POWER COMPENSATION BY DISTRIBUTED GENERATION

MOHD HANAFFI BIN YAA'KOB

UNIVERSITI MALAYSIA PAHANG

"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the Bachelor of Electrical Engineering (Power System)"

Signature : ________________________

Name : Mr. Omar Bin Aliman

Date : 29 NOVEMBER 2010

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **ANALYTICAL STUDY OF POWER COMPENSATION BY DISTRIBUTED GENERATION**

SESI PENGAJIAN: **2010/2011**

Saya **MOHD HANAFFI BIN YAA'KOB (890325086365)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda/~~Sarjana~~ /~~Doktor Falsafah~~)* ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

[ ]	**SULIT**	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
[ ]	**TERHAD**	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
[√]	**TIDAK TERHAD**	

Disahkan oleh:

(TANDATANGAN PENULIS)	(TANDATANGAN PENYELIA)

Alamat Tetap:

NO 4, LORONG 4, JBLI 1
TAMAN BUKIT LARANG INDAH
75460 TELOK MAS
MELAKA

OMAR BIN ALIMAN
(Nama Penyelia)

Tarikh: **29 NOVEMBER 2010**

Tarikh: : **29 NOVEMBER 2010**

CATATAN:
* Potong yang tidak berkenaan.
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai atau TERHAD.
♦ Tesis dimaksudkan sebagai tesis bagi Ijazah doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

POWER COMPENSATION BY DISTRIBUTED GENERATION

MOHD HANAFFI YAA'KOB

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

Faculty of Electrical & Electronics Engineering
Universiti Malaysia Pahang

NOVEMBER, 2010

"References of information from other sources are quoted accordingly; otherwise the information presented in this report is solely work of the author."

Signature : ______________________________

Author : MOHD HANAFFI BIN YAA'KOB

Date : 29 NOVEMBER 2010

DEDICATION

Specially dedicated to
My beloved family, and those who have guided and inspired me
Throughout my journey of learning

ACKNOWLEDGEMENT

First and foremost, I am very grateful to the almighty ALLAH S.W.T for giving me this opportunity to accomplish my Final Year Project.

Throughout the development of this project I have gained chances to learn new skills and knowledge. I wish to express my sincere appreciation and gratitude to my supervisor, Mr Omar bin Aliman for his continuous guidance, concern, encouragement and advices which gave inspiration in accomplishing my final year project.

My sincere appreciation to the lecturers of Faculty of Electrical and Electronics Engineering who have put in effort to the lectures and always nurture and guide us with precious advices. Thank you for sharing those experiences.

To all my lovely current and ex roommates and friends who always willingly assist and support me throughout my journey of education, you all deserve my wholehearted appreciation. Many thanks.

Last but not least, my beloved family members who always stand by my side concerning the ups and downs of my life. Home is where I find comfort. Endless love.

Mohd Hanaffi Yaa’kob

ABSTRACT

In order to reduce electricity cost, together with improving the performance of distribution systems, it has to deal with the problem of power losses minimisation. Although losses in the system can never be entirely eliminated, they can be controlled and minimised in several ways for example by installing Distributed Generation (DG) and shunt capacitor. DG can reduce line losses, increase system voltage profile, and improve power quality of the system. The shunt capacitor can be improving the power factor if the installation DG affects the power factor of network system. In this thesis, the proposed method is tested on standard IEEE 14 bus system and the results of the simulation carried out using MATLAB. While, DIgSILENT software was used to simulate the 26-bus test system by. By adding the DG, the losses of the system will be reducing while it can stabilize the network system. Therefore, distributed generation has improved the overall system performance.

ABSTRAK

Untuk mengurangkan kos elektrik, bersama-sama dengan meningkatkan prestasi sistem pengedaran, ia hendaklah berdepan dengan masalah meminimumkan kehilangan kuasa. Walaupun kehilangan (kuasa) dalam sistem tidak pernah dilhilangkan sepenuhnya, ia dapat dikawal dan diminimumkan dalam beberapa cara misalnya dengan memasang Penjana Agihan (DG) dan selari kapasitor. Penjana Agihan (DG) dapat mengurangkan kehilangan pada litar, meningkatkan profil sistem voltan, dan meningkatkan kuasa kualiti pada sistem. Selari kapasitor dapat memperbaiki faktor kuasa jika pemasangan penjana agihan (DG) mempengaruhi faktor kuasa dalam sistem rangkaian.Dalam kajian ini, kaedah yang dicadangkan ini diuji pada standard 14 sistem bas IEEE dan hasil simulasi dilakukan dengan menggunakan perisian MATLAB. Sementara itu, DIgSILENT perisian digunakan untuk mensimulasikan sistem uji 26-bas. Dengan menambah Penjana Agihan DG, kehilangan kuasa pada sistem ini akan dikurangkan sementara itu ia boleh menstabilkan sistem rangkaian sesuai dengan permintaan pelanggan. Oleh kerana itu, Penjana Agihan (DG) telah meningkatkan prestasi sistem secara keseluruhan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

POWER COMPENSATION BY DISTRIBUTED GENERATION

MOHD HANAFFI YAA'KOB

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

Faculty of Electrical & Electronics Engineering
Universiti Malaysia Pahang

NOVEMBER, 2010

"References of information from other sources are quoted accordingly; otherwise the information presented in this report is solely work of the author."

Signature : ______________________________

Author : MOHD HANAFFI BIN YAA'KOB

Date : 29 NOVEMBER 2010

DEDICATION

Specially dedicated to

My beloved family, and those who have guided and inspired me

Throughout my journey of learning

ACKNOWLEDGEMENT

First and foremost, I am very grateful to the almighty ALLAH S.W.T for giving me this opportunity to accomplish my Final Year Project.

Throughout the development of this project I have gained chances to learn new skills and knowledge. I wish to express my sincere appreciation and gratitude to my supervisor, Mr Omar bin Aliman for his continuous guidance, concern, encouragement and advices which gave inspiration in accomplishing my final year project.

My sincere appreciation to the lecturers of Faculty of Electrical and Electronics Engineering who have put in effort to the lectures and always nurture and guide us with precious advices. Thank you for sharing those experiences.

To all my lovely current and ex roommates and friends who always willingly assist and support me throughout my journey of education, you all deserve my wholehearted appreciation. Many thanks.

Last but not least, my beloved family members who always stand by my side concerning the ups and downs of my life. Home is where I find comfort. Endless love.

Mohd Hanaffi Yaa'kob

ABSTRACT

In order to reduce electricity cost, together with improving the performance of distribution systems, it has to deal with the problem of power losses minimisation. Although losses in the system can never be entirely eliminated, they can be controlled and minimised in several ways for example by installing Distributed Generation (DG) and shunt capacitor. DG can reduce line losses, increase system voltage profile, and improve power quality of the system. The shunt capacitor can be improving the power factor if the installation DG affects the power factor of network system. In this thesis, the proposed method is tested on standard IEEE 14 bus system and the results of the simulation carried out using MATLAB. While, DIgSILENT software was used to simulate the 26-bus test system by. By adding the DG, the losses of the system will be reducing while it can stabilize the network system. Therefore, distributed generation has improved the overall system performance.

ABSTRAK

Untuk mengurangkan kos elektrik, bersama-sama dengan meningkatkan prestasi sistem pengedaran, ia hendaklah berdepan dengan masalah meminimumkan kehilangan kuasa. Walaupun kehilangan (kuasa) dalam sistem tidak pernah dilhilangkan sepenuhnya, ia dapat dikawal dan diminimumkan dalam beberapa cara misalnya dengan memasang Penjana Agihan (DG) dan selari kapasitor. Penjana Agihan (DG) dapat mengurangkan kehilangan pada litar, meningkatkan profil sistem voltan, dan meningkatkan kuasa kualiti pada sistem. Selari kapasitor dapat memperbaiki faktor kuasa jika pemasangan penjana agihan (DG) mempengaruhi faktor kuasa dalam sistem rangkaian.Dalam kajian ini, kaedah yang dicadangkan ini diuji pada standard 14 sistem bas IEEE dan hasil simulasi dilakukan dengan menggunakan perisian MATLAB. Sementara itu, DIgSILENT perisian digunakan untuk mensimulasikan sistem uji 26-bas. Dengan menambah Penjana Agihan DG, kehilangan kuasa pada sistem ini akan dikurangkan sementara itu ia boleh menstabilkan sistem rangkaian sesuai dengan permintaan pelanggan. Oleh kerana itu, Penjana Agihan (DG) telah meningkatkan prestasi sistem secara keseluruhan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE NO	TITLE	PAGE

CHAPTER 1

INTRODUCTION

1.1 Background

The electric utility industry can trace its beginnings to the early 1880s. The earliest distribution system surrounded Thomas Edison's 1882 Pearl Street Station in lower Manhattan, using direct current (DC) placing small generators right next to the load. The fast growth of electricity demand and the development of high-voltage power transmission lines using alternating current (AC) encouraged electric utilities to build larger generators near the primary energy source (example: coal mines, water dams, etc.) and use transmission lines to deliver electricity to load centers, sometimes over spans of hundreds of miles. As a result of this production scheme electric utilities made technological advances by constructing larger generating plants to capture economies of scale [7].

A general definition was then suggested in which are now widely accepted as follows: "Distributed Generation is an electric power source connected directly to the distribution network or on the customer site of the meter" [1]. The definitions of DG do not define the technologies, as the technologies that can be used vary widely. However, a categorization of different technology groups of DG seems possible, such as, non-renewable DG and renewable DG. From distribution system planning point of view, DG is a feasible alternative for new capacity especially in the competitive electricity market environment and has immense benefit such as: Short lead time and low investment risk since it is built in modules, Small-capacity modules that can track load variation more closely, Small physical size that can be installed at load centers and does not need government approval or search for utility territory and land availability, Existence of a vast range of DG technologies. For these reasons, the first signs of a possible technological change are beginning to arise on the international scene, which could involve in the future the presence of a consistently generation produced with small and medium size plants directly connected to the distribution network (LV and MV) and characterized by good efficiencies and low emissions. DG provides electric power thereby eliminating the need to upgrade transmission lines and increase the capacity of remote power plants [13]. This will create new problems and probably the need of new tools and managing these systems.

Shunt capacitor banks (SCB) are installed at primary feeders in electric power distribution systems to improve voltage profiles and the power factor as well as to reduce power losses generated by the flow of reactive power in the system [8]. The use of SCBs has increased because they are relatively inexpensive, easy and quick to install and can be deployed virtually anywhere in the network. Its installation has other beneficial effects on the system such as: improvement of the voltage at the load, better voltage regulation (if they were adequately designed), reduction of losses and reduction or postponement of investments in transmission. The main disadvantage of SCB is that its reactive power output is proportional to the square of the voltage and consequently when the voltage is low and the system needs them most, they are the least efficient [11].

1.2 Project Objectives

1) To analyse the impact of Distributed Generation (DG) interconnection to the existing distribution network in term of voltage control and system losses

2) To compare the effect of Distributed Generation with Shunt Capacitor Bank in network system in term of power factor improvement and system losses.

1.3 Problems statement

Distributed generators are small, decentralized power plants situated closed to end user. The generators can supply electricity to a single location, or pump power directly into national electricity grids. Distributed Generation is the best answer to energy supply shortfalls because the traditional electricity grid will never be able to satisfy today's needs for quantity or quality of power. Therefore, DG was installed in the network power system to fulfill the demand of the power from the consumer.

Distributed generation will change the power flows in the network and so will change network losses. If a small DG is located close to large loads then the network losses will be reduce as both real and reactive power and power can be supply to the load from the adjacent generator. But, if the large DG is located far away from network loads then it's likely to increase losses on the distribution system. Hence, the DG will bother the stability of the power flow and the network system in term of voltage level and system efficiency.

By adding the DG in the distribution network, the power flow of the network will change and it also will change the network losses. But after adding the DG, the power factor of the system will change either improved or not. And the DG must be maintenance for four or five year after do the installation of it. If the system DG was shut down for maintenance, the network system will be change automatically and it will cause the increasing of losses. Hence, injecting the reactive power (shunt capacitor) is the best option to solve this power factor problem while it also can reduce the losses of the network system.

1.4 Project Scopes

This analysis study will focus on the effect of the impact of the performance on existing distribution network by adding the DG only in term of network losses of the system by using the MATLAB and DIgSILENT software. The limitation of getting the real data from utilities for the base case systems have decide to utilise the IEEE Reliability Test System of 14 bus as the test systems will use by MATLAB software and 26-bus test system will be simulate by using DIgSILENT software. The network system will be analysing for improvement the power factor and to stabilize the network system by adding the capacitor bank. DigSILENT software was use to simulate the network system by continuing the network system using the same 26-bus test system. The limitation of this simulation will only use the network that was improvement by the DG in the system.

1.5 Thesis outline

This thesis contain of 5 chapters they include Chapter 1: Introduction, Chapter 2: Literature reviews, Chapter 3: Methodology, Chapter 4: Result and discussion and Chapter 5: Conclusion and Recommendations. Each chapter will contribute to explain different focus and discussion relating with the corresponding chapters heading.

Chapter 1 contain introduction which present about the overviews of the project that is constructed. It consists of project background, objective, problem statement and project scope.

Chapter 2 contain literature review which discussed about the reference that is taken for this project completion.

Chapter 3 will discuss about the methodology in this project which consist of characteristic study of Distributed Generation and Capacitor Bank in power the network system. This chapter also discuss the software that was used to simulated and analysed the system

Chapter 4 contain result and discussion focused on the analysis of the result from the simulating the network systems and discussed the outcome that is obtained. The results was getting by analysis from both of software and was discuss with the results.

Chapter 5 contain conclusion and recommendations for this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Distributed Generation

2.1.1 Introduction

Electrical power systems are complex networks and devices interacting to reliably generate transmit and distribute electrical energy to its customers. Centralized generation (CG) supplies large amounts of electrical energy from generators through transmission lines and distribution lines to the consumption area. The electrical demand around the world is growing continuously and presents some limitations to the CG model. Each mile of transmission line costs about one (1) million dollars to construct and approximately seven (7) percent of electricity is lost during the transmission as heat [9]. To provide reliable and less expensive electrical energy to customers, new emphasis is being placed on DG. Figure 2.1 shows differences between centralized generation and distributed generation.

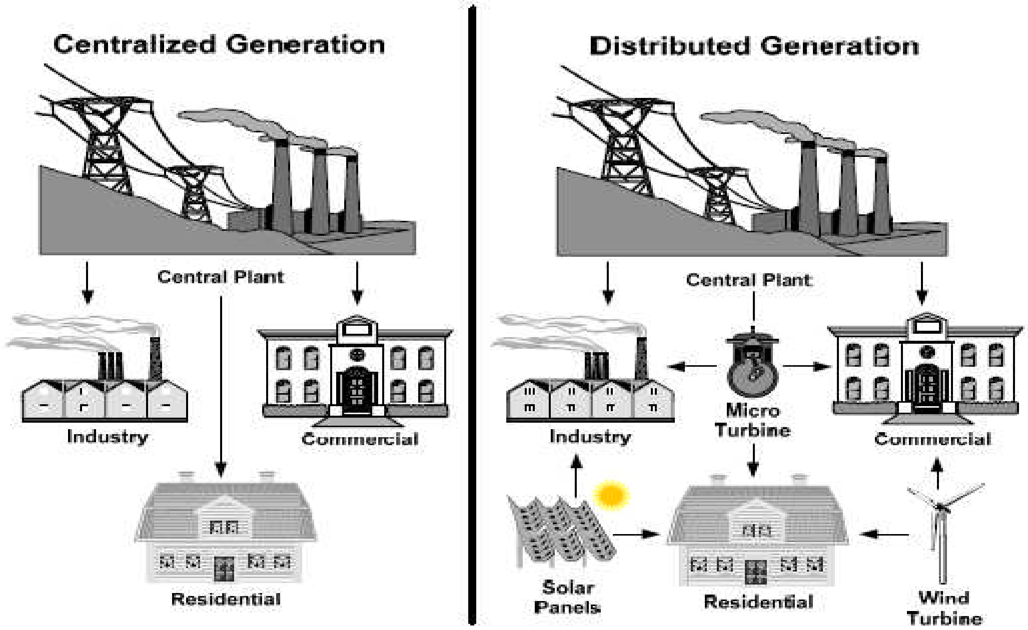


Figure 2.1: Centralized Generation vs. Distributed Generation [9]

Different technologies are being developed to generate electrical energy close to the consumption areas (load centers). Distributed generators are small, decentralized power plants situated closed to end user. The generators can supply electricity to a single location, or pump power directly into national electricity grids. Distributed Generation (DG) is the best answer to energy supply shortfalls because the traditional electricity grid will never be able to satisfy today's needs for quantity or quality of power. Generally, the capacity range of distributed generation is between 100 kW and 10 MW. Therefore, DG was installed in the network power system to fulfill the demand of the power from the consumer. Before installing distributed generation, its effects on voltage profile, line losses, short circuit current, amounts of injected harmonic and reliability must be evaluated separately. The planning of the electric system with the presence of DG requires the definition of several factors, such as: the best technology to be used, the number and the capacity of the units, the best location, the type of network connection, etc. The impact of DG in system operating characteristics, such as electric losses, voltage profile, stability and reliability needs to be appropriately evaluated.

Reduction of power losses by Distributed Generation (DG) is becoming a popular technique worldwide. Since an integration of DG into distribution systems will alter the power flows, it is obvious that the power losses in the system are affected. DG is utilized for improving the system voltage profile, power quality, system reliability and security.

2.1.2 Technology of DG

A key factor when implementing DG is the underlining technology. Technologies can be separated in generation and storage. Generation is further divided into conventional and nonconventional. Conventional includes combustion turbines, diesel engines, micro-turbines and natural gas engines. Non-conventional are mostly renewable energy technologies. Table 2.1 summarizes preliminary cost, size and efficiency estimates for DG technologies [9]. An important factor to consider is the relation between fixed and variable costs. Depending on the technology, DG could have high installation costs, but low operation and maintenance (O&M) costs. Thus, depending on the application, investing in DG technologies could be a feasible long term alternative.

Table 2.1: Distributed Generation Technologies [9]

Technology	Size Range (kW)	Installed Cost ($/kW)	Variable O&M ($/kWh)	Heat Rate (BTU/kWh)	Approx. Efficiency (%)
Diesel Engine	1-10,000	350-800	0.025	7,800	45
Natural Gas Engine	1-5,000	450-1,100	0.025	9,700	35
Dual Fuel Engine	1-10,000	625-1,000	0.023	9,200	37
Micro-turbine	15-60	950-1,700	0.014	12,200	28
Combustion Turbine	300-10,000	550-1,700	0.024	11,000	31
Fuel Cell	100-250	5,500+	0.01-0.05	6,850	50
Photovoltaic	Limited by Available Space	7,000-10,000	0.002	--	N/A
Wind Turbine	0.2-5,000	1,000-3,000	0.010	--	N/A

2.1.3 DG application in network system

Many researchers have been working in the DG field to minimize power losses and also include the effect of voltage profile and also will effect of the efficiency of the overall system. Authors in [1] have presented an Evolutionary Algorithms to determine a near optimal location of the DG with respect to system losses. Genetic Algorithm (GA) was apply to present the result of optimize the location of DG in this paper. Genetic Algorithm is a general- purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. Their basic principle is the maintenance of a population of solutions to a problem (genotypes) as encoded information individuals that evolve in time. Generally, GA comprises three different phases of search:

Phase 1: creating an initial population;
Phase 2: evaluating a fitness function;
Phase 3: producing a new population.

