). Power Capacitors, Electrical Electronics Insulation *.Proceedings of Conference of the 20th Boston '91 EEIC/ICWA Exposition .*
- [4] Dr. G. Thomas Bellarmine.(1997). Optimum Series Compensated High Voltage Transmission Lines, Southeastcon '97 *.Proceeding of Engineering New Century.:IEEE, P307-309.*
- [5] Ramon A. Callego, Alcir Jose Monticelli & Ruben Romero.(2001). Optimal Capacitor Placement in Radial Distribution Networks. *IEEE Transactions on power systems, Vol.16, No.4.*
- [6] H.N.Ng.M.M.A.Salama.(1995).Fuzzy Optimal Capacitor Sizing and Placement. *Canadian Conference on Electrical and Computer Engineering Vol.2(5-8). P680-683*
- [7] A.M.Sharaf & S.T. Ibrahim.(1996). Optimal capacitor placement in distribution networks. *Electric Power System Research 37,pp. 181-187 .*
- [8] Songur, M and Ercan,B. POWERHU- A PC Based Electric Power System Software Package For Electric Power System Courses,Nasar: IEEE. 1997.
- [9] Hadi Saadat.(1991). *Power System Analysis*. New York: McGraw-Hill.pp.142 446.
- [10] Asmarashid, Erwan, Kok Boon Ching, Shamsul Aizam & Zarafi . (2006).*Electric Power System*. 1st.ed. Kolej Universiti Teknologi Tun Hussein Onn.: pp.81-199.
- [11] Grainger,J.J. & Stevenson, W.D.(1994). *Power System Analysis*. Singapore: McGraw- Hill.pp.329-337.

- [12] D Goldberg .(1989). *Genetic Algorithm in Search, Optimization and Machine Learning*. New York: Addison Wesley.
- [13] B. Baran, J. Vallejos, R. Ramos & U. Fernandez.(2001). Reactive Power Compensation using a Multi-objective Evolutionary Algorithm. *IEEE Porto Power Tech Conference, Porto, Portugal* :IEEE.
- [14] J.T. Ma &L.L. Lai. (1996).Evolutionary Programming Approach to Reactive Power Planning. *IEE Proceedings - Generation, Transmission, Distribution*:IEEE,Vol 143, No. 4.
- [15] John E. Harder.(1990). Developments in Capacitor Protection. *Proceedings of the 11th IEEE/PES Transmission and Distribution Conference and Exposition, New Orleans, Louisiana*:IEEE.
- [16] John Grainger, William Stevenson, William Stevenson, Jr. & Stevenson.(1994). *Power System Analysis*. McGraw-Hill Companies.
- [17] Allen J. Wood &Bruce F. Wollenberg.(1996). *Power Generation , Operation, and Control*:Wiley, John & Sons.
- [18] Bergen, Arthur R. / Vittal, Vijay Bergen, Arthur R. / Vittal &Vijay.(1999). *Power System Analysis*: Pearson.
- [19] Prabha Kundur &P. Kundur.(1994). *Power System Stability and Control*.: McGraw-Hill Companies.
- [20] ANSI/IEEE Standard (1992). *IEEE Standard for Shunt Power Capacitors*.18.
- [21] John Grainger & William Stevenson, Jr.(1994).*Power System Analysis*. McGraw-Hill Companies.
- [22] D. P. Kothari & I. J. Nagrath.(1994).*Modern Power System Analysis*, Tata McGraw Hill Publishing Co. Ltd..New Delhi.
- [23] Hadi Saadat.(2002). *Power System Analysis*. Tata McGraw Hill Publishing Co. Ltd.. NewDelhi.
- [24] Nasser D.Tleis.(2008). *Power Systems Modelling and Fault Analysis, Theory and Practice*. London: Elsevier.
- [25] D P Kothari & I J Nagrath.(2003). *Modern Power System Analysis*. 3rd.ed. Tata McGraw Hill Publishing Co. Ltd..New Delhi.