SIZING IMPACT OF DISTRIBUTED GENERATION IN DISTRIBUTION NETWORKS

NUR HANA BINTI MOHD FAUZI

"This thesis is submitted fulfillment of the requirement for the award of the Bachelor of Electrical Engineering (Power System)"

Faculty of Electrical & Electronic Engineering
University Malaysia Pahang

NOVEMBER 2009

ABSTRACT

Distributed generation (DG) is a method of generating electricity on a small scale from renewable and non-renewable energy sources. DG capacities vary from 1 kW to as large as 100 MW. DG provides an alternative to the traditional electricity sources i.e. oil, gas, coal, water etc. and can also be used to enhance the current electrical system. The technologies for DG are based on reciprocating engines, photovoltaic, fuel cells, combustion gas turbines, micro turbines and wind turbines. The DGs are becoming increasingly popular due to their low emission, low noise levels and high efficiency. Some of the main applications of DG are to provide support and reliability to the power system in a grid-connected mode or isolated mode. With the growing use of DG, it is very important to study its impact on residential distribution network operation. In this study case, the impacts of installing DG in a distribution networks are explored. The work is focused on analyzing the impact of DG installation on distribution network operation specifically in term of losses in the system. This power flow study discusses a procedure for evaluating the impact of size on both the original distribution power system as well as a power system after injects the Distribution Generator (DG). The investigation for finding the best size of DG will be done by using DIgSILENT software version 13.2. The data of the original load flow from industry will compare with the analysis result of the reconfigured system. The optimal sizes of DG depend on the power losses in this system. The best size of DG will be selected when the system can reduce the power losses. The sizing of DG also related with the placement of DG. Thus, this study will also depend on the best placement of DG.

ABSTRAK

Distributed generation (DG) berfungsi menghasilkan tenaga elektrik dalam jumlah yang kecil. Ia terdiri daripada sumber tenaga yang boleh diperbaharui atau sumber tenaga yang tidak boleh diperbaharui. Kapasiti DG adalah dari 1 kW sehingga mencecah 100 MW. DG merupakan alternatif kepada sumber tenaga elektrik kini sebagai contoh ialah minyak, gas, arang batu, air dan sebagainya. Contoh teknologi DG yang semakin meluas kepenggunaannya ialah *reciprocating engines, photovoltaic, fuel cells, combustion gas turbines, micro turbines and wind turbines*. DG semakin terkenal melalui kadar gangguan yang rendah dan penggunaan yang lebih berkesan. Salah satu aplikasi utama DG adalah untuk menampung sistem dan memastikan kestabilan sistem. Dengan perkembangan penggunaan DG yang semakin meluas, ia adalah penting untuk mengkaji kesan terhadap operasi rangkaian pengedaran tenaga di kawasan perumahan. Dalam kajian ini, kesan daripada penggunaan DG dalam kawasan pengedaran elektrik telah dikaji. Kajian ini lebih memfokus kepada tahap kehilangan tenaga dalam sistem tersebut. Dalam kajian ini, turut dibincangkan mengenai teknik untuk menilai kesan daripada saiz DG terhadap sistem. Kajian untuk mendapatkan saiz yang terbaik untuk DG akan dilaksanakan dengan mengunakan program DIgSILENT versi 13.2. Maklumat yang diperoleh dari industri akan dibandingkan dengan keputusan selepas meletakkan DG. Saiz yang terbaik untuk DG dipilih melalui tahap kehilangan kuasa yang paling rendah. Pemilihan saiz juga turut dipengaruhi oleh pemilihan tempat untuk meletakkan DG.

TABLE OF CONTENTS

CHAPTER **TITLE** **PAGE**

1 INTRODUCTION

2 LITERATURE REVIEW

3 METHODOLOGY

4 RESULTS AND DISCUSSIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Power flow studies commonly referred to as load flow, are the backbone of power system analysis and design. They are necessary for planning, operation, economic scheduling and exchange of power between utilities. In addition, power flow analysis is required for many other analyses such as transient stability and contingency studies [1]. Distributed generation (DG) is a method of generating electricity on a small scale from renewable and non-renewable energy sources. Systems are located close to where the electricity is being used, and serve as an alternative to or an enhancement of the traditional electric power system [2]. DG is normally defined as small generation units (<10 MW) installed in distribution systems. It is expected to play an increasing role in emerging electric power systems. Studies have predicted that DG will be a significant percentage of all new generation going on line. It is predicted that they would have about 20% of new generations being installed. They use different types of resources and technologies to serve energy to power systems. [10]

Some of the advantages of distributed generation are that it increases reliability of the grid, can be configured to match customer demand, diversifies the range of energy sources used, and reduces the necessity to build new transmission or distribution lines, or upgrade existing ones. Although there are many advantages of employing a DG, new problems arise with their injection, such as protection issues, voltage and frequency issues, and operational issues.