A genetic search starts with a randomly generated initial population within which each individual is evaluated by means of a fitness function. Individual in this and subsequent generations are duplicated or eliminated according to their fitness values. Further generations are created by applying GA operators. This eventually leads to a generation of high performing individuals. The main goal of the proposed algorithm is to determine the best locations for new distributed generation resources by minimizing loss reduction and voltage profile Improvement.

In [3], an optimization method was used to analyze the Sizing and Placement. The unique radial distribution structure is exploited in developing a Fast and Flexible Radial Power Flow (FFRPF) method to deal with a wide class of distribution systems. The FFRPF technique is incorporated in both utilized deterministic and metaheuristic optimization methods to satisfy the power flow equality constraints requirements. In the deterministic solution method, the DG sizing problem is formulated as a nonlinear optimization problem with the distribution active power losses as the objective function to be minimized, subject to nonlinear equality and inequality constraints. Endeavouring to obtain the optimal DG size, an improved version of the Sequential Quadratic Programming (SQP) methodology is used to solve for the DG size problem. The conventional SQP uses a Newton-like method, which consequently utilizes the Jacobean, in handling the nonlinear equality constraints. The radial low X/R ratio and the tree-like topology of distribution systems make the system ill-conditioned. A Fast Sequential Quadratic Programming (FSQP) methodology is developed in order to handle the DG sizing nonlinear optimization problem. The FSQP hybrid approach integrates the FFRPF within the conventional SQP in solving the highly nonlinear equality constraints. By utilizing the FFRPF in dealing with equality constraints instead of the Newton method, the burden of calculating the Jacobean and consequently its inverse, as well as the complications of the ill-conditioned Y-matrix of the RDS, is eliminated. Another advantage of this hybridization is the drastic reduction of computational time compared to that consumed by the conventional SQP method. In this thesis, a new application of the Particle Swarm Optimization (PSO) method in the optimal planning of single and multiple DGs in distribution networks is also presented. The algorithm is utilized to simultaneously search for both the optimal DG size and its corresponding bus location in order to minimize the total network power losses while satisfying the constraints imposed on the system. The proposed approach hybridizes PSO with the developed distribution radial power flow, i.e. FFRPF, to simultaneously solve the optimal DG placement and sizing problem. The difficult nature of the overall problem poses a serious challenge to most derivative based optimization methods due to the discrete flavour associated with the bus location, in addition to the sub problem of determining the most suitable DG size. Moreover, a major drawback of the deterministic methods is that they are highly-dependent on the initial solution point. The developed PSO is improved in order to handle both real and integer variables of the DG mixed-integer nonlinear constrained optimization problem. Problem constraints are handled within the proposed approach based on their category. The equality constraints, i.e. power flows, are satisfied through the FFRPF subroutine while the inequality bounds and constraints are treated by exploiting the intrinsic and unique features associated with each particle. The proposed inequality constraint handling technique hybridizes the rejection of infeasible solutions method in conjunction with the preservation of feasible solutions method. One advantage of this constraint handling mechanism is that it expedites the solution method converging time of the Hybrid PSO (HPSO).

In [4], a methodology for evaluating the effects of DG sizing and sitting in terms of reliability, losses and voltage profile has been introduced. Conceptually, the methodology is based on the following methods:

1) The electric losses and voltage profile evaluation is based on a power flow method with the representation of generators (PV buses).
2) The reliability indices evaluation is based on analytic methods modified to handle multiple generations.

The proposed methodology can be used as standalone by a specialist to evaluate different DG installation alternatives or it can be used as integral part of an automatic optimization method. The methodology adopted in this work is based on the power summation method with each DG unit represented by a PV bus with specified voltage magnitude. The PV bus is modelled as a network breakpoint. At every each iteration, the voltage mismatch between the two sides of the breakpoint is calculated and reactive power injections are calculated in order to correct the voltage mismatch. This process continues until the voltage mismatch is less than an acceptable tolerance. In the developed methodology on distribution reliability evaluation, it is considered that the DG can supply all or part of the load in the case of main source unavailability. It is also considered that the occurrence of a failure causes the disconnection of both the main supply and the DG from the system. After the isolation of the fault via proper switches operation, the DG is re-connected to the system. In this way, the frequency related indices are not modified in the presence of DG. On the other hand, there will be a reduction on duration related indices since part of the load can be attended by DG while the main supply interruption cause is being repaired. This benefit is greater is the DG energy source is considered always available and the units can be prescheduled.

In [5], line losses reduction of the network system was analyze of Distributed Generation in Electrical Distribution Systems. This paper focuses on line loss reduction analysis. In this study, one-concentrated load is assumed at the end of the line. With the introduction of DG, line loss reduction can be expected. This factor is analyzed, quantified and presented in this paper for different locations of the DG along the feeder and for different DG power outputs. Two simple radial systems are considered:

(I) System without DG

(II) System with the inclusion of DG.

Electrical line loss occurs when current flows through transmission and distribution systems. The magnitude of the loss depends on amount current flow and the line resistance. Therefore, line loss can be decreased by reducing either line current or resistance or both. If DG is used to provide energy locally to the load, line loss can be reduced because of the decrease in current flow in some part of the network. DG can be operated in three modes: lagging or leading or unity power factor. Under lagging power factor operation, DG produces reactive power for the system. Thus, Q is positive. Also Q is negative for leading power factor operation because DG absorbs reactive power from network. There are four possible combinations of power factors of load and DG.

Case 1, DG operates at a lagging power factor while load has leading power factor.
Case 2, DG operates at a lagging power factor and load is also lagging.
Case 3, DG operates at a leading power factor and load is leading as well.
Case 4, DG operates at a leading power factor while load has lagging power factor.

In [6], the author was investigated the impact of utilizing selected DG units with different penetration levels on the various forms of power system stability. A hypothetical network with two conventional power plants and many DG units is simulated. The DG can improve the stability of power systems if suitable types and appropriate locations are selected. Regarding the oscillatory stability, the utilization of DG improves the damping of the electromechanical modes and slightly increases their frequency. This fact is confirmed through the time-domain simulation of some disturbances. The transient stability analysis shows that the maximum power angle deviations between the generators are decreased with the increase of the penetration level of the DG units. With more power from the DG units, the absolute reserve power from synchronous generators and the network inertia constant are smaller due to the lower rated power of the rotating synchronous generators. As a result, the frequency response shows faster behaviour with higher maximum frequency deviations when more DG units are employed. The voltage profiles at load terminals are also improved due to the use of active DG sources near end-user terminals. The controllers designed to regulate the performance of the DG units participate also in improving the voltage stability of the network. To maximize the benefits of utilizing DG units, the stability of the individual DG units themselves has to be improved to ensure their continuous and reliable operation to provide effective support to the stability of the entire network.

In [10], the results of an investigation of the impact of distributed generation technology and penetration level on power system transient stability are presented. Starting from a base case, the New England test system, the load was increased in a number of steps and the load increases were covered by various distributed generation technologies. Then, for each case a line fault was applied and the rotor speed deviation and oscillation duration of the large scale synchronous generators were studied. It was concluded that the impact of distributed generation on power system transient stability depends both on the penetration level and the technology of the distributed generators. Distributed generation based on asynchronous generators does not have much impact on the transient stability, probably because the opposite effects of near and remote generators counterbalance. Distributed generation based on synchronous generators decreases the over speeding of the large scale generators, but seems to decrease the transient stability by increasing the oscillation duration. The latter might be caused by the inter area oscillation phenomenon. Distributed generation based on power electronics decreases the over speeding of generators, because it is disconnected during a fault.

In this paper, only one test system has been analyzed. It proved possible to explain most of the observations using generally accepted theoretical insights obtained from the literature. Therefore, it can be expected that in other test systems similar results will be obtained. However, some results could not be fully clarified. Especially these need further research, using other test systems and methods of investigation.

2.2 Reactive Power by Shunt Capacitor

2.2.1 Introduction

Reactive power is a subject of great concern for the operation of alternating current (AC) power systems. The power system is made up of many different elements, many of which are modeled as energy storage devices such as inductors and capacitors. Since AC circuits involve constantly changing values of voltage and current, these storage elements are constantly storing and dissipating their energy. Over a given time span, this energy is both stored and released, resulting in no net consumption of energy. This energy flow between storage elements does not accomplish any work, but it is present along with the energy which is being transmitted from generator to load. This energy flow is necessary to maintain the constant change in magnetic and electric fields of the storage devices. This energy is flowing in reaction to the elements that comprise the system and is termed “reactive” power. This reactive power only circulates within the power system, between the storage elements. It is not like active power, which is transferred into the power system by some form of work and is dissipated out of the power system for the purpose of performing other work. Even though the reactive power performs no real work, it performs a vital function in maintaining system operation.

Shunt-connected capacitors make up the overwhelming majority of reactive power sources on distribution systems. This is due to their low cost, reliable operation, low active power losses, ease of installation, and simplicity of control. Of the seven distribution engineers surveyed, none reported that they used or were considering the use of a reactive power source other than shunt capacitors [14]. Until technologies that provide a more optimum compensation strategy become economically attractive, the topics discussed below will continue to have significant impact on shunt capacitor-based reactive power compensation. The main questions of concern regarding the use of shunt capacitors are: placement (where to physically locate the capacitor on the system) and size (rated kVAR output of bank),

2.2.2 Placement

The problem of optimal placement of capacitor bank to find the solution which maintains a proper voltage profile and power factor at all points in the system, at minimum and maximum load. An optimal solution should also minimize real power losses, compensate for the reactive power requirements of the loads, and maintain suitable power factor for wholesale power billing at transmission connection points. This task is complicated by the many constraints associated with determining the optimal solution. Several constraints involved in determining proper placement include:

- Fixed-increment kVAr ratings of capacitors. Power system capacitors are typically available in ratings of multiples of 100-kVAr. Typical (total 3- phase) bank ratings are 300, 600, or 1200 kVAr. Solutions which do not yield an exact multiple of available sizes are most likely less than optimum.

- Reactive requirements of customer loads. Most often, only the peak active/reactive power demands are known for commercial and industrial customers. Most utilities do not even measure reactive loads of residential customers. Any calculated solution would have to be based on estimates for total reactive power demand. Solutions based on peak demand conditions may overcompensate during off-peak times, resulting in high voltages.

- Inadequate information database. Many utilities do not have an accurate system map with enough detail on line parameters (sizes, spacings, material) or distribution equipment (transformer sizes/impedances).

- Finite Locations. In overhead systems, a capacitor bank is most economically placed at an existing pole location. Locating a bank at an adjacent pole will likely not affect the bank's performance to a significant degree. In an underground distribution system, however, there are far fewer locations available for installation

2.2.2 Sizing

The sizing of shunt capacitor banks are dictated to a great degree by the sizes offered by manufacturers and the engineer's preference for what size units to use. Capacitors are manufactured with several specific kVAR ratings at common system voltages. Cooper Power Systems makes capacitors for power system use with ratings of 50, 100, 150, 200, 300, and 400 kVAR. Distributors of electric power typically stock one or two ratings of capacitors for their system voltage. Capacitor banks are built on integer multiples of three of the stocked ratings. For example, a distributor that stocks 200 kVAR capacitors may install 3-phase banks rated at 600, 1200, or 1800 kVAR.

The sizes chosen by a distributor for use on a particular system dictate placement strategies to some degree. With a finite number of available sizes to use, the banks must be located so that they provide sufficient compensation with minimal risk of over-voltage during lightly loaded periods (due to over-compensation). Occasionally, when harmonic resonance is a concern, the size of a bank may be adjusted to change the distribution system's frequency response characteristic. The bank may be enlarged or reduced in size to prevent resonance with customer loads that have significant harmonic current content. The distributor's surveyed report that the most commonly stocked sizes are 100, 200, and 300 kVAr rated capacitors. Some distributors use units which are rated at a higher voltage than the nominal system voltage to which they are applied. This is to reduce the voltage stress on the units in order to prolong the life. Units with higher voltage ratings are also specifically installed to tolerate the effects of high levels of harmonic current. 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 3.1 for a photograph of an automatically switched, line-mounted capacitor bank and its components.

2.2.4 Shunt Capacitor application in network system

Many researchers have been working in the reactive power compensation by Capacitor Bank to maintain the power factor, minimize power losses and also include the effect of voltage profile of the power network system. In [8], the author was analyzing the optimal size and location of shunt capacitor on distribution feeders suing the reduction of PPL and EL. Reducing peak power and energy losses, improving the power factor and keeping the voltage profile within the maximum and minimum permissible range (± 10% of the nominal voltage) providing that the voltage drop on the feeder is within the allowable value (5% of the voltage value) are investigated in this work. The benefits are achieved through the proper selection of capacitors by finding the optimal location and compensation levels as well as the maximum net dollar savings due to optimized shunt capacitor installation. The optimization technique used is based on an objective function that takes into account the maximum net dollar savings due to the reduction of peak power and energy losses while deducting the cost of the capacitor bank installation. The method is simple and does not require sophisticated optimization techniques. The optimal capacitor location and compensation level problem is solved using the Optimal Reduction of Peak Power and Energy Losses (ORPPL&EL). The reduction loss formula for determining the optimum location and compensation level of the capacitor banks considering an end-load on the uniform feeders is used. Analysis of optimal reduction of OPPL & EL is carried out for three different values of fixed end load reactive current using one to five capacitors. Results of optimal location and size of shunt capacitors, maximum net savings, and improvements in voltage drop, power factor and released KVA are obtained and evaluated using a realistic test feeder system.

The installation of capacitor bank in the network system will also affect on the harmonic of the system. In [15], Capacitor Bank Impact on Harmonic Filters Operation in Power Supply System was analyze by the author which more concern regarding power system harmonics has grown due to increased use of power electronic converters in many power supplies. Power factor correction of the facilities requires a design that is able to compensate for reactive power demand as well as for harmonic currents injected by the equipment into power supply system. In the circumstances many of industrial supply systems consist of a combination of tuned filters and a capacitor bank. Hence, by doing this research, the capacitor bank can lead to magnification or attenuation of the filters loading. Filter detuning significantly affects the phenomenon. Therefore, specifying harmonic filters requires considerable care under analysis of possible system configurations for avoidance of harmonic problems.

The optimal location and size of shunt capacitor and filter for distribution system with the harmonic distortion was studying in [16]. This paper also developed a systematic procedure to determine the optimal reactive power compensation by shunt capacitors and filters for distribution systems with nonlinear loads. The

MINOS package is applied to solve the nonlinear programming to find the optimal location and size of the reactive power compensation. The harmonic load flow is used to calculate the system harmonic distortion and power loss. The proper harmonic filters are designed to find the tuning frequency, voltage and current ratings of the inductor and capacitor for those buses with harmonic distortion violation. According, to the computer simulation of the sample feeder, it is concluded that the reactive power compensation must be incorporated with harmonic filters to eliminate the harmonic distortion as well as to provide the reactive power compensation.

Hence, based on the entire research above, this study will be used the shunt capacitor bank to improve, stabilize the network system in term of power factor while reducing losses of the network system.

CHAPTER 3

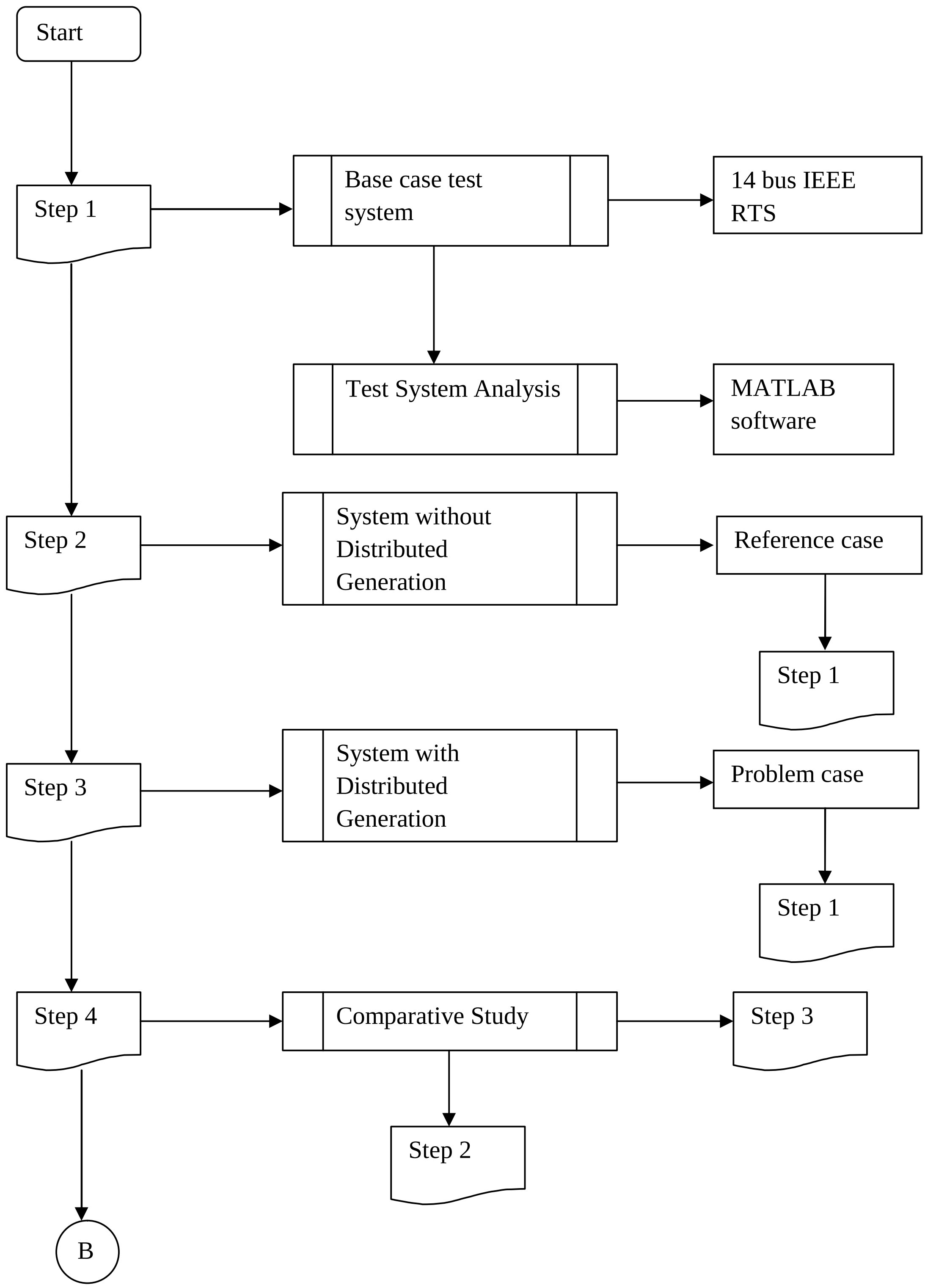
METHODOLOGY

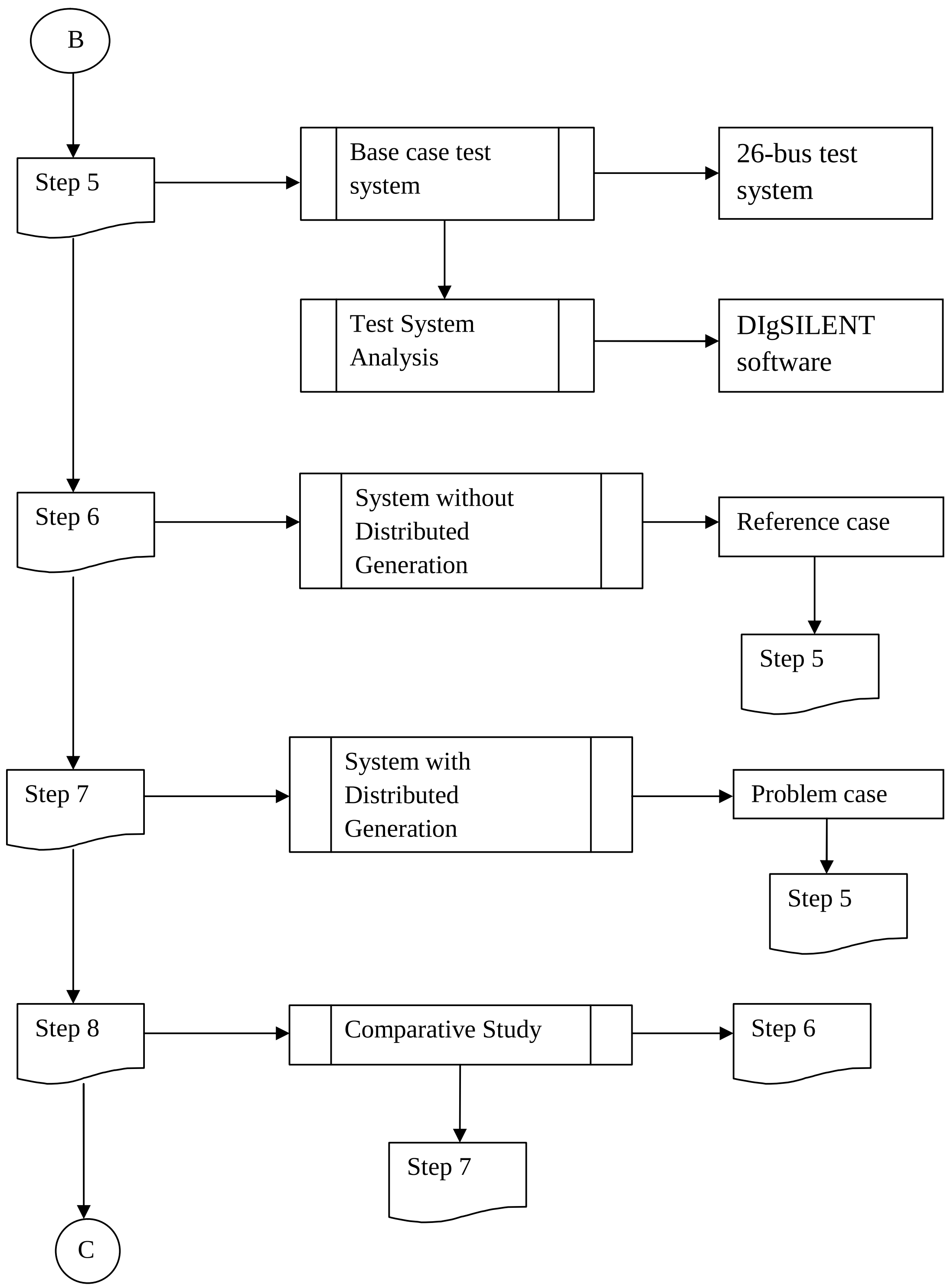
3.1 Introduction

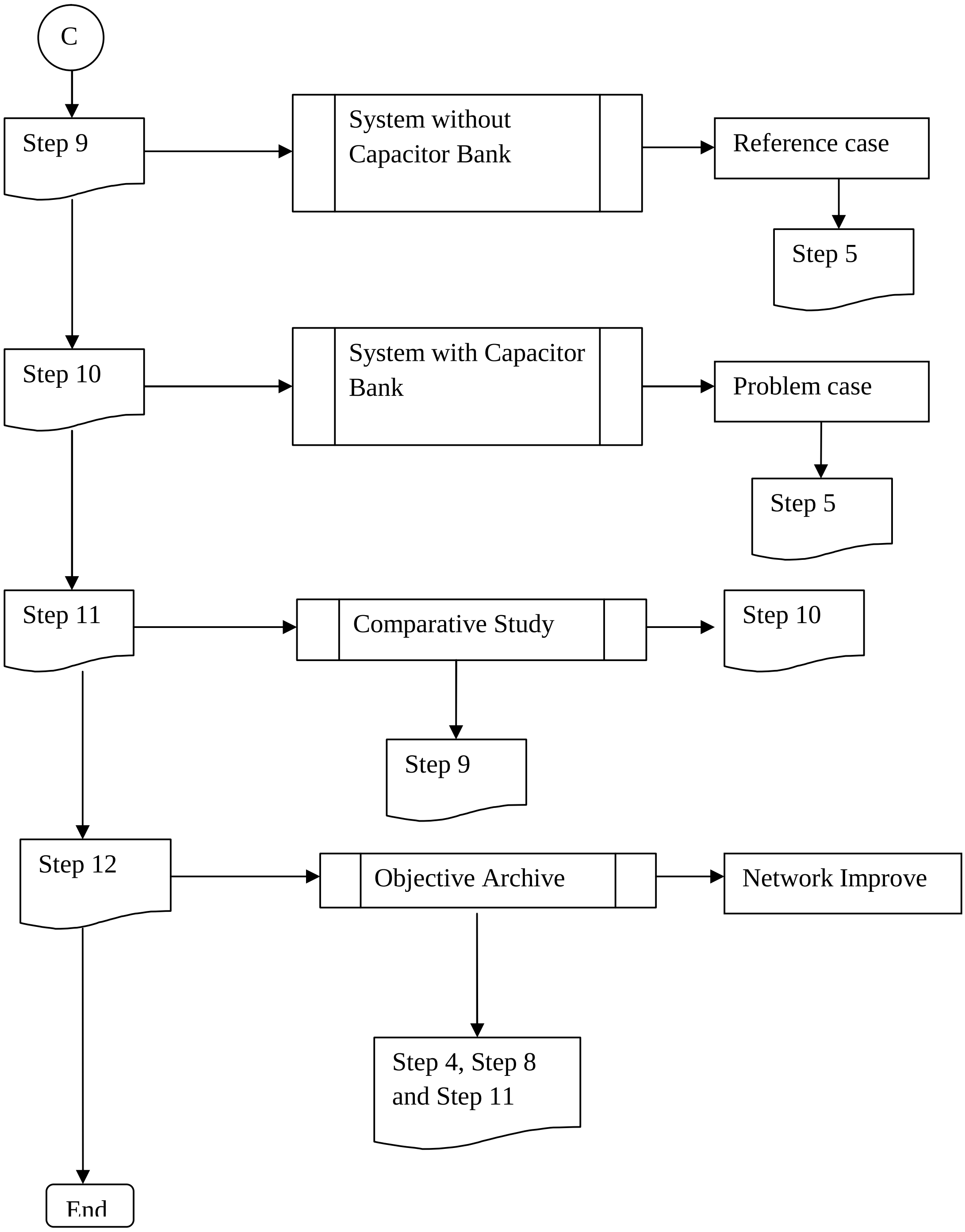
This chapter was describes on how the project is organized and the flow of the steps in order to complete this project. The methodology is diverged in two parts, which is the simulation and analysis of distribution network with and without distributed generation with MATLAB and DIgSILENT software and the other is analysis the network system by injecting shunt capacitor bank in the network system from the part before.

There are three mains step for software development of this project. Before the project is developing using MATLAB, it is needed to study the method of distribution network. The flowchart illustrated the sequence of steps for this project. The first step is to study about distribution network analysis. The second step is to analyze the network with and without the DG by using MATLAB and DIgSILENT. The last step is analyzing the network by adding the shunt capacitor in the network system.

3.2 Flow Chart of Project




B
Step 5
Base case test system
26-bus test system
Test System Analysis
DIgSILENT software
Step 6
System without Distributed Generation
Reference case
Step 5
Step 7
System with Distributed Generation
Problem case
Step 5
Step 8
Comparative Study
Step 6
Step 7
C


C
Step 9
System without Capacitor Bank
Reference case
Step 5
Step 10
System with Capacitor Bank
Problem case
Step 5
Step 11
Comparative Study
Step 10
Step 9
Step 12
Objective Archive
Network Improve
Step 4, Step 8 and Step 11
End

From the flow chart above, there were some steps that were used to complete this thesis. The important steps for this thesis were to find the network as a base case that was used in both of software. 14 bus IEEE test system was used in MATLAB and the 26-bus test system was used in DIgSILENT software.

For MATLAB software, the analysis was continuing by adding the DG at the system. Every busbar had added with a DG but only single DG was added at one time in the network system. Every busbar was simulated by adding a DG at each busbar to get the suitable and valuable place to install the DG in the system. Every busbar was getting the different results of losses and from that the placement of DG was determined. There have five value of DG that was used to analysis this network and that shown at table 3.3. The result was analysis by comparing with the references case to choose the best placement for installed the DG in the system. This step was repeated by adding the two DG at the different place at one time and there were following by the analysis.

For DIgSILENT software, the network was modelling the system by using the data and information of 26-bus test system. After the modelling, the network had the overloading transformer and there have to fixed that problem before used the network as a reference case. Then, the analysis was continuing by adding the DG at the system and the results were comparing with the references case. The analysis was focusing on the network losses and the improvement of it. After that, the analysis was continuing by analysis with the capacitor bank. The network for this analysis was used the same network 26-bus test system after the fixed the overloading problem. The network was added with the capacitor bank to get the effect of the injected capacitor. The network was focusing more on power factor of the network and also of the network losses.

From the step above, all the analysis was used to archive the objective of this thesis. The main objective is to get the network improvement by adding these two components of power system which are Distributed Generation and Capacitor Bank. But, both of the components have their advantages and disadvantages for network system and it was used for improvement of the network system.

3.3 MATLAB Software

3.3.1 14-Bus Power System Network

The system that is studied is the IEEE 14-bus network. The modeling of the network was shown at the figure 3.1 and the data was use in table 3.1 and table 3.2.

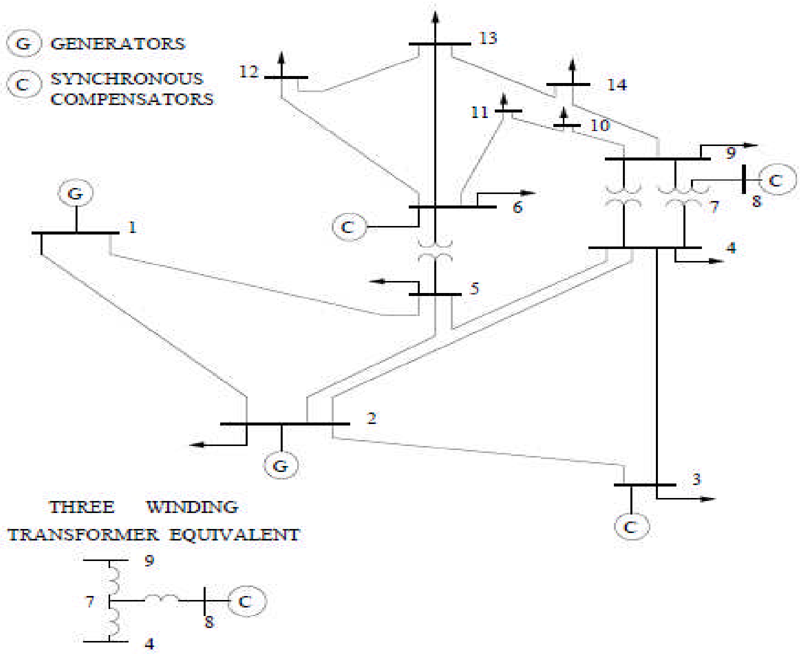


Figure 3.1: IEEE 14-Bus Test System

The data of the 14-Bus network was taken from the IEEE 14-Bus test system in m-file that use in MATLAB software. All the data was use in MATLAB sofware are defined in matrix form. Generation and loads are defined as busdata and line data was defined as linedata Code 0, code 1, code 2 are use for load buses, slack bus and the voltage controlled buses. Values for basemva, accuracy and maxiter was specified which are basemva=100, accuracy=0.0001 and maxiter= 100. The bus and line data were compiling by using Newton Rapshon method that was use in this project. The data was shown below:

Table 3.1: Busbar data of 14-bus test system

Bus		Voltage Magnitude		Load		Generation	
No	Code	Mag	Angle	MW	MVAR	MW	MVAR
1	1	1.060	0	0	0	0	0
2	2	1.045	0	21.7	12.7	40	42.4
3	2	1.010	0	94.2	19.0	0	23.4
4	0	1.0	0	46.8	-3.9	0	0
5	0	1.0	0	7.6	1.6	0	0
6	2	1.070	0	11.2	7.5	0	12.3
7	0	1.0	0	0.0	0.0	0	0
8	2	1.09	0	0.0	0.0	0	17.4
9	0	1.0	0	29.5	16.6	0	0
10	0	1.0	0	9.0	5.8	0	0
11	0	1.0	0	3.5	1.8	0	0
12	0	1.0	0	6.1	1.6	0	0
13	0	1.0	0	13.5	5.8	0	0
14	0	1.0	0	14.9	5.0	0	0

Table 3.2: Line data of 14-bus test system

Bus		R	X	1/2 B =	1for lines
nl	nr	p.u	p.u	p.u	Tap
1	2	0.01938	0.05917	0.0264	1.0
1	5	0.05403	0.22304	0.0246	1.0
2	3	0.04699	0.19797	0.0219	1.0
2	4	0.05811	0.17632	0.0170	1.0
2	5	0.05695	0.17388	0.0173	1.0
3	4	0.06701	0.17103	0.0064	1.0
4	5	0.01335	0.04211	0.0	1.0
4	7	0.0	0.20912	0.0	0.978
4	9	0.0	0.55618	0.0	0.969
5	6	0.0	0.25202	0.0	0.932
6	11	0.09498	0.19890	0.0	1.0
6	12	0.12291	0.25581	0.0	1.0
6	13	0.06615	0.13027	0.0	1.0
7	8	0.0	0.17615	0.0	1.0
7	9	0.0	0.11001	0.0	1.0
9	10	0.03181	0.08450	0.0	1.0
9	14	0.12711	0.27038	0.0	1.0
10	11	0.08205	0.19207	0.0	1.0
12	13	0.22092	0.19988	0.0	1.0
13	14	0.17093	0.34802	0.0	1.0

3.3.2 Value of DG installation

An advantage of deploying DG-units in distribution networks is to minimize the total system real power loss while satisfying certain operating constraints [15]. DG are available in sizes from less than 100kW to 10MW. The larger sizes DG are usually installed at the primary distribution voltage. The smaller DG is intended for much dispersed applications, as generator for individual homes and small businesses or as portable power units for construction site.

The value of DG was chosen from some specification needed of the generator set that supply from many supplies. The decided DG was choosing based on many factors such as the voltage, power factor, performance and it and also it compatible with the network system. The DG also must be economical for the installation to the network system. Five value of DG was use to do the analysis the total losses of this network. All the values were choosing randomly based on the range size of DG and the size is not fixed because it just to get the changes of the reducing losses for each busbar. The DG was inserted for one busbar at one time to analysis the effect of losses for the network and it was continuing for all the busbar.

Table 3.3: Value of DG

No of DG	MW
1	1
2	2
3	3
4	9
5	25

The value of DG was inserted into the coding of m-file in generator column. The installation of DG will be effect the overall of the network and especially for the losses and voltage profile of the system. The figure below had shown the example coding of how to insert the value of DG. The first row is for the number of bus that was used to added the DG, then the value of the generator in MW that was injected and the last raw is for the number of column that represented for generation in the bus data coding.

```
clear
basemva = 100 ; accuracy = 0.0001; maxiter = 100;

bus_no=14;
gen_value=3;
busdata(bus_no,7)=gen_value;
```

Figure 3.2: Coding of inserted value of DG

3.4 DIgSILENT software

26 –bus of power system network was used for simulation and analysis using DIgSILENT. The simulation had done by using Newton Raphson method. The data and information of the 26 buses was getting from the Project Based Learning (PBL) of Power System Analysis subject.

3.4.1 26-Bus Power System Network

For this power system network, some of the information of the transformer, cable and motor was shown on the appendices. On the 11kV side of the main intake substation, there are 2 x incoming feeders which are from the two power transformers and 7 x 11kV outgoing feeders. Typically an 11/0.433kV substation comprises of switches for incoming and outgoing feeders as well as for distribution transformer feeder. Loads at 433V are assumed to be connected in star-grounded. Normally, MV network at 11kV are operated in radial. Loads at each substation are connected to the secondary side of either 11/0.433kV or 33/11kV transformers. At 433V, loads are to be connected in grounded-star while at 11kV loads are delta connected.