Adding DG to a distribution system imposes some impact on the network, such as power losses, voltage profile, stability and reliability. The problem of DG sizing is one of great importance. The installation of DG units at non-optimal size can result in an increase in system losses, implying in an increase in costs and, therefore, having an effect opposite to the desired. The preferable size of the DG units in distribution network also depends on the best places for DG installation.

For that reason, the development of an optimization methodology capable of indicating the DG unit allocation and sizing that improves the system operation characteristics can be very useful for the system planning engineer when dealing with the increase of DG penetration that is happening nowadays.

1.2 PROBLEM STATEMENT

DG affects the flow of power and voltage conditions on the system equipment. These impacts may manifest themselves either positively or negatively depending on the distribution system operating conditions and the DG characteristics. Positive impacts are generally called 'system support benefits', and include voltage support and improved power quality; loss reduction; transmission and distribution capacity release; and improved utility system reliability. On account of achieving the above benefits, the DG must be reliable, dispatchable, of the proper size and at the proper location [3].

DG has advantages to the network, such as defer transmission upgrades and can delay the upgrading process as it can supply the power. Besides, DG reduces the losses in the distribution system because, if a distributed generator is located near a large load, its exported power will also tend to cut system losses. Thus DG improves security of supply, power quality and the reliability of the system. However, DG also has negative impact on power quality issues, these includes changes in frequency, protection, reactive power and power conditioning, power flow, power losses and voltage quality. [4]

Studies have indicated that inappropriate selection of size of DG, may lead to greater system losses than the losses without DG. Utilities already facing the problem of high power loss especially, in the developing countries cannot tolerate any increase in losses.

By optimum allocation, utilities take advantage of reduction in system losses; and improvement in reliability of supply. Therefore, tools are needed to be developed to examine locations and sizing of such DG installation. [5]

Distribution systems are usually voltage regulated through tap changing at substation transformers and by the use of voltage regulators and capacitors on the feeders. This form of voltage regulation assumes power flow circulating from the substation to the loads. DG introduces reversed power flows that may interfere with the traditionally used regulation practices. For this reason, the inappropriate DG allocation can cause poor voltage profile in the network. A precise way of analyzing the voltage regulation of a system with embedded DG is through simulation using power flow algorithms capable of analyzing multiple sources of DG together with the operation of voltage regulators. In this analysis, it is important to recognize that the power injected by the DG unit can result in voltages within the allowed limits at the DG installation site, but it could, also, result in undesired values at other parts of the feeder. [6]

This case study will analyze the test power system to obtain the results of losses n order to determine the optimal size of DG in distribution networks. A technical evaluation will be done to look at the impact of a change in size of DG. This research may help in finding some trends for the optimal sizing of DG for bigger and real power systems in future.

1.3 OBJECTIVES

The objectives of this case study are:

i. To study the characteristic at the Distribution Power System with the presence of DG and without DG.

ii. To obtain the optimal size of DG to reduce losses in Distribution Network.

iii. To obtain the fast and accurate method of sizing DG in Distribution Network.

1.4 SCOPE OF PROJECT

i. This scenario of research study is base only one DG connection.
ii. Use random technique to get the optimal size of DG.
iii. Use *MATLAB* software to compute the methods after get the result, then directly applied in *DigSILENT powerfactory* software.

The limitation of this research is the power flow is only injected by only one DG. The more DG used, the more complicated the connection of power flow thus not achieves the objective which is to obtain the fast method. There are many of methods to get the optimal size of DG. This study will take only two best methods to compare and propose the best between both of the method. For the tools that will be used in this research, *MATLAB* software and *DigSILENT Powerfactory* software are the suitable tools to solve the method and power flow system. The limitation of getting the real data from utilities for the base case systems have decided u utilizes the IEEE 34 bus system as the test system. Besides, a power plant or chemical industrial plant will be used to validate the method of optimized sizing.