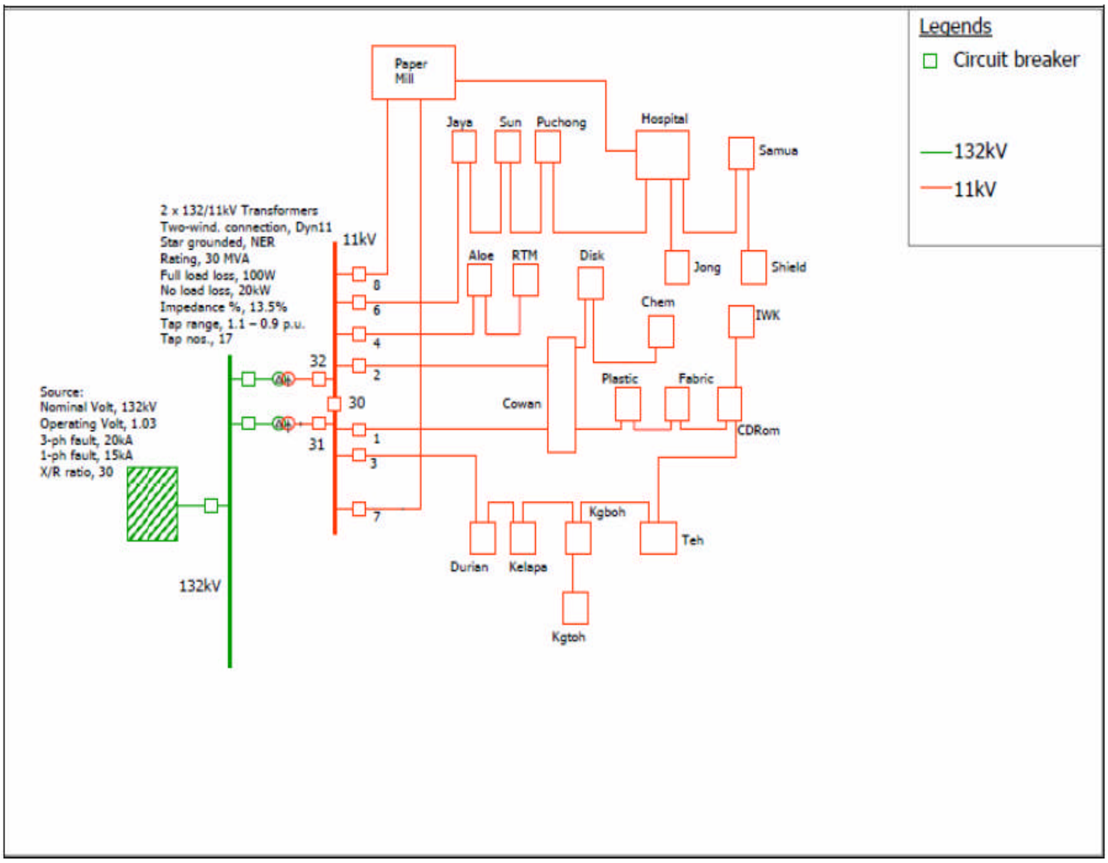


Figure 3.3: 26-Bus Test System

Appendix A had shown that all the information about the type, size and distance of each cable. Every substations have different cable and it depends on the load and distance at the substations. The selected of the cable at each substations must proper size and not exceed the current carrying capacity for that size of cable and also for the protection. The data for type and size of the cable at the software was chosen from the library of the software and used it for this project and varied the value of length.

The size of transformer and the static loads for each substation was shown at Appendix B. Only the power factor and the rating of load were used for this network. The transformer was step down transformer which is from 11kV to 0.433kV except the transformer at the incoming feeder (at grid system). The rating of the transformer was 132kV to 11kV with connection of the transformer is Dyn11 and was star grounded. The characteristic of the transformer was shown at the appendix D and appendix E and some data need to put in to the software. The data for the motor was shown at the appendix C. For this network, only 3 substations was used motor as a load.

3.4.2 Inserted DG in the system

DG was inserted on the system by selecting asynchronous motor at the sidebars at the software. The generator was selected either than motor for this application and the selected value was inserted which are value of rating power and power factor of the generator at the characteristic of DG. There was two type of DG that use on this software which is PQ and PV types. PQ type of generator will fix the value of reactive power and power factor but varied the voltage. The other type which PV will fix the value of voltage at the substation but can be varied the value of reactive power and power factor.

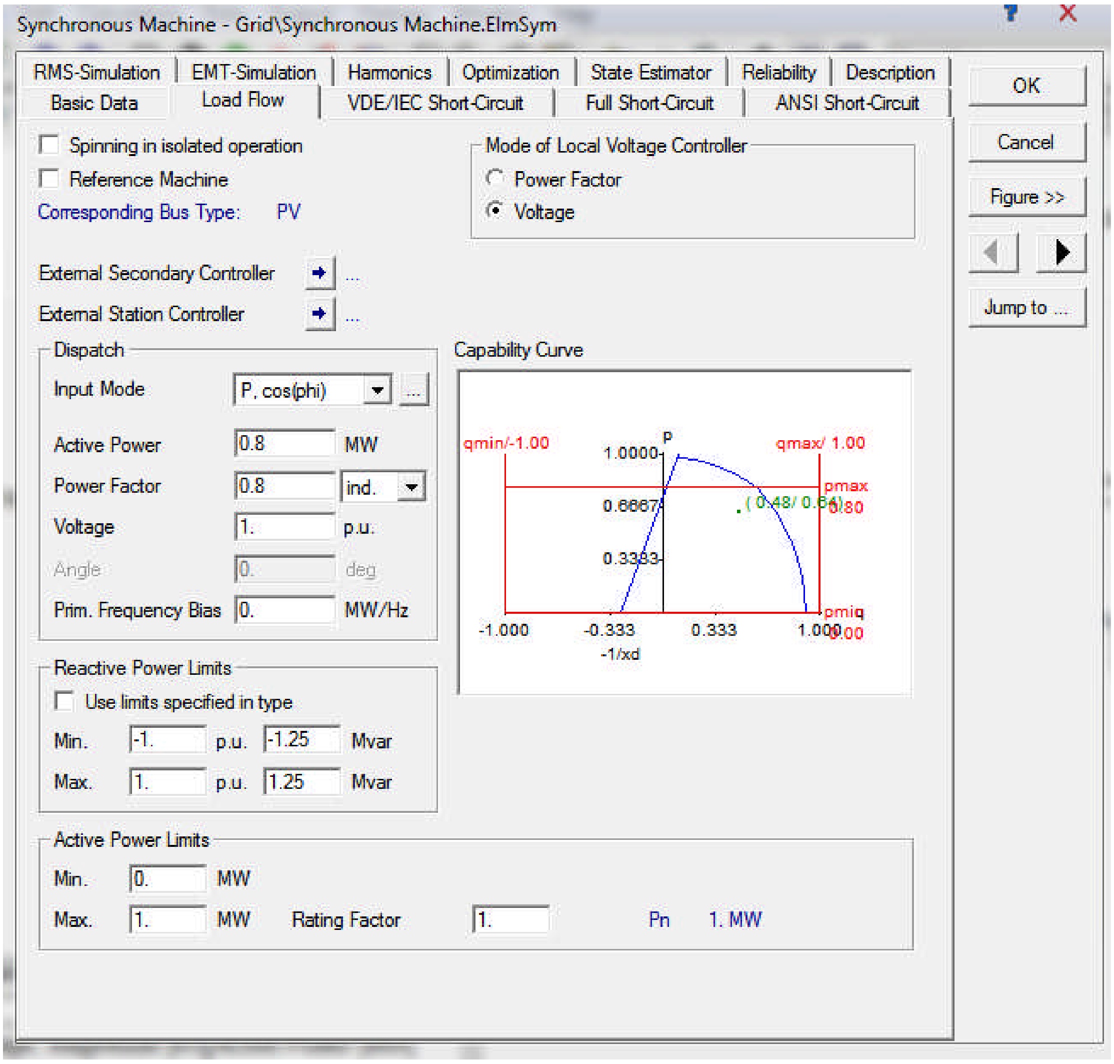


Figure 3.4: Sample for characteristic of inserted DG

3.4.3 Inserted Capacitor Bank in the system

The capacitor bank was injected to correct the power factor of the network system. Capacitor was inserted on the system by selecting shunt capacitor at the sidebars at the software. The selected value of capacitor that was used in this system was inserted at the characteristic of shunt capacitor as shown at figure 3.5.

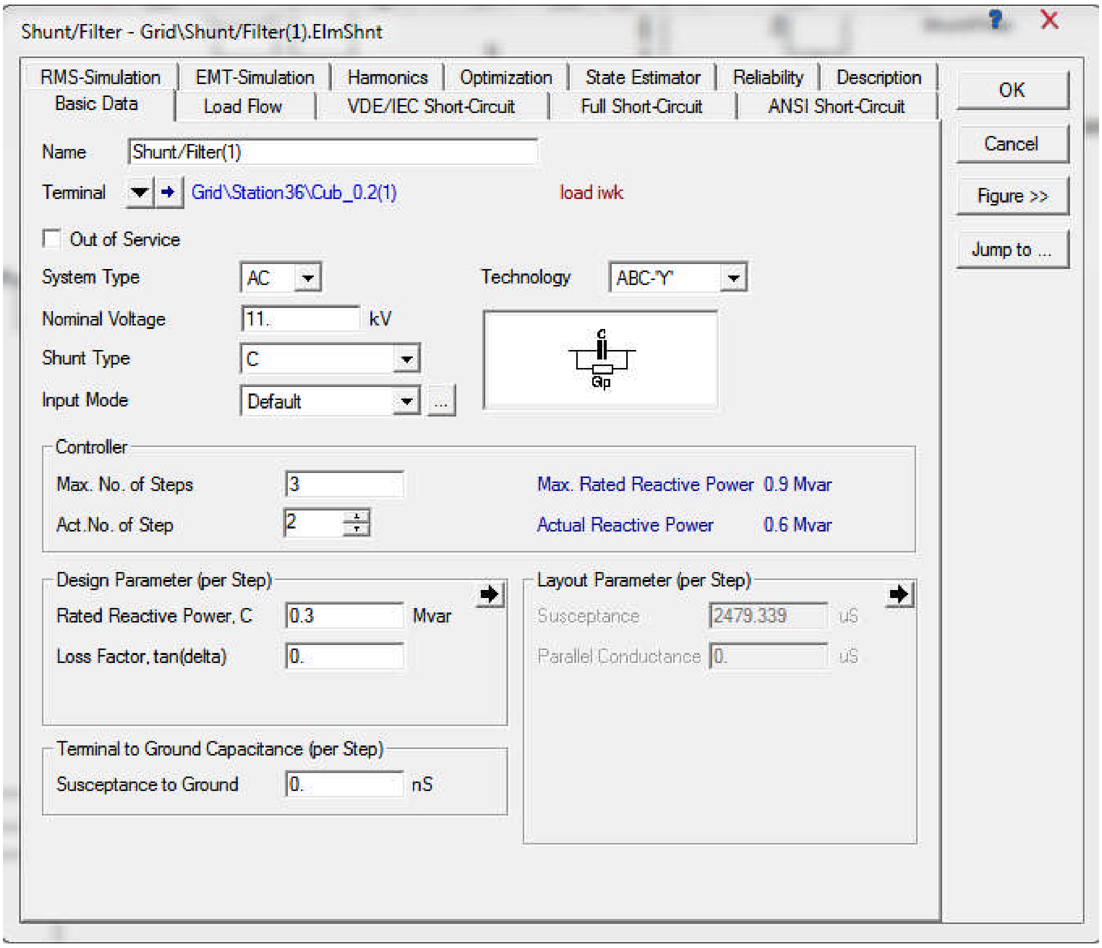


Figure 3.5: Sample for characteristic of shunt capacitor

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

The discussion of this chapter was categorized by two parts. The first parts consist of the discussion on the results of installation DG into the network system using MATLAB. Meanwhile the second part consist the discussion on the optimization power flow method.

4.2 Installation of Distributed Generation Using MATLAB

For simulation using MATLAB, the power flow analysis has been done using Newton Raphson method. The 14 bus of one line diagram was chosen for the simulation.

4.2.1 Result for One-line Diagram of 14-busbar

Before install the DG in the system, the result was getting by using the standard data of IEEE 14 test system. The total losses without DG are **13.821MW** and **34.088MVAR**. The simulations were performed for two cases:

1) Loss minimization by locating Single DG units at a busbar

2) Loss minimization by locating double DG unit at the different placement

4.2.1.1 Loss Minimization by Locating Single DG units

For this IEEE test system, the network was analysing by adding a DG at a busbar at one time and this will continues for every bus at the system. For the first case to analyse this system, DG was added at each bus with different values. Every bus will get the different reduction losses based on the location of the bus and also from the sizing of the DG. The table below show that the results of the total losses from each substations after installing the DG.

Table 4.1: The result after install the DG at each bus in the network system

Installation DG	1M	2M	3M	9M	25M
Bus No	(MW)	(MW)	(MW)	(MW)	(MW)
1	13.821	13.821	13.821	13.821	13.821
2	13.767	13.714	13.661	13.349	12.58
3	**13.683**	**13.547**	**13.475**	**12.678**	**10.747**
4	13.712	13.604	13.496	12.865	11.306
5	13.732	13.643	13.554	13.037	11.761
6	13.73	13.64	13.551	13.036	12.054
7	13.713	13.605	13.499	12.875	11.347
8	13.713	13.605	13.499	12.875	11.347
9	13.713	13.607	13.501	12.884	11.394
10	13.71	13.601	13.493	12.875	11.477
11	13.72	13.622	13.525	12.984	11.875
12	13.72	13.623	13.529	13.045	12.386
13	13.709	13.598	13.49	12.884	11.631
14	**13.682**	**13.546**	**13.412**	**12.674**	**11.211**

Table 4.2: The results of reducing losses of every bus

No of Bus	1MW	2MW	3MW	9MW	25MW
1	0	0	0	0	0
2	0.054	0.107	0.16	0.472	1.241
3	**0.138**	**0.274**	**0.346**	**1.143**	**3.074**
4	0.109	0.217	0.325	0.956	2.515
5	0.089	0.178	0.267	0.784	2.06
6	0.091	0.181	0.27	0.785	1.767
7	0.108	0.216	0.322	0.946	2.474
8	0.108	0.216	0.322	0.946	2.474
9	0.108	0.214	0.32	0.937	2.427
10	0.111	0.22	0.328	0.946	2.344
11	0.101	0.199	0.296	0.837	1.946
12	0.101	0.198	0.292	0.776	1.435
13	0.112	0.223	0.331	0.937	2.19
14	**0.139**	**0.275**	**0.409**	**1.147**	**2.61**

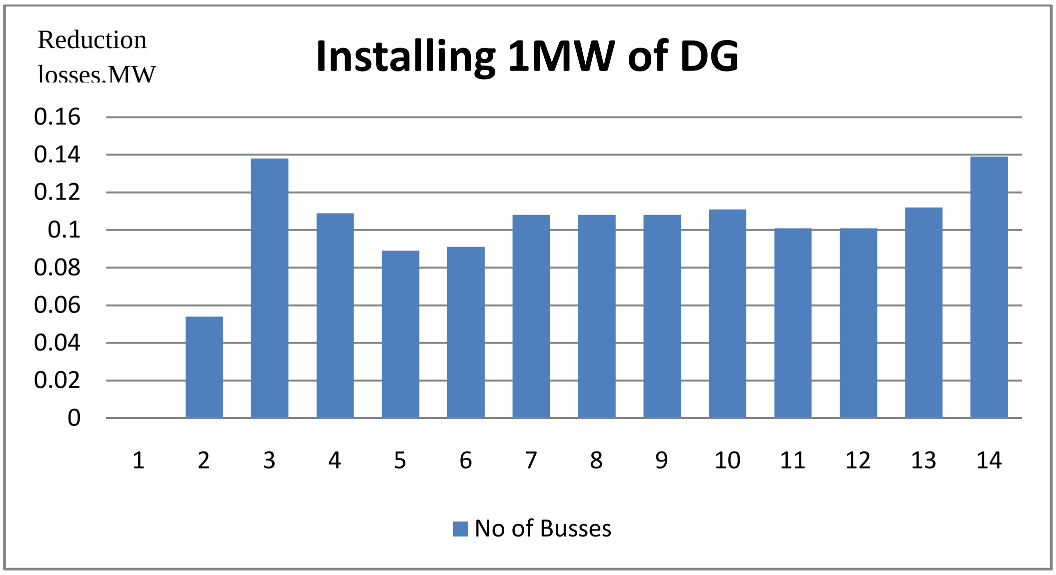


Figure 4.1: Graph of reduction losses by adding the lowest value of DG (1MW)

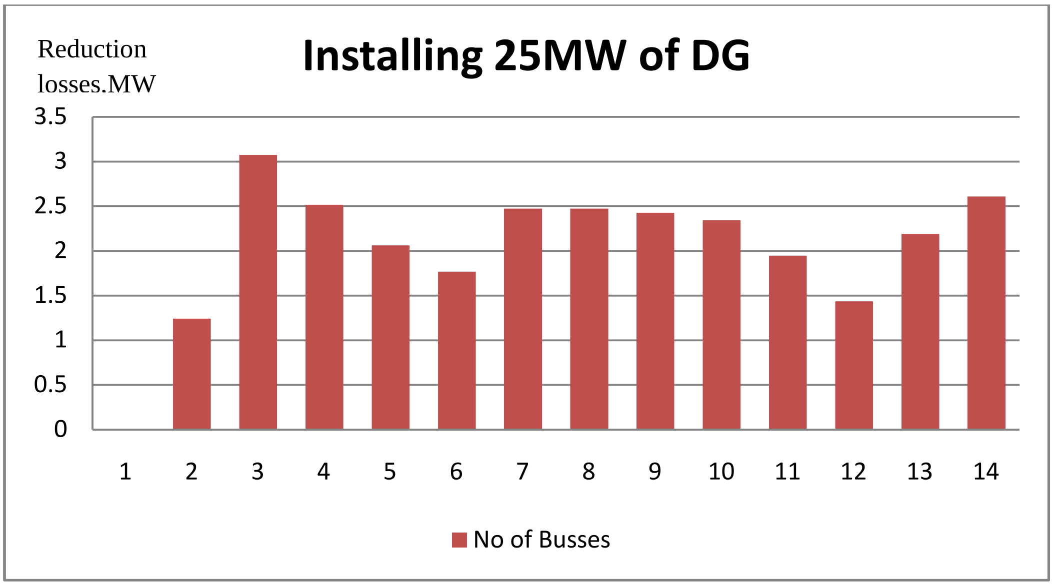


Figure 4.2: Graph of reduction losses by adding the highest value of DG (25MW)

From the table 4.1 and 4.2, total losses at each busses was reduce but the value of the reducing losses was depends on the placement and the sizing of the installation DG. DG units should be allocated in places where they provide a higher reduction of losses [4]. The DG units cause impact on both the active and reactive power. The most of losses reduce of the bus will be chosen to analyse it.

When refer to graph 4.1 and 4.2, the reducing losses at bus 3 and 14 were the higher value from the other bus. Hence, only both of the busses will be analyse for this system. When refer to the figure of the 14-busses network system, the placement and the load of the bus is the main factor for the reduction of losses. The range of the connection between the buses also will affect the result.

The allocation of bus 3 was far away from the other bus. Based on the data from IEEE, load at the bus 3 is the larger value compare to other load. From the theoretical knowledge of the power system, when adding generator at the larger load placement, it will directly reduce the losses because the power will distribute at short range. The situation of bus 14 was different with bus 3 which are the load is not the maximum and the allocation of the bus 14 was near to the other bus.