CHAPTER 2

LITERATURE REVIEW

2.1 DISTRIBUTION SYSTEM

Electricity is produced and delivered through generation, transmission and distribution systems. Distribution system must deliver electricity to each customer's service entrance. This system may consist of distribution substations, primary distribution systems, distribution transformers and secondary distribution systems.

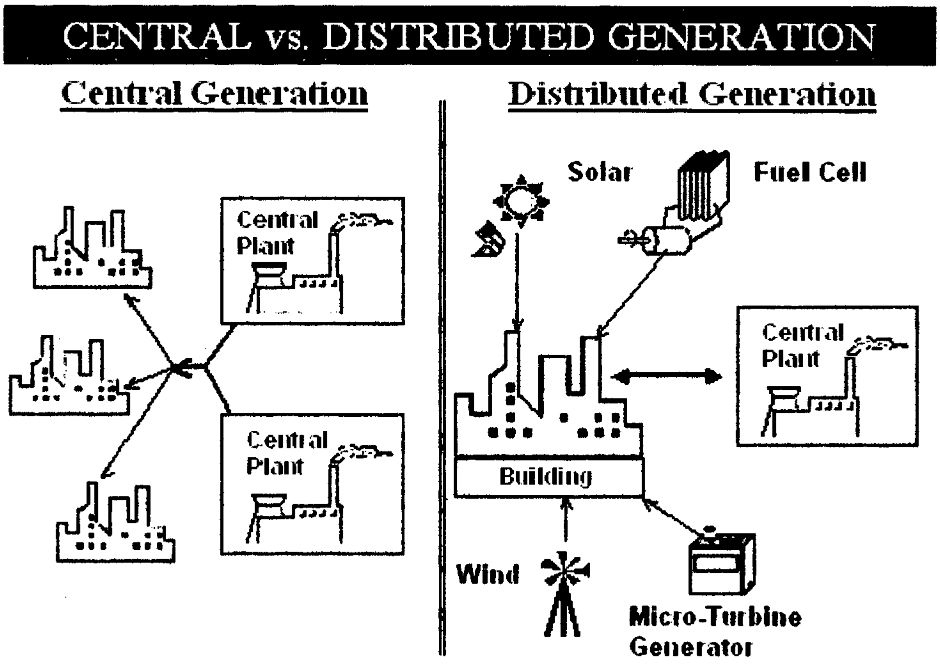


Figure 2.1 : The example of DG technologies.

2.2 Different types of DG technologies

The technologies for DG are based on reciprocating engines, photovoltaic, fuel cells, combustion gas turbines, micro turbines and wind turbines. The technologies are also called alternate energy systems as they provide an alternative to the traditional electricity sources i.e. oil, gas, coal, water etc. and can also be used to enhance the current electrical system.

Some of them are conventional such as the diesel generators and some are new technologies such as the micro-turbines. [22]

Fuel cells: A fuel cell is an electrochemical device that converts chemical energy directly into electrical energy. The fuel cell unit uses hydrogen and oxygen to perform the required chemical reaction and produce power. Fuel cells are inverter interfaced DGs, meaning the unit produces dc power that is converted to ac power via a 3-phase converter

Micro-turbine: Micro-turbines are small gas fired turbines rotating at a very high rate of speed (90,000 rpm). A high rpm DC generator is used to generate dc power. The DC generator is coupled to a dc/ac power converter to produce voltages at the rated frequency

Reciprocating engines: The most common form of distributed generation. [21] This is a mature technology that can be fueled by either diesel or natural gas, though the majority of applications are diesel fired. The technology is capable of thermal efficiencies of just over 40 percent for electricity generation, relatively low capital costs, but relatively high running costs. The technology is also suitable for back-up generation as it can be started up quickly and without the need for grid-supplied power. When fueled by diesel, this technology has the highest nitrogen oxide (NO_x) and carbon dioxide (CO_2) emissions of any of the distributed generation technologies considered in this entry.