After get the result from these two substations, the others impact after installing the DG must be checked such as the voltage level, power factor and also the economical for installing the DG for that placement. But for this project, it only covered in reducing losses and also the voltage level of the system.

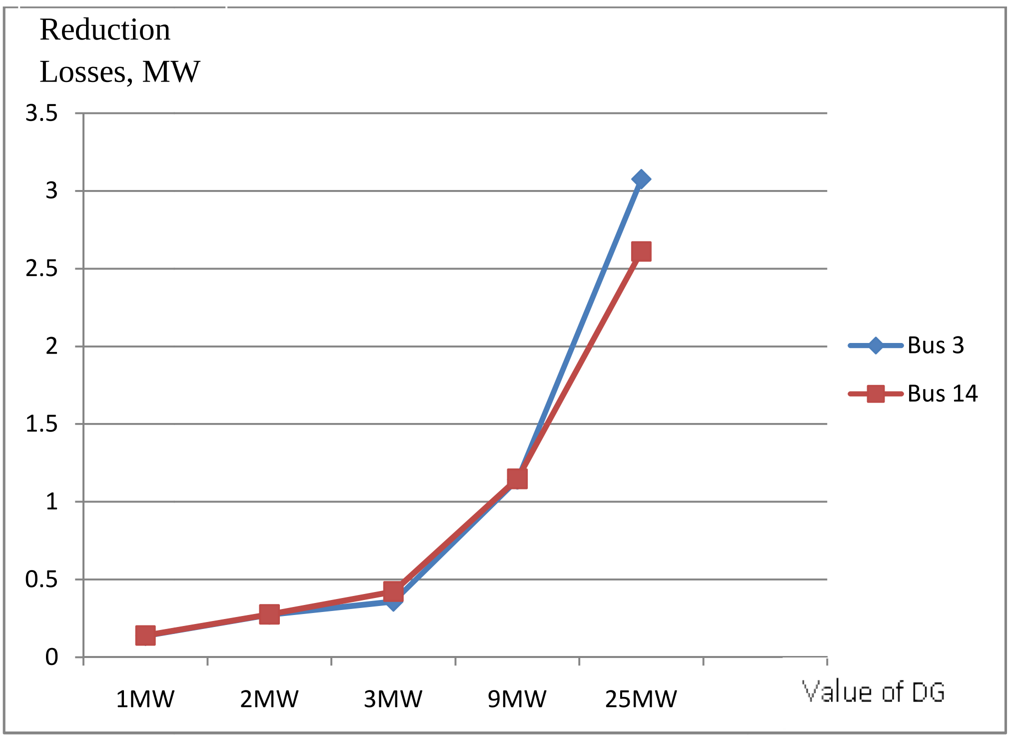


Figure 4.3: Graph of reducing losses for bus chosen

From the figure 4.3, bus 3 was very higher in reducing losses compare to bus 14. Therefore substation 3 was chosen for placement of inserted DG in the network system. But for the sizing of the installation generator, the value must be available in market for the real application to install the DG in the network.

Table 4.3: Available value of DG

Real Power	Apparent Power
1MW	1.250MVAR
2 MW	2.500 MVAR
2.765MW	3.456MVAR
6.52MW	8.148MVAR
7.45 MW	9.312MVAR
13.970 MW	17.460 MVAR

4.2.1.2 Loss minimization by locating double DG unit at the different placement

For this case, the DG units will be added both of the chosen busses which are substation 3 and substation 14. The sizing of DG is the same with the step 1 and the result of this to substation with different size of DG will be compare to with the result in the step 1.

Table 4.4: Reduction losses by different allocation of DG

Sizing of DG		Total Losses(MW)	Reduction Losses(MW)
Busbar 3	Busbar 14		
1MW	1MW	13.545	0.276
1MW	2MW	13.409	0.412
2MW	1MW	13.408	0.413

By optimally sizing two DG units at the optimal locations (buses 3and 14) in the 14 bus system, the real power losses are reduced. Any other combination of locations would not cause the real power losses to be as minimal. From table above, the results of the reduction losses of this case is more worth compare to first case. When install 2MW at the first case, the higher reduction losses was 0.275MW. But when inserted at both bus 3 and 14, the reduction losses is 0.276MW which means 1KW more than first case. Hence, this case is more suitable method to install the DG units compare to other case.

4.3 Installation of Distributed Generation Using DigSILENT software

For simulation using DigSILENT software, the 26 busses of a distribution network system was chosen for the simulation. The data and information was using from the Project Based Learning (PBL) of Power System Analysis. The modeling of the network system has done according with the parameters given. The power flow analysis has been done using Newton Raphson method.

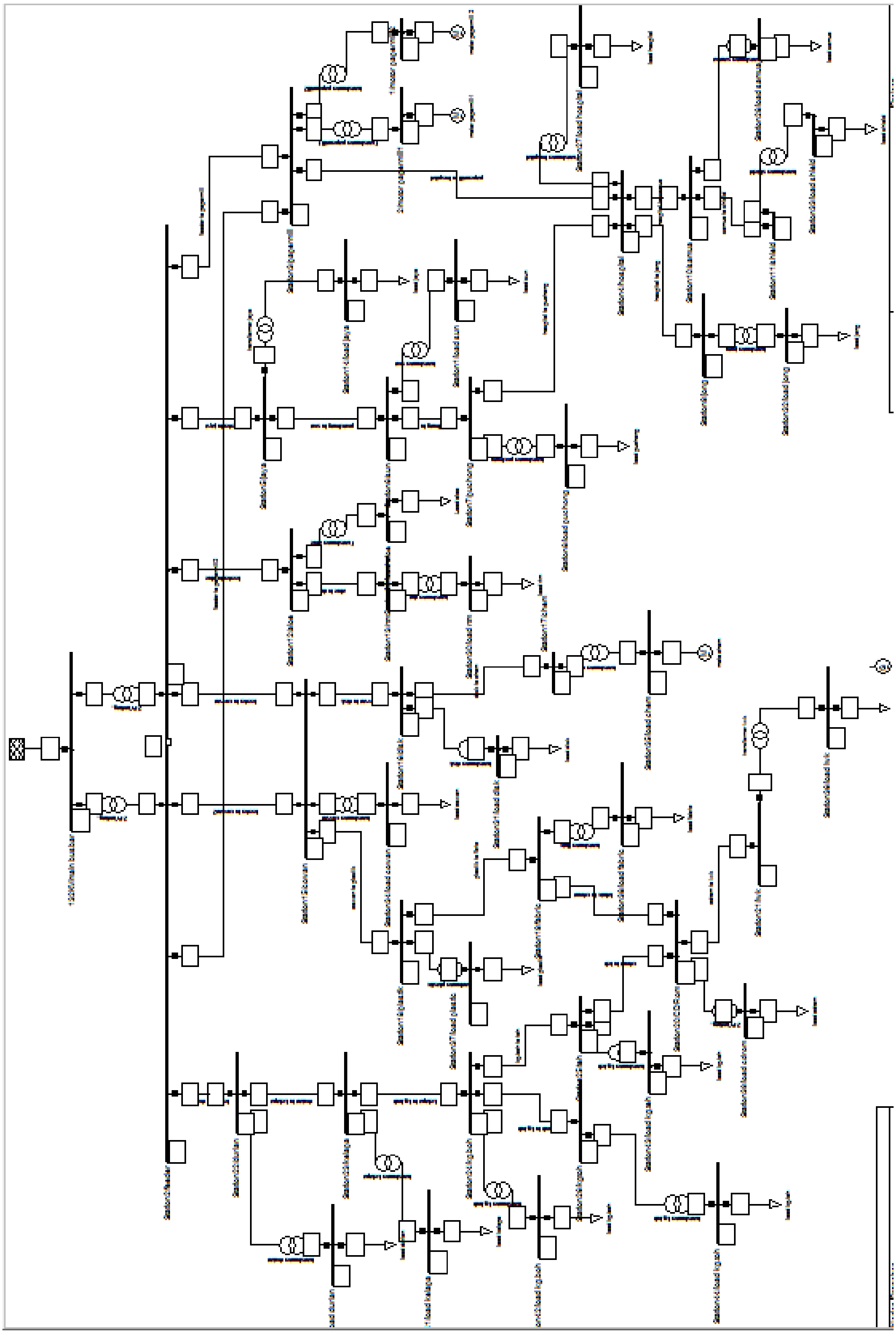


Figure 4.4: Complete network system of 26 busses

4.3.1 Result on simulating the network system

When using the information and data given, there have some over loading of the transformer and voltage violation for this network. If loading of the transformer are over 80% of the rating transformer, it was consider overloading. The level voltage of busbar is between 0.95 p.u until1.05 p.u and if the level is below or above this limit, it will consider violation of the voltage for the busbar. All the over limit and overloading of this network was shown at figure 4.5 below.

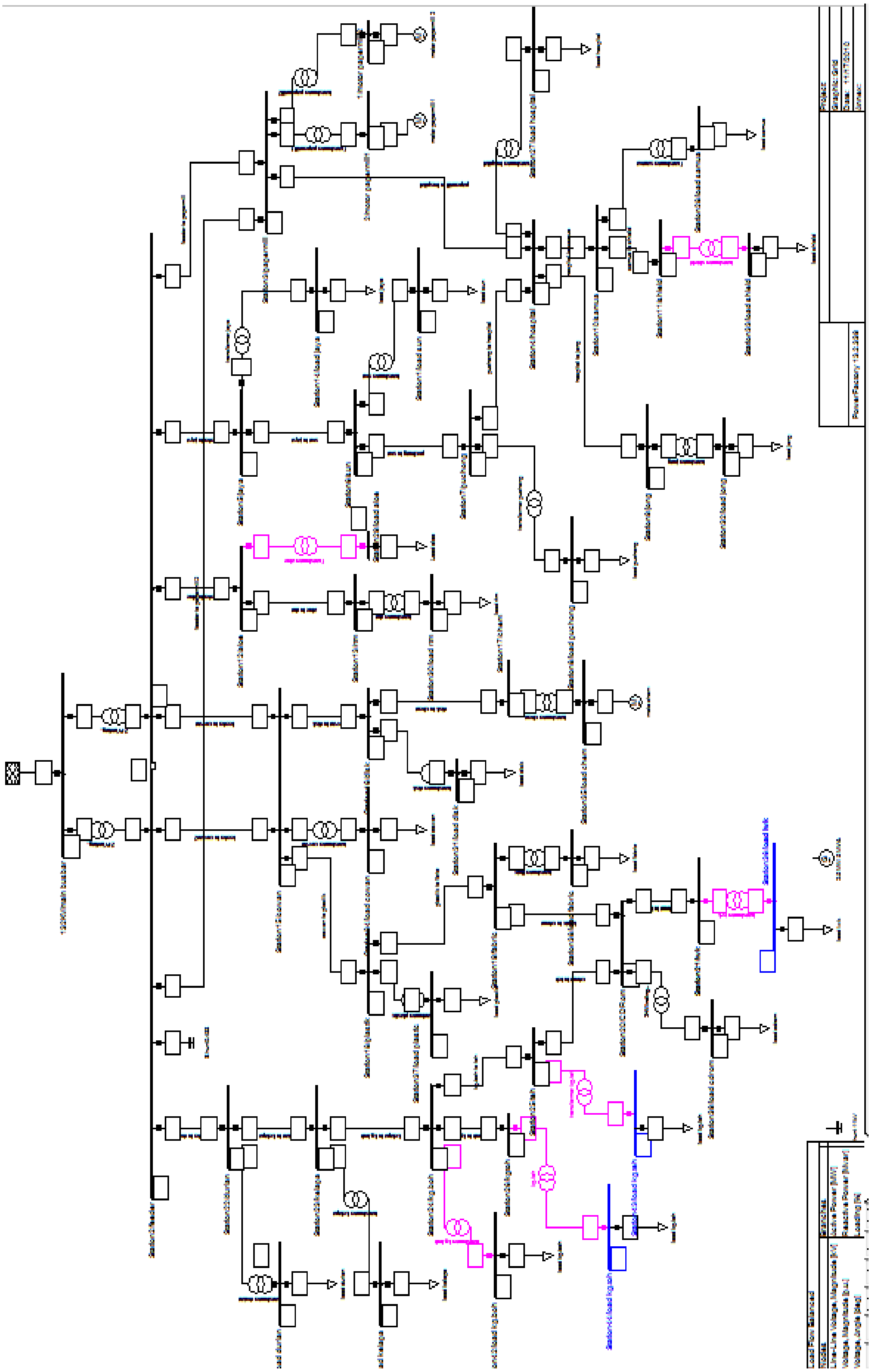


Figure 4.5: Six of the transformer was overloading condition

This problem of this network must be solved before proceed to reducing losses of the network. The figure of the overloading of each transformer and voltage violation problem was shown below and was tabulate in table 4.5.

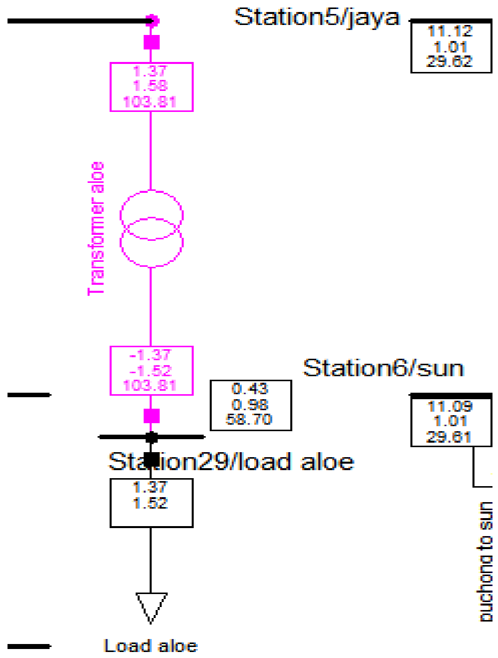


Figure 4.6: Overloading at aloe station

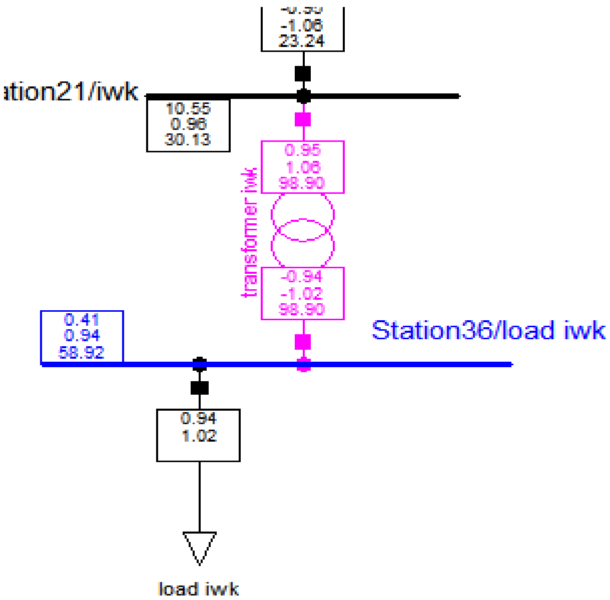


Figure 4.7: Overloading at IWK station

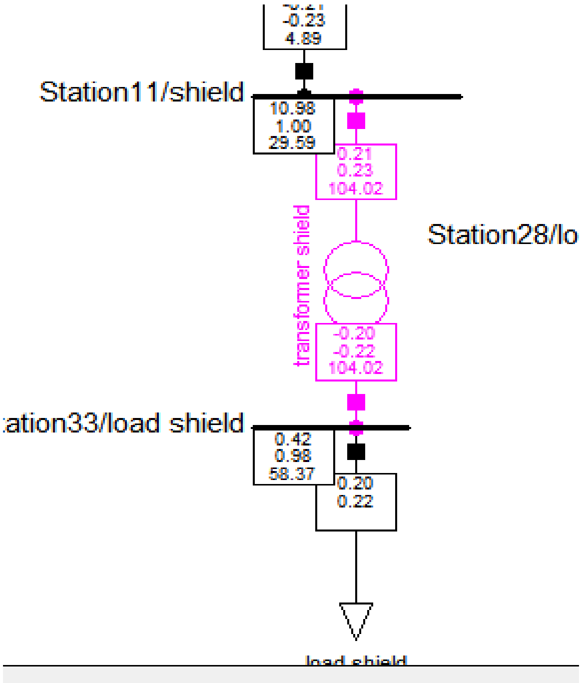


Figure 4.8: Overloading at Shield station

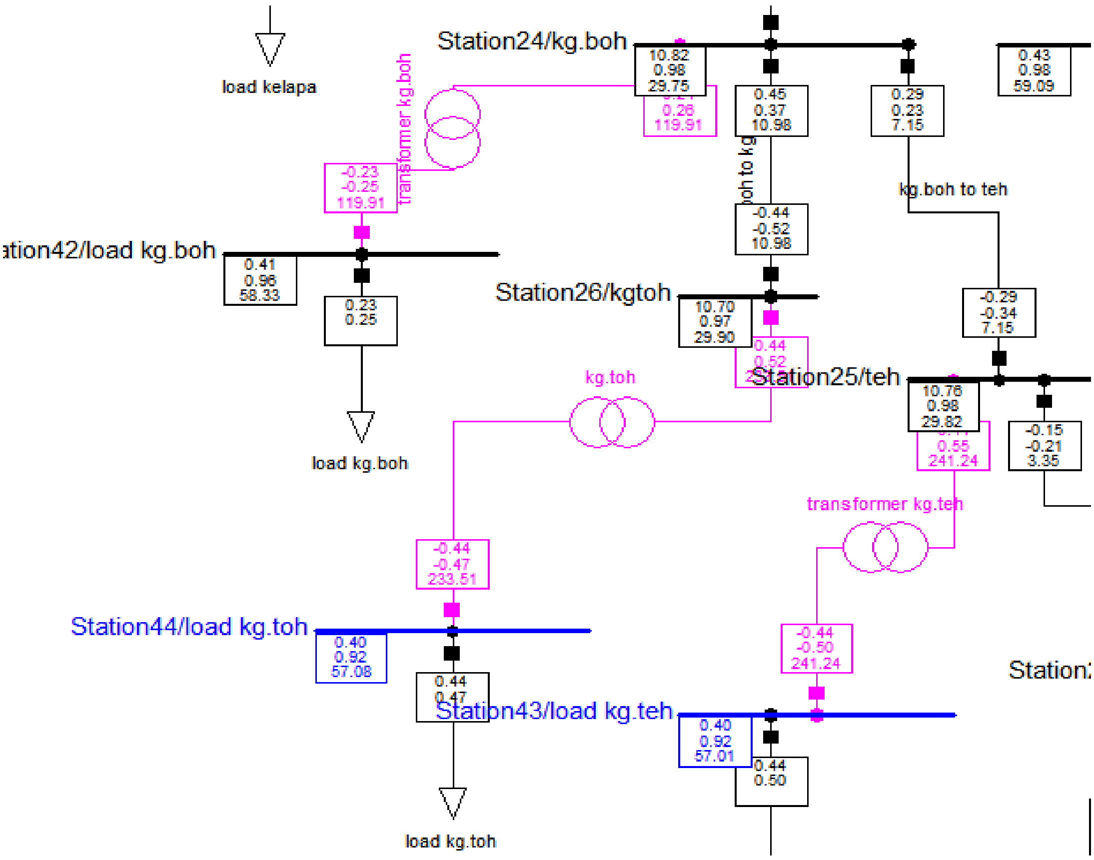


Figure 4.9: Overloading at Kg Toh, Kg Boh and Kg Teh station

Table 4.5: Table of overloading transformer

Area of Transformer	% of overloading
Aloe – Load	103.81
Kg. Boh - Load	119.91
Kg. Toh - Lod	233.51
Kg. Teh - Lod	241.24
IWK- Load	98.90
Shield-Load	104.02

Table 4.6: Table of violation voltage

Busbar	Violation voltage
Kg. Toh	0.92
Kg. Teh	0.92
IWK	0.94

From table 4.5 and 4.6, there have two method that will suggest to solve or overcome the overloading and voltage violation problem but before that must be consider many criteria such as the about the spacing of that area, sizing of transformer, long term period and economical. The methods are installing other transformer with same rating in parallel to divide the loading system and the other method by replacing the transformer with higher rating and sizing at the area problem. But the second method is more practicable and valuable for the real network.

From the theoretical knowledge of power system, the power loading will be divided and reduce by installing the transformer in parallel connection. But there have many criteria that must be consider for example the spacing of the area. There need wide space to install the transformer, need to change other equipment such as substation and also the circuit breaker and also redesign the system of protection at that area. It was not economical to utility for this method because many system need to change and replace many equipment when installing the other transformer. This method also is not practicable to do in the real network compare to do in software.

The second method is replacing the transformer with higher rating and sizing at the area problem. The rating of transformer must be available in market and the price of the replacing is more valuable compare with previous method. It will use the same placement of the old transformer and no need more space or area to install it. For the long time period of the operating transformer, of replacing transformer must below than 60% of the loading. It is because the load of consumer was always increasing in time to time and from the percentage of the loading, it can operate for five up to ten years.

The sizing and rating of transformer is not that can be decided randomly but it must be to consider that the sizing is available in market. 300kVA, 750kVA 1000kVA, 1500kVA, 2500kVA, 3500kVA and up to 80MVA are mostly use for high voltage network. Hence, when chosen the rating for replacement transformer, it must choose the minimum rating but the loading must be less than 60% and from that it will suggest the economical value for the replacement transformer of the network system.

Table 4.7: Reduce overloading transformer by replacing transformer with higher rating power

Transformer	Old Rate Power(MVA)	New Rate Power(MVA)	Old Loading (%)	New Loading (%)
Kg. Teh-Load	0.30	1.2	103.81	57.72
Kg Toh- Load	0.30	1.2	119.91	55.98
Aloe – Load	2.0	3.5	233.51	58.70
Kg. Boh– Load	0.3	0.75	241.24	47.16
IWK- Load	1.5	3	98.90	48.93
Shield-Load	0.3	0.75	104.02	41.04

By replacing the transformer, the violation voltage was automatically fixed and the voltages that change were tabulated in table 4.8. Hence, the voltages were in allowed voltages which are in range 0.95 p.u to1.05 p.u.

Table 4.8 Reduce voltage violation by changing rating power of transformer

BUSBAR	VOLTAGE LIMIT (PU)	
	OLD	NEW
Kg Toh – Load	0.92	0.96
Teh – Load	0.92	0.97
IWK - Load	0.94	0.95

4.3.2 Loss Minimization by Adding DG unit

After solving the network system problem, the network was analysing by adding the DG at each substation. The total losses of the system before adding the DG was 0.46MW and -0.99MVAR. The distribution network is connected to the grid with some loads being supplied by a remote mini-hydro generating unit. Hence, the type of DG that will be installing in this network system was mini-hydro. IWK station was chosen for installing the DG system based the network. In order to reduce the losses in this network 5MVA of DG was installed at the IWK station and for mini hydro it can generate until that value. The DG (mini hydro) was generated 1MW to supply for the system. After install the DG at the network, the loss was reduced to 0.36MW and -1.12MVAR. It means that 100KW was reduced after installed the DG in the network system. The result of this reduction loss was tabulated at table 4.7.

Total System Summary				Study Case: Study Case			Annex:		/ 9
	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\napie\PSM\Grid									
	0.00	3.70	8.37	0.00	12.53	0.00	0.46	0.40	0.06
	0.00	2.50	9.20	0.00	10.71	0.00	-0.99	0.75	-1.74
Total:									
	0.00	3.70	8.37	0.00	12.53		0.46	0.40	0.06
	0.00	2.50	9.20	0.00	10.71		-0.99	0.75	-1.74

Figure 4.10: Losses before installed the DG in the system

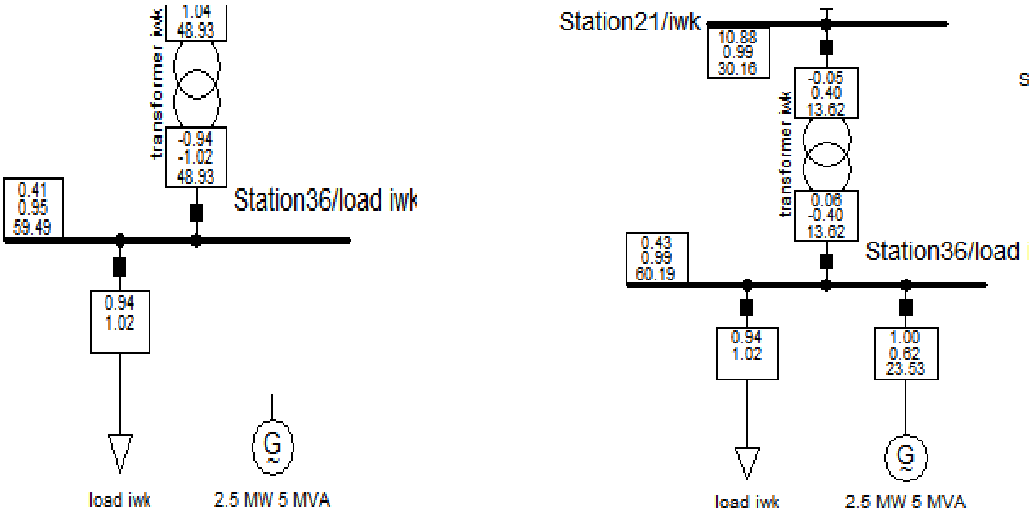
Total System Summary				Study Case: Study Case			Annex:		/ 9
	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\napie\PSM\Grid									
	1.00	3.70	8.37	0.00	11.43	0.00	0.36	0.30	0.06
	0.62	2.50	9.20	0.00	9.95	0.00	-1.12	0.63	-1.75
Total:									
	1.00	3.70	8.37	0.00	11.43		0.36	0.30	0.06
	0.62	2.50	9.20	0.00	9.95		-1.12	0.63	-1.75

Figure 4.11: Losses after installed the DG in the system

Table 4.9: Result reduction losses by installing DG

	Without DG	With DG	Reduction Losses
Total Losses, MW	0.46	0.36	0.1

Another effect of the system after installing the DG was improvement of voltage profile at the substation. Figure 4.12 below showed that the comparison between before and after installing DG for this system. The voltage profile or voltage level of the substation was improved from 0.95 p.u to 1.0 p.u. Even the level voltage of that substation was 0.95p.u which considering as good condition for the voltage level, but it the optimum value of voltage level for substation is 0.99 p.u. Hence, the DG also improved the voltage level of the system while the losses were reducing at the same time.



a) Before b) After

Figure 4.12: Improvement of voltage profile when installing DG

4.4 Installation of Shunt Capacitor Using DigSILENT software

By using the same network, the analysis was continuing by injecting Capacitor Bank (shunt capacitor) to the network system. There have two cases before install the shunt capacitor which are injecting shunt capacitor with DG and without DG on the system.

4.4.1 Installing shunt capacitor with DG in the system

By adding the DG in the distribution network, the power flow of the network will change and it also will change the network losses. Another factor that must be considered in the power system network was the power factor of the system. After adding the DG, the power factor of the system will change either improved or not. By installing the DG at this system, it was change the value of power factor from 0.76 to 0.75 and it showed at figure 4.13. The value of power factor still not exceeds the limitation by utility which below than 0.65 but it still bother the performance of the system.

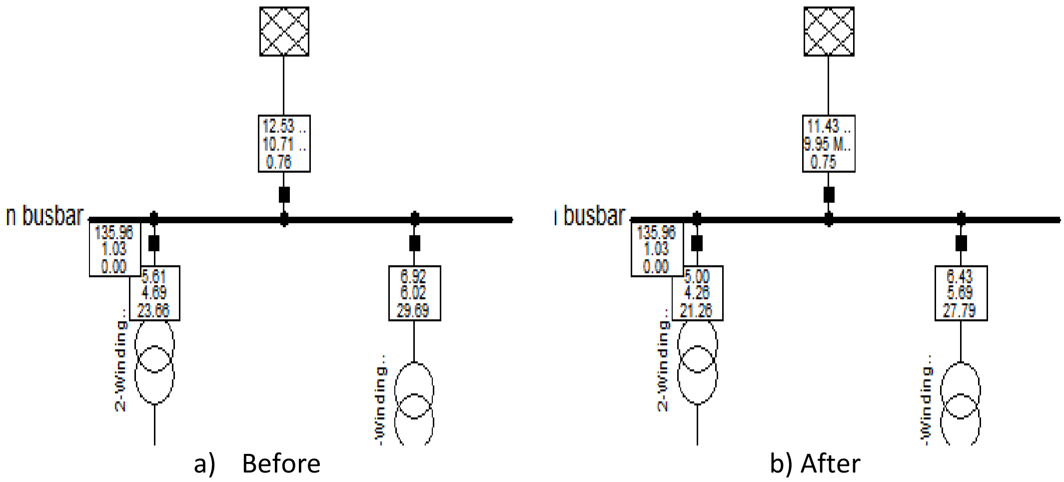


Figure 4.13: Comparison of power factor in the system before and after installing the DG unit

After injecting the shunt capacitor at the system, the power factor was increased. The shunt capacitor was injecting on the high voltage side of the transformer. After injecting the shunt capacitor, the power factor was improved from 0.75 to 0.85. The losses also were reducing from 0.36MW to 0.35MW after injecting the shunt capacitor. The DG must be maintenance for four or five year after start the operation of generation. If the system DG was shut down for maintenance, the network system will be change automatically and it will cause the increasing of losses. Hence, injecting the shunt capacitor on the network system can fixed these changes of the system. But if the DG was shutdown or disconnected from the system by doing the maintenance, the system was same as the other case which is installing the shunt capacitor without DG in the system. Therefore, the analysis was continuing on the next cases.

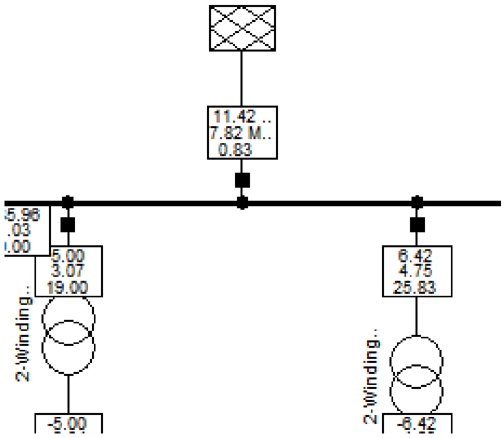


Figure 4.14 Improvement of power factor after injecting shunt capacitor with the DG in the system

4.4.2 Installing shunt capacitor without DG in the system

Installing the DG and shunt capacitor can cause the reducing losses of the network system. By installing the shunt capacitor, it will improve the power factor and reducing losses. From the figure 4.15, the reduction losses of network system by installing the shunt capacitor was lower than reduction losses by installing the DG. The maximum loss that was getting is 0.39MW for this system. But the power factor was improved directly from 0.76 to 0.82.

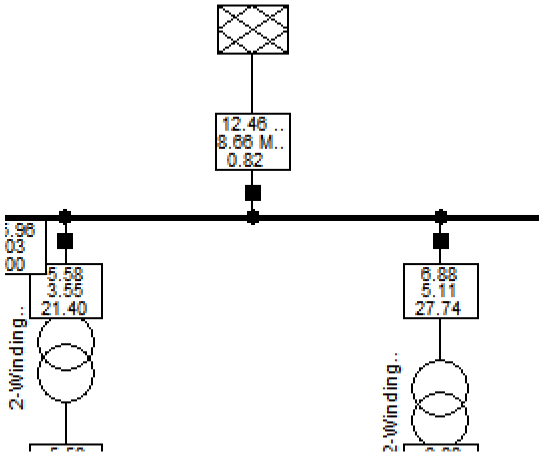


Figure 4.15 Improvement of power factor after injecting shunt capacitor without the DG in the system

Table 4.10 Comparison on effect of losses and power factor with different cases

Network system	Power factor	Losses, MW
Reference Case	0.76	0.46
Installing DG	0.75	0.36
Installing DG with Capacitor	0.83	0.35
Installing Capacitor	0.82	0.39

Therefore, both of the components have their advantages in order to improve this network system. To reducing more losses in the network system, the DG was injected but the power factor was degraded from the original value and the shunt capacitor was injected to improve the power factor from the effect of installing DG. The capacitor also can reduce the losses but the reduction was lower compare to installing the DG. By comparing these two component of power system, the DG was use to reduce more power losses in the system and the capacitor was used to improve the power factor. And from both components also different in price and the economical issue is not covered in this thesis.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.0 Conclusion

The objective of this project is to analyse the impact of Distributed Generation on the performance an existing distribution network in term of system losses and also comparing the effect of DG with shunt capacitor in term of power factor improvement and system losses. Generally, the first and second objectives with the scope of this project have been successfully achieved.

The DG was able to minimise the network losses but failed to improve the power factor of the system. Improvement of power factor is the main advantages for installing the shunt capacitor in the network system. The shunt capacitor also can reduce losses but the reducing is lower by installing the DG in the system. Hence, in order to minimise the losses in the system, DG was suggested compared to shunt capacitor and shunt capacitor was suggested to stabilize the power factor of the network.

Hopefully, this project can be a platform for other students to come up with the development of other method or technique to solve the power network system by taking this project as a reference for them.

5.1 Future Recommendation

For further research, there are several recommendations to enhance and improve such as:

i. Use multiple network system

For this study, it only covers by using IEEE Reliability Test System of 14 busses and also 26-bus test system. To understand more in the impact of DG, use larger network such 30 or 69 busses test systems. The larger network systems will give more effect on the DG installation.

ii. Focusing on either on allocation or sizing of DG

The optimal and sizing of the DG is more important part for network problem. But for this study, the method of used for allocation and sizing are not the best method to solve this network system because it only focusing on the reduction of network losses.

iii. Using same network system for both of software

To analysis more effective, use same network system for both of the software. The result from both of the software will be analyzed for the same network and comparable of both which one more better and accurate for the result.

REFERENCES

[1] M. Sedighizadeh, and A. Rezazadeh “Using Genetic Algorithm for Distributed Generation Allocation to Reduce Losses and Improve Voltage Profile”, World Academy of Science, Engineering and Technology 37 2008.

[2] An D.T. Le, M.A. Kashem, M. Negnevitsky, G. Ledwich “Minimising Power Losses in Distribution Systems with Distributed Resources” Australia

[3] Mohamad AlHajri “Sizing and Placement of Distributed Generation in Electrical Distribution Systems Conventional and Heuristic Optimization Methods”, Dalhousie University Halifax, Nova Scotia June 2009

[4] Carmen L. T. Borges and Djalma M. Falcão “ Impact of Distributed Generation Allocation and Sizing on Reliability, Losses and Voltage Profile” Bologna, Italy 2003

[5] P. Chiradeja “Benefit of Distributed Generation: A Line Loss Reduction Analysis” Department of Electrical Engineering, Faculty of Engineering Srinakharinwirot University, Bangkok, Thailand, 2005

[6] Ahmed M. Azmy and István Erlich “Impact of Distributed Generation on the Stability of Electrical Power Systems” 0-7803-9156-X/05/$20.00© 2005

[7] Edy Ernesto Jiménez Toribio, “Impact of Distributed Generation on Unbalanced Power System”, University of Puerto Rico Mayaguez Campus, 2009

[8] Houssen Salh Milad “Optimal Siza and Location of Shunt Capacitors on Distribution feeder Using The Reduction of PPL and EL” Dalhousie University, Canada 2008

[9] Damián Galarza-Torres, “Stability Optimization Installing Distributed Generation in The Electrical System of Puerto Rico” University of Puerto Rico Mayaguez Campus, 2009

[10] J.G. Slootweg and W.L. Kling. “Impacts of Distributed Generation on Power System Transient Stability” GA Delft, Netherlands 2002

[11] W. El-Khattam, Y.G. Hegazy and M. M. A. Sdama, “Stochastic Power Flow Analysis of Electrical Distributed Generation Systems” Canada 2003

[12] Gustavo Brunello, Dr. Bogdan Kasztenny and Craig Wester “Shunt Capacitor Bank Fundamentals and Protection” Texas A&M University 2009

[13] Shivkumar Iyer, Arindam Ghosh and Avinash Joshi “Power Flow Control in a Distribution System through an Inverter Interfaced Distributed Generator” Kanpur, INDIA 2006

[14] Chris A Quillen “Analysis of Reactive Power Compensation Methods in Distribution System” Tennessee Technological University August 2009

[15] Yuriy Varetsky and Zbigniew Hanzelka “Capacitor Bank Impact on Harmonic Filters Operation in Power Supply System” 2009

[16] C.T.Hsu Y.H.Yan, C.S. Chen and S. L “Optimal Reactive Power Planning for Distribution System with Nonlinear Loads” Taiwan China, 2003

REFERENCES

[1] M. Sedighizadeh, and A. Rezazadeh "Using Genetic Algorithm for Distributed Generation Allocation to Reduce Losses and Improve Voltage Profile", World Academy of Science, Engineering and Technology 37 2008.

[2] An D.T. Le, M.A. Kashem, M. Negnevitsky, G. Ledwich "Minimising Power Losses in Distribution Systems with Distributed Resources" Australia

[3] Mohamad AlHajri "Sizing and Placement of Distributed Generation in Electrical Distribution Systems Conventional and Heuristic Optimization Methods", Dalhousie University Halifax, Nova Scotia June 2009

[4] Carmen L. T. Borges and Djalma M. Falcão " Impact of Distributed Generation Allocation and Sizing on Reliability, Losses and Voltage Profile" Bologna, Italy 2003

[5] P. Chiradeja "Benefit of Distributed Generation: A Line Loss Reduction Analysis" Department of Electrical Engineering, Faculty of Engineering Srinakharinwirot University, Bangkok, Thailand, 2005

[6] Ahmed M. Azmy and István Erlich "Impact of Distributed Generation on the Stability of Electrical Power Systems" 0-7803-9156-X/05/$20.00© 2005

[7] Edy Ernesto Jiménez Toribio, "Impact of Distributed Generation on Unbalanced Power System", University of Puerto Rico Mayaguez Campus, 2009

[8] Houssen Salh Milad “Optimal Siza and Location of Shunt Capacitors on Distribution feeder Using The Reduction of PPL and EL” Dalhousie University, Canada 2008

[9] Damián Galarza-Torres, “Stability Optimization Installing Distributed Generation in The Electrical System of Puerto Rico” University of Puerto Rico Mayaguez Campus, 2009

[10] J.G. Slootweg and W.L. Kling. “Impacts of Distributed Generation on Power System Transient Stability” GA Delft, Netherlands 2002

[11] W. El-Khattam, Y.G. Hegazy and M. M. A. Sdama, “Stochastic Power Flow Analysis of Electrical Distributed Generation Systems” Canada 2003

[12] Gustavo Brunello, Dr. Bogdan Kasztenny and Craig Wester “Shunt Capacitor Bank Fundamentals and Protection” Texas A&M University 2009

[13] Shivkumar Iyer, Arindam Ghosh and Avinash Joshi “Power Flow Control in a Distribution System through an Inverter Interfaced Distributed Generator” Kanpur, INDIA 2006

[14] Chris A Quillen “Analysis of Reactive Power Compensation Methods in Distribution System” Tennessee Technological University August 2009

[15] Yuriy Varetsky and Zbigniew Hanzelka “Capacitor Bank Impact on Harmonic Filters Operation in Power Supply System” 2009

[16] C.T.Hsu Y.H.Yan, C.S. Chen and S. L “Optimal Reactive Power Planning for Distribution System with Nonlinear Loads” Taiwan China, 2003

APPENDIX A

(List of cable size between substations)

List of Cable size between substations

From S/S	To S/S	Cable Type	Cable Size (sq mm)	Cable Length (KM)
Main Intake Feeder 1	Cowan	XLPE (3-core)	185	8
main Intake Feeder 2	Cowan	XLPE (3-core)	185	8
Main Intake Feeder 3	Durian	XLPE (3-core)	185	10
Main Intake Feeder 4	Aloe	XLPE (3-core)	120	5
Main Intake Feeder 6	Jaya	XLPE (3-core)	120	5
Main Intake Feeder 7	Papermill	XLPE (3-core)	240	10.5
Main Intake Feeder 8	Papermill	XLPE (3-core)	240	10.5
Paper Mill	Hospital	XLPE (3-core)	240	3.4
Hospital	Puchong	XLPE (3-core)	120	0.95
Hospital	Disk	XLPE (3-core)	185	2
Hospital	Jong	XLPE (3-core)	120	7
Hospital	Samua	XLPE (3-core)	120	5
Puchong	Sun	XLPE (3-core)	120	2.5
Sun	Jaya	XLPE (3-core)	120	1.2
Aloe	RTM	XLPE (3-core)	300	4
RTM	Cowan	XLPE (3-core)	185	1.8
Cowan	Disk	XLPE (3-core)	185	8
Cowan	Plastic	XLPE (3-core)	185	0.5
Disk	Chem	XLPE (3-core)	185	0.9
Chem	Fabric	XLPE (3-core)	185	1.5

From S/S	**To S/S**	**Cable Type**	**Cable Size (sq mm)**	**Cable Length (KM)**
Kelapa	KG Boh	XLPE (3-core)	120	7.5
Kg Boh	Teh	XLPE (3-core)	120	8
Kg Boh	Kg Toh	XLPE (3-core)	120	10.5
Samua	Shield	XLPE (3-core)	120	4.5
Plastic	Fabric	XLPE (3-core)	185	3
Fabric	CDRom	XLPE (3-core)	185	0.55
CDRom	IWK	XLPE (3-core)	120	11
CDRom	Teh	XLPE (3-core)	185	5
Durian	Kelapa	XLPE (3-core)	185	5

APPENDIX B

(List of rating of transformer and load at each substation)

List of rating of transformer and load at each substation

		Transformer 1			Transformer 2	
Substation	Size kVA	Load kVA	Load P.F	Size kVA	Load kVA	Load P.F
Papermill	2500	400	0.68	2500	600	0.868
Jaya	500	327.23	0.68			
Sun	2500	595.45	0.69			
Puchong	2500	480.44	0.66			
Hospital	750	393.3	0.67			
Samua	2500	284.44	0.68			
Aloe	2000	2041.2	0.67			
RTM	2500	313.47	0.68			
Disk	750	451.1	0.67			
Jong	300	175.88	0.66			
Shield	300	300.55	0.68			
Cowan	1000	751.06	0.69			
Chem	1500	813.23	0.66			
IWK	1500	1388.99	0.68			
Plastic	2000	1074.76	0.67			
Fabric	1000	676.65	0.67			
CDRom	2500	853.84	0.66			
Durian	2500	381.26	0.68			
Kelapa	2500	300.04	0.68			
Kg Boh	300	340.65	0.68			
Teh	300	665.53	0.66			
Kg Toh	300	642.51	0.68			

APPENDIX C

(List of motor load)

List of motor load

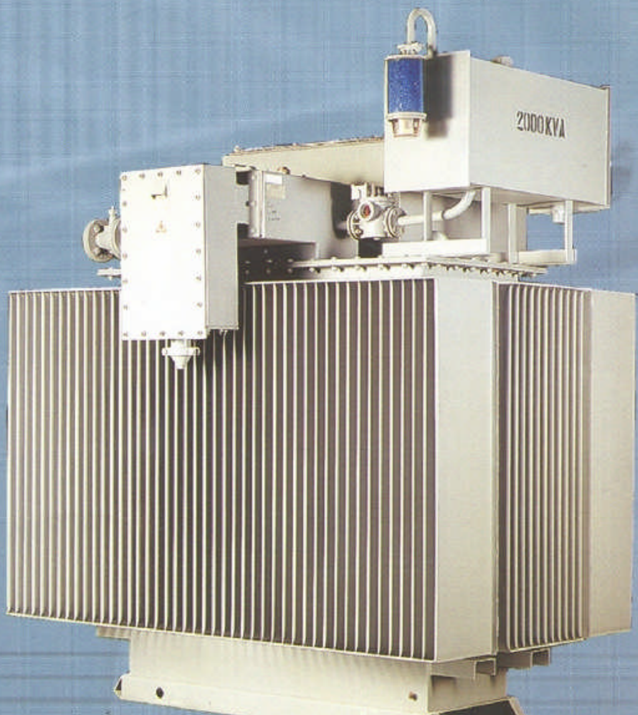
	Substation	Papermill Transfomer 1	Papermill Transfomer 2	Chem
	Rated Voltage (kV)	3.3	3.3	3.3
	Rate power (kW)	2000	2000	2000
	Loading (kW)	1200	1500	1000
Loacked Rotor	R p.u	0.753	0.161	0.0753
	X p.u	0.149	0.104	0.149
Reactance (p.u)	Subtransient	0.119	0.0991	0.119
	Transient	0.1958	0.0991	0.1958

APPENDIX D

(Characteristic of Transformer)

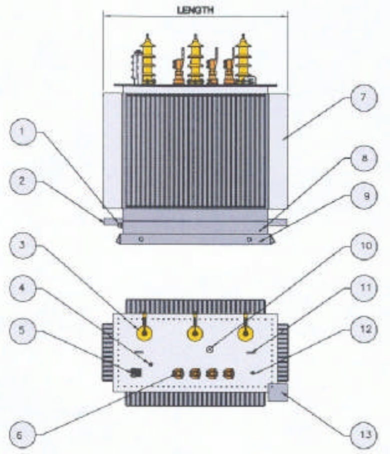
MALAYSIA TRANSFORMER

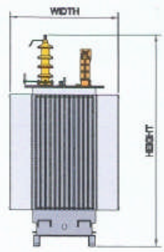
Distribution Transformers



Distribution *Transformers*

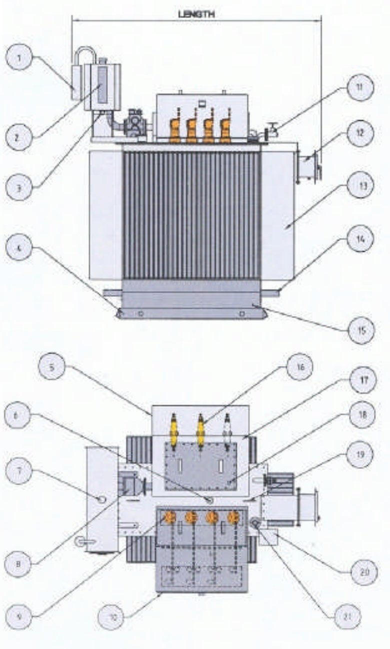
Diagram A - Outline Arrangement of Hermetically-Sealed Distribution Transformer

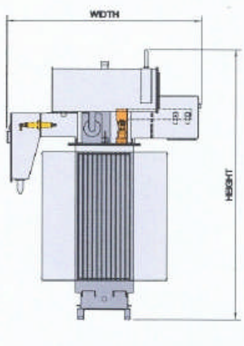




ITEM	DESCRIPTION
1	Oil Sampling Device
2	Jacking Pad
3	High Voltage Bushings
4	Pressure Relief Device
5	Oil Level Gauge
6	Low Voltage Bushings
7	Finwalls
8	Earthing Terminals
9	Skid Base
10	Off Load Tap Changer
11	Lifting Hook For Complete Unit
12	Thermometer Pocket
13	Rating And Diagram Plate

Diagram B - Outline Arrangement of Conservator-Type Distribution Transformer





ITEM	DESCRIPTION
1	Dehydrating Breather
2	Oil Level Gauge
3	Oil Sampling Device
4	Skid Base
5	HV Cable Box
6	Off Load Tap Changer
7	Oil Filling Cap
8	Buchholz-Relay
9	Low Voltage Bushings
10	LV Cable Box
11	Filter Valve
12	Control Compartment Box
13	Finwalls
14	Jacking Pad
15	Earthing Terminals
16	High Voltage Bushings
17	HV Disconnecting Chamber
18	Air Release Plug
19	Lifting Hook For Complete Unit
20	Rating And Diagram Plate
21	Oil Temperature Indicator

Distribution Transformers

Technical Data of Distribution Transformer 6.6/0.433 kV Dyn 11

kVA	TYPE	LOSSES (W)		IMPEDANCE (%)	TOTAL WEIGHT (KG)	OIL QUANTITY (LITRE)	OVERALL DIMENSION(mm)			DIAGRAM
		NO LOAD	LOAD				LENGTH	WIDTH	HEIGHT	
100	S	300	1500	4.75	663	151	918	622	1050	A
300	S	600	2800	4.75	1628	320	1237	787	1270	A
500	S	1000	4100	4.75	1967	452	1360	840	1418	A
750	S	1200	6000	4.75	2607	461	1649	986	1475	A
1000	S	1400	7000	4.75	3278	533	1700	920	1580	A
1500	C	1600	16300	6.00	3923	762	1829	1768	2001	A

S – *Hermetically Sealed Type* **C** – *Conservator Type*

Technical Data of Distribution Transformer 11/0.433 kV Dyn 11

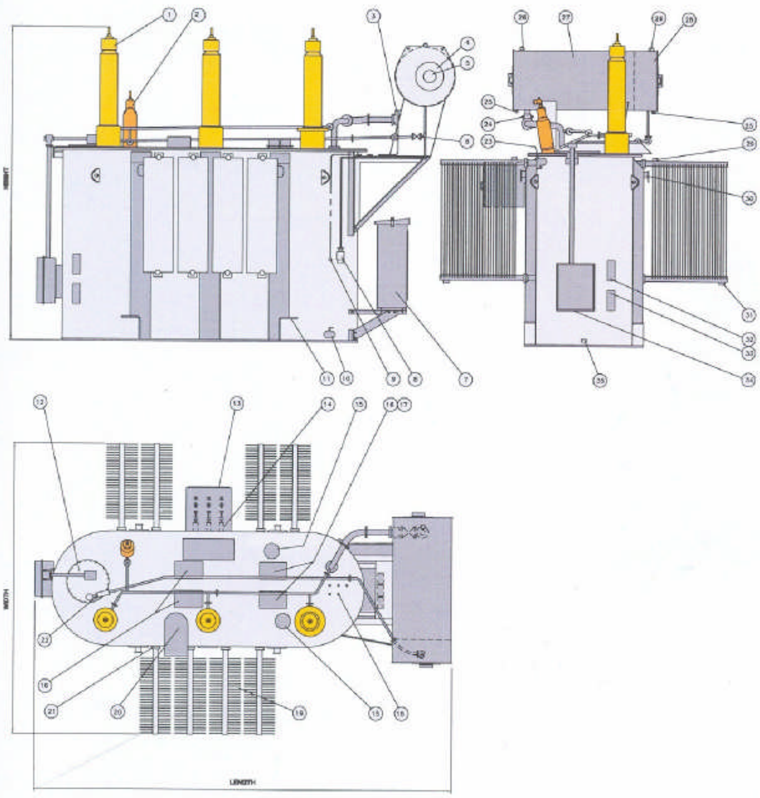
kVA	TYPE	LOSSES (W)		IMPEDANCE (%)	TOTAL WEIGHT (KG)	OIL QUANTITY (LITRE)	OVERALL DIMENSION(mm)			DIAGRAM
		NO LOAD	LOAD				LENGTH	WIDTH	HEIGHT	
50	S	150	900	4.75	551	159	1035	855	1040	A
100	S	300	1500	4.75	620	140	918	697	1050	A
300	S	6000	2800	4.75	2323	326	1212	781	1288	A
500	S	1000	4100	4.75	2342	436	1370	850	1387	A
750	S	1200	6000	4.75	2676	507	1622	1002	1502	A
1000	S	1400	7000	4.75	3447	612	1679	930	1625	A
1250	C	1600	10000	5.00	4023	762	2009	2003	1983	B
1500	C	1600	14570	6.00	4246	926	2011	1765	2120	B
2000	C	2200	25000	6.00	5248	1233	2110	1810	2422	B
2500	C	2500	25000	7.00	5466	1244	2041	2986	2588	B

S – Hermetically Sealed Type C – Conservator Type

MTM reserves the right to change the Technical Specifications without notice.

Power Transformers

Outline Arrangement of Power Transformer 132/11kV



ITEM	DESCRIPTION
1	High Voltage Bushing
2	High Voltage Neutral Bushing
3	Buchholz-Relay
4	Inspection Cover
5	Oil Level Indicator
6	Expansion Tank Valve For Tap Changer
7	Local Control Panel
8	Dehyrating Breather
9	Gas Sampling Device Test Cock (For Buchholz-Relay)
10	Drain Valve with Sampling Device
11	Jacking Bracket
12	On Load Tap Changer
13	LV Cable Box
14	Low Voltage Bushing
15	Current Transformer Terminal
16	Cover For Access Lifting Core And Windings
17	Cover For Grounding Magnetic Circuit
18	Thermometer Pocket
19	Radiator
20	Pressure Relief Device With Protection Cover
21	Radiator Valve
22	Pressure Relay
23	Filter Valve
24	Expansion Tank Valve For Transformer
25	Drain Valve
26	Oil Filling Cap
27	Expansion Tank
28	Expansion Tank For On Load Tap Changer
29	Air Release Plug For Radiator
30	Lifting Hook For Complete Unit
31	Oil Drain Plug For Radiator
32	Rating And Diagram Plate
33	Location And Function Of All Valve Plate
34	Motor Drive
35	Earthing Terminals

Power
Transformers

Technical Data of Power Transformer 33/11kV

RATED MVA	VECTOR GROUP	COOLING TYPE	NOISE LEVEL (dBA)	LOSSES (kW) LOAD	LOSSES (kW) NO LOAD	IMPEDANCE (%)	TOTAL WEIGHT (METRIC TON)	OIL QUANTITY (LITRE)	OVERALL DIMENSION(mm) LENGTH	OVERALL DIMENSION(mm) WIDTH	OVERALL DIMENSION(mm) HEIGHT
30	Dyn 11	ONAF	55	120	15	10	45.3	11334	7483	3743	4115
30	Dyn 11	ONAF	64	125	17	10	41	8000	7274	3615	3590
15	Dyn 11	ONAF	64	80	11	10	27	5046	6124	3140	3240
7.5	Dyn 11	ONAN	64	36	8	7.5	20	5402	5881	3136	3048
7.5	Ynd 1	ONAN	64	36	7	7.5	19	5057.5	5041	3112	2829

MTM reserves the right to change the Technical Specifications without notice.

Technical Data of Power Transformer 132/11kV

RATED kVA	VECTOR GROUP	COOLING TYPE	NOISE LEVEL (dBA)	LOSSES (kW) LOAD	LOSSES (kW) NO LOAD	IMPEDANCE (%)	TOTAL WEIGHT (METRIC TON)	OIL QUANTITY (LITRE)	OVERALL DIMENSION(mm) LENGTH	OVERALL DIMENSION(mm) WIDTH	OVERALL DIMENSION(mm) HEIGHT
30	YNd 11	ONAN	60	100	20	13.5	69.4	20689	7286	4796	5460
30	YNynO (d)	ONAN	60	100	20	13.5	79	18750	7200	5030	5850

MTM reserves the right to change the Technical Specifications without notice.

APPENDIX E

(Characteristic of Distributed Generation)

DIESEL GENERATOR SET

STANDBY
1000 ekW 1250 kVA
50 Hz 1500 rpm 400 Volts

Caterpillar is leading the power generation marketplace with Power Solutions engineered to deliver unmatched flexibility, expand

FEATURES

FUEL/EMISSIONS STRATEGY

- Low Fuel consumption

DESIGN CRITERIA

- The generator set accepts 100% rated load in one step per NFPA 110 and meets ISO 8528-5 transient response.

FULL RANGE OF ATTACHMENTS

- Wide range of bolt-on system expansion attachments, factory designed and tested

WORLDWIDE PRODUCT SUPPORT

- Cat dealers provide extensive post sale support including maintenance and repair agreements
- Cat dealers have over 1,600 dealer branch stores operating in 200 countries
- The Cat® S•O•S℠ program cost effectively detects internal engine component condition, even the presence of unwanted fluids and combustion by-products

CAT 3512 TA DIESEL ENGINE

- Reliable, rugged, durable design
- Field-proven in thousands of applications worldwide
- Four-stroke-cycle diesel engine combines consistent performance and excellent fuel economy with minimum weight

CAT SR5 GENERATOR

- Matched to the performance and output characteristics of Cat engines
- Industry leading mechanical and electrical design
- Industry leading motor starting capabilities
- High Efficiency

CAT EMCP 3 SERIES CONTROL PANELS

- Simple user friendly interface and navigation
- Scalable system to meet a wide range of customer needs
- Integrated Control System and Communications Gateway

STANDBY 1000 ekW 1250 kVA

50 Hz 1500 rpm 400 Volts

TECHNICAL DATA

Open Generator Set - - 1500 rpm/50 Hz/400 Volts	DM8218	
Low Fuel Consumption		
Generator Set Package Performance		
Genset Power rating @ 0.8 pf	1250 kVA	
Genset Power rating with fan	1000 ekW	
Coolant to aftercooler		
Coolant to aftercooler temp max	82 ° C	180 ° F
Fuel Consumption		
100% load with fan	259.8 L/hr	68.6 Gal/hr
75% load with fan	199.9 L/hr	52.8 Gal/hr
50% load with fan	138.8 L/hr	36.7 Gal/hr
Cooling System[1]		
Air flow restriction (system)	0.12 kPa	0.48 in. water
Air flow (max @ rated speed for radiator arrangement)	1558 m^3/min	55020 cfm
Engine Coolant capacity with radiator/exp. tank	286.8 L	75.8 gal
Engine coolant capacity	156.8 L	41.4 gal
Radiator coolant capacity	130.0 L	34.3 gal
Inlet Air		
Combustion air inlet flow rate	90.5 m^3/min	3196.0 cfm
Exhaust System		
Exhaust stack gas temperature	447.7 ° C	837.9 ° F
Exhaust gas flow rate	227.7 m^3/min	8041.2 cfm
Exhaust flange size (internal diameter)	203.2 mm	8.0 in
Exhaust system backpressure (maximum allowable)	6.7 kPa	26.9 in. water
Heat Rejection		
Heat rejection to coolant (total)	604 kW	34349 Btu/min
Heat rejection to exhaust (total)	995 kW	56586 Btu/min
Heat rejection to aftercooler	152 kW	8644 Btu/min
Heat rejection to atmosphere from engine	114 kW	6483 Btu/min
Heat rejection to atmosphere from generator	60.4 kW	3434.9 Btu/min
Alternator[2]		
Motor starting capability @ 30% voltage dip	2883 skVA	
Frame	1424	
Temperature Rise	150 ° C	270 ° F
Lube System		
Sump refill with filter	310.4 L	82.0 gal

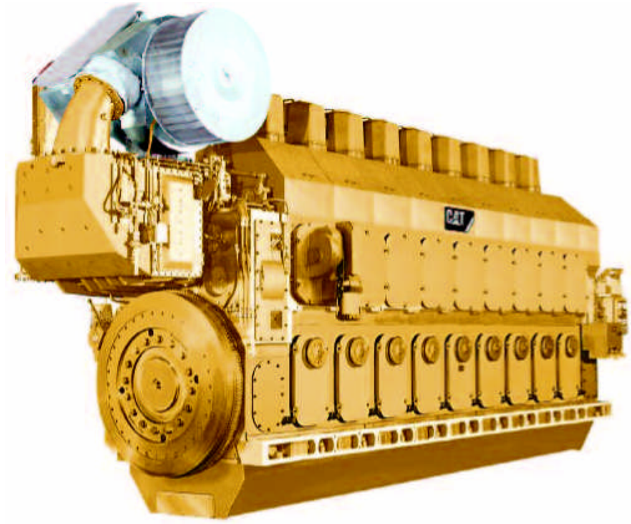
[1]For ambient and altitude capabilities consult your Caterpillar dealer. Air flow restriction (system) is added to existing restriction from factory.

[2]Generator temperature rise is based on a 40°C (104°F) ambient per NEMA MG1-32.

CM32

DIESEL ENGINE GENERATOR SET

2765–4190 kWe
600
rpm
50/60
Hz



ENGINE

- Engine type: 4-stroke cycle diesel engine
- Cylinder configuration: In-line - 6, 8, 9
- Fuel type: LFO, CRO and HFO up to 700 cSt
- Bore: 320mm (12.6 in)
- Stroke: 480 mm (18.9 in)
- Cylinder displacement: 38.6 L (2356 cu in)
- Cylinder output: 480 kW (644 bhp)
- Mean piston speed: 9.6 m/s (31.5 ft/s)
- Mean effective pressure: 24.9 bar (361 psig)
- Aspiration: Turbocharged and after-cooled
- Compression ratio: 15.5:1
- Engine rating: 2880–4320 kW
- Generator set rating: 2765–4190 kWe

FEATURES

Designed for Reliable Operation

- Intensive cooling of key components including exhaust valve seats, injector cooling integrated into lube oil system and high-efficiency turbocharger
- Capable of operation up to 700 cSt/50° C fuel quality according to CIMAC H55/K55

Minimized Mechanical Wear

- Modular design
- State-of-the-art material ensure long life of components

Overall Economy

- High availability and long life
- Low fuel and oil consumption
- Low maintenance requirements

Highest Quality Engine Parts

- Semi-dry wear resistant liners with calibration inserts
- Pistons with forged steel crown and aluminum skirt
- Inlet/outlet valves with armored seats
- High-efficiency turbocharger

One-Piece Dry Engine Block

- High-strength nodular cast iron with under slung crankshaft and free from cooling water

Ease of Maintenance and Reliability

- Easily removable cylinder heads, quick removable fluid connections
- Split connecting rods to allow piston removal without disturbing the big end bearing
- High reliability, modular design and integral construction reduce the number of components by 40% over conventional designs

Total Power Solutions

- Caterpillar® can develop, finance, design, build, test, maintain and operate medium speed reciprocating engine power plants, plant assets and at the customer's option provide:
  - Power generation equipment
  - Engineered systems
  - Combined heat and power systems
  - Construction and installation services
  - Operation and maintenance services
  - Turnkey power plants
  - Contract power

Worldwide Product Support

- With nearly 200 Cat® dealers and 1,500 facilities worldwide serving in excess of 200 countries, you're never far from the Caterpillar support you need
- Customer Support Agreements offer back-to-back services including scheduled inspections, preventive maintenance and overhauls to full operations and maintenance

CM32

DIESEL ENGINE GENERATOR SET

NOMINAL PERFORMANCE

	ENGINE RATING	GENERATOR SET RATING		SPEED	FREQUENCY	HEAT RATE		SPECIFIC LUBE OIL CONSUMPTION	
	kWm	kWe	kVA	rpm	Hz	kJ/kWh	Btu/kWh	g/kWh	lb/kWh
6CM32	2,880	2,765	3,456	600	50/60	7,962	7,546	0.6	0.0013
8CM32	3,840	3,725	4,656	600	50/60	7,836	7,427	0.6	0.0013
9CM32	4,320	4,190	5,238	600	50/60	7,836	7,427	0.6	0.0013

RATING DEFINITIONS AND CONDITIONS

Fuel type: Light fuel oil (LFO), crude oil (CRO) and heavy fuel oil (HFO) with fuel quality limit at 50° C according to CIMAC H55/K55.

Ratings: Based on ISO3046/1 standard reference conditions.

Power output: May require adjustment for values other than ISO3046/1 standard reference conditions.

Continuous output: Available for an unlimited time without varying load.

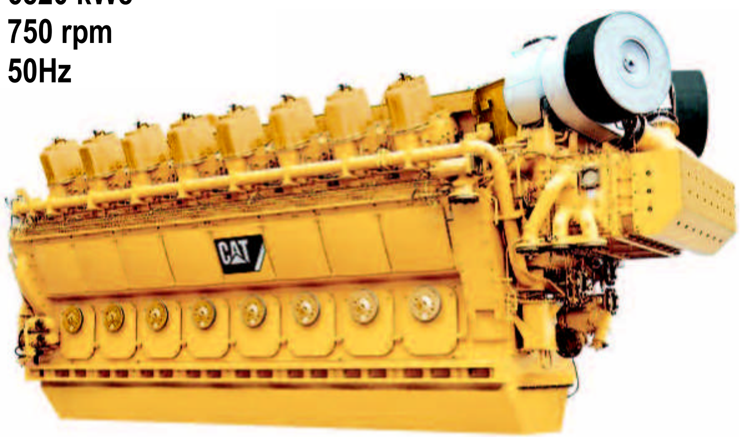
Generator efficiency: Efficiency of 97.0% (96.0% for the 6CM32) based on 0.8 pf with medium voltage class generator; actual efficiency will depend on generator selection.

Materials and specifications are subjectto change without notice.© 2007 Caterpillar
CAT, CATERPILLAR, their respective logos and "Caterpillar Yellow,"and the POWER EDGE All rights reserved
trade dress as well as corporate and product identity used herein, are trademarks of DSCM32/TD/LEHX8581-07/1004/EO
Caterpillar and may not be used without permission.

GCM34

GAS ENGINE GENERATOR SET

6520 kWe
750 rpm
50Hz



FEATURES

Designed for Reliable Operation

- Spark ignition, lean burn combustion and pre-chamber design
- Intensive cooling of key components including spark plugs, main! pre-chamber and exhaust valve seats
- Proven Cat® electronic control system, precise fuel delivery and long stroke design result in world-class efficiency
- Robust engine platform based on proven heavy fuel engine design

Low Emissions

- Air-to-fuel ratio control, optimized pre-chamber design and Cat electronic control result in low emissions
- Configurations with NOx emissions to 500 or 250 mg!N·m^3 at 5% 0_2 available

Minimized Mechanical Wear

- Modular design and state-of-the-art material ensure long life of components

Overall Economy

- Cost savings include high availability, long life, low fuel and oil consumption and low maintenance requirements

Highest Quality Engine Parts

- Semi-dry wear resistant liners with calibration inserts
- Pistons with forged steel crown and aluminum skirt
- Inlet!outlet valves with armored seats
- High-efficiencyturbocharger

One-Piece Dry Engine Block

- Cast from nodular cast iron with under slung crankshaft and free from cooling water

Ease of Maintenance and Reliability

- Designed to provide efficient maintenance including easily removable cylinder heads, quick removable fluid connections and split connecting rods to allow piston removal without disturbing the big end bearing
- High reliability, modular design and integral construction reduce the number of components by 40% over conventional designs

ENGINE

- Engine type: 4-stroke cycle gas engine
- Cylinder configuration: Vee - 16
- Fuel type: Natural gas
- Methane number: 80 (minimum 70)
- Bore: 340 mm (13.4 in)
- Stroke: 420 mm (16.5 in)
- Cylinder displacement: 38.1 L (2328 cu in)
- Cylinder output: 420 kW (564 bhp)
- Mean piston speed: 10.5 m!s (34.5 ft!s)
- Mean effective pressure: 17.6 bar (255 psig)
- Aspiration: Turbocharged and after-cooled
- Compression ratio: 11.4:1
- Engine rating: 6720 kW
- Generator set rating: 6520 kWe

Total Power Solutions

- Caterpillar® can develop, finance, design, build, test, maintain and operate medium speed reciprocating engine power plants, plant assets and at the customer's option provide:
  - Power generation equipment
  - Engineered systems
  - Combined heat and power systems
  - Construction and installation services
  - Operation and maintenance services
  - Turnkey power plants
  - Contract power

Worldwide Product Support

- With nearly 200 Cat dealers and 1,500 facilities worldwide serving in excess of 200 countries, you're never far from the Caterpillar support you need
- Customer Support Agreements offer back-to-back services including scheduled inspections, preventive maintenance and overhauls to full operations and maintenance

GCM34

GAS ENGINE GENERATOR SET

NOMINAL PERFORMANCE

	ENGINE RATING	GENERATOR SET RATING		SPEED	FREQUENCY	HEAT RATE		SPECIFIC LUBE OIL CONSUMPTION	
	kWm	kWe	kVA	rpm	Hz	kJ/kWh	Btu/kWh	g/kWh	lb/kWh
G 1 6CM34	6,720	6,520	8,148	750	50	7,748	7,344	0.3	0.0007

RATING DEFINITIONS AND CONDITIONS

Ratings: Based on ISO3046/1 standard reference conditions and natural gas having a methane number of 80 or higher.

Power output: May require adjustment for values other than ISO3046/1 standard reference conditions.

Continuous output: Available for an unlimited time without varying load.

Generator efficiency: Efficiency of 97% based on 0.8 pf with medium voltage class generator; actual efficiency will depend on generator selection.

Fuel consumption: Based on ISO3046/1 standard reference conditions of 25° C (77° F) and 100 kPa (29.61 in Hg), natural gas with methane number of 80, including engine-driven pumps and with 5% tolerance. Value based on measurement at the generator terminals.

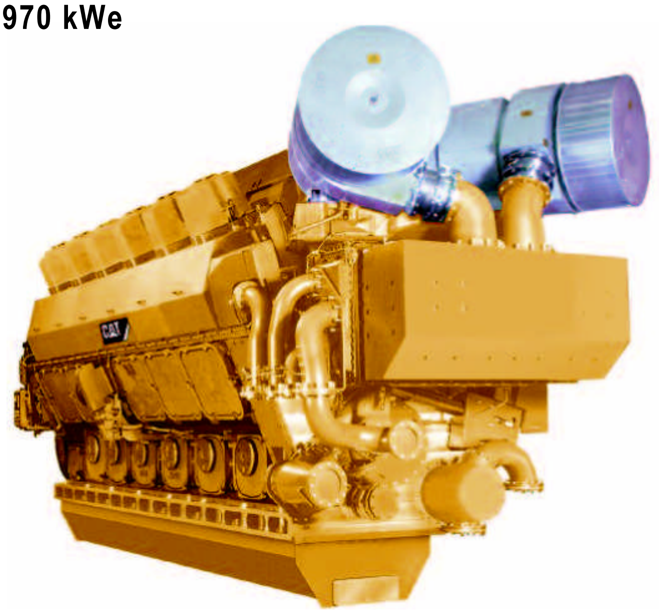
Lube oil consumption: Tolerance on value of +/-0.15 g/kWh (0.00035-lb/kWh). Lube oil consumption can only be demonstrated after 500 hours of operation.

Materials and specifications are subjectto change without notice.© 2007 Caterpillar
CAT, CATERPILLAR, their respective logos and "CaterpillarYellow," and the POWER EDGE All rights reserved
trade dress as well as corporate and product identity used herein, are trademarks of DSGCM34/TD/LEHE3964-04/1004/EO
Caterpillar and may not be used without permission.

CM43

DIESEL ENGINE GENERATOR SET

10475 -13970 kWe
500 rpm
50 Hz



ENGINE

- Engine type: 4-stroke cycle diesel engine
- Cylinder configuration: Vee - 12, 16
- Fuel type: LFO, CRO and HFO up to 700 cSt
- Bore: 430mm (16.9 in)
- Stroke: 610 mm (24.0 in)
- Cylinder displacement: 88.6 L (5406 cu in)
- Cylinder output: 900 kW (1207 bhp)
- Mean piston speed: 10.2 m/s (33.4 ft/s)
- Mean effective pressure: 24.4 bar (354 psig)
- Aspiration: Turbocharged and after-cooled
- Compression ratio: 15.5:1
- Engine rating: 10 800–14 400 kW
- Generator set rating: 10475–13970 kWe

FEATURES

Designed for Reliable Operation

- Design includes intensive cooling of key components including exhaust valve seats, injector cooling integrated into lube oil system and high-efficiencyturbocharger
- Capable of operation up to 700 cSt/50° C fuel quality according to CIMAC H55/K55

Minimized Mechanical Wear

- odular design and state-of-the-art material ensure long life of components

Overall Economy

- ost savings include high availability, long life, low fuel and oil consumption and low maintenance requirements

Highest Quality Engine Parts

- Semi-dry wear resistant liners with calibration inserts
- Pistons with forged steel crown and aluminum skirt
- Inlet/outlet valves with armored seats
- High-efficiencyturbocharger

One-Piece Dry Engine Block

- High-strength nodular cast iron with under slung crankshaft and free from cooling water

Ease of Maintenance and Reliability

- Designed to provide efficient maintenance including easily removable cylinder heads, quick removable fluid connections and split connecting rods to allow piston removal without disturbing the big end bearing
- High reliability, modular design and integral construction reduce the number of components by 40% over conventional designs

Total Power Solutions

- Caterpillar® can develop, finance, design, build, test, maintain and operate medium speed reciprocating engine power plants, plant assets and at the customer's option provide:
  - Power generation equipment
  - Engineered systems
  - Combined heat and power systems
  - Construction and installation services
  - Operation and maintenance services
  - Turnkey power plants
  - Contract power

Worldwide Product Support

- With nearly 200 Cat® dealers and 1,500 facilities worldwide serving in excess of 200 countries, you're never far from the Caterpillar support you need
- Customer Support Agreements offer back-to-back services from scheduled inspections, preventive maintenance and overhauls to full operations and maintenance

CM43

DIESEL ENGINE GENERATOR SET

NOMINAL PERFORMANCE

	ENGINE RATING	GENERATOR SET RATING		SPEED	FREQUENCY	HEAT RATE		SPECIFIC LUBE OIL CONSUMPTION	
	kWm	kWe	kVA	rpm	Hz	kJ/kWh	Btu/kWh	g/kWh	lb/kWh
12CM43	10,800	10,475	13,094	500	50	7,572	7,176	0.6	0.0013
16CM43	14,400	13,970	17,460	500	50	7,572	7,176	0.6	0.0013

RATING DEFINITIONS AND CONDITIONS

Fuel type: Light fuel oil (LFO), crude oil (CRO) and heavy fuel oil (HFO) with fuel quality limit at 50° C according to CIMAC H55/K55.

Ratings: Based on ISO3046/1 standard reference conditions.

Power output: May require adjustment for values other than ISO3046/1 standard reference conditions.

Continuous output: Available for an unlimited time without varying load.

Generator efficiency: Efficiency of 97.0% based on 0.8 pfwith medium voltage class generator; actual efficiency will depend on generator selection.

Fuel consumption: Based on ISO3046/1 standard reference conditions of 25° C (77° F) and 100 kPa (29.61 in Hg), excluding engine-driven pumps, with 5% tolerance and LCV = 42700 kJ/kg (18,358 Btu/lb). Value based on measurement at the generator terminals.

Lube oil consumption: Tolerance on value of ±0.3 g/kWh (0.0007 lb/kWh). Lube oil consumption can only be demonstrated after 500 hours of operation.

Materials and specifications are subjectto change without notice.© 2007 Caterpillar
CAT, CATERPILLAR, their respective logos and "Caterpillar Yellow," and the POWER EDGE All rights reserved
trade dress as well as corporate and product identity used herein, are trademarks of DSCM43/TD/LEHE3873-04/1004/EO
Caterpillar and may not be used without permission.