In Malaysia, The promotion of energy efficiency and renewable energy resources by the Malaysian government have contributed to an increasing number of distributed generation (DG) connection applications. Most of these applications are from developers of renewable energy, mainly mini-hydro & Biomass (Palm Oil Waste) and industrial customers, who are migrating to cogeneration for energy efficiency. [19]

2.3 Application of DG

Accidents, human errors, weather related issues, and etc can cause the failures and disturbances to power system. DG can be a backup source in order to ensure the reliability of power supply which is important to industry and business. The overall reliability of the system can be improved. DG can be used to continuous supply to some of the load feeders using switch operations. As shown in Figure 2.2 the operation is known as islanded mode. A fault occurs on feeder 2, but continuous power can be supplied to load points B and C through DG in the form of an island. [12]

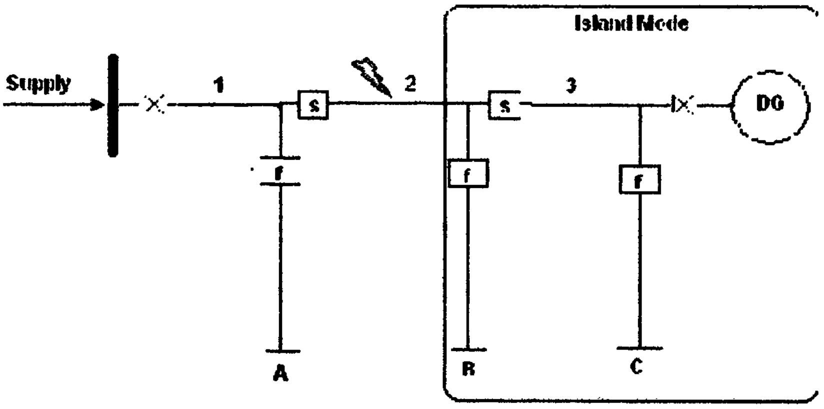


Figure 2.2: Islanded Mode

DG can also be used in parallel to the main grid as a support for the loads and also by injecting excess power back to the grid network when the DG capacity is more than the required feeder demand. The DG can help the main grid during peak load hours when the feeder capacity is not enough to meet the demands of the customers. The load shedding can be avoided by having a DG support. The DG improves the reliability of the system and also helps reduces the customer electric bills.

DG can be used as a standby for consumers that cannot tolerate interruption of service such as hospitals. The DG can also be used as a stand-alone to supply power to the customers that are not connected to the grid. For example, the DG can be used as standalone in remote areas where cost of connecting to the main grid is too high. [12]

2.4 Advantages and Disadvantages of DG

DGs are becoming increasingly popular due to their low emission, low noise levels and high efficiency. One of the main advantages of DG is their close proximity to the customer loads they are serving. DG can play an important role in improving the reliability of the current grid, reducing the losses, providing voltage support and improving power quality. [12]

One of the characteristic of most distributed generation is its size. Generation capacities of customer-owned units, used primarily to meet on-site requirements, typically range from a few kilowatts to several hundred kilowatts. Generators in that ranges are typically best suited to applications that meet the energy demands of individual homes and businesses or of small groups of customers. Very few customers require generators larger than 1MW to serve only their on-site needs. [7]

A study can be done to see the impact of DG on criteria like voltage, losses, reliability, and economics. Focusing on the optimal placement and size of a DG in a distribution system to keep the system in an economical and secured state is paramount. With rapid penetration of DG into distribution systems, assessing power system impacts accurately is critical, so that these DG units can be applied in a manner that avoids causing degradation of power quality, reliability, and control of the utility system. On the other hand, DG has great potential to improve distribution system performance. Thus, studying the changes that a DG causes with a change in its location, size, and the loading conditions is imperative. [8]

2.5 Method of Sizing DG

Reference [2] presents the analytical, method which the methodology are based on the exact loss formula. The method is computationally less demanding. The method proposed first identifies a sequence of nodes to be compensated. The sequence is determined by repetitive application loss minimization technique by a singly located Dg unit. Once the sequence of nodes to be compensated is identified, the corresponding optimal size at the compensated nodes can be determined simultaneously by minimizing the loss saving equation.

A study by Carmen L.T. Borges and Djalma M. Falca˜o propose the genetic algorithm method. The methodology presented in this paper aims to optimize the allocation and sizing of DG in order to minimize the primary distribution network losses and to guarantee acceptable reliability level and voltage profile. Conceptually, the methodology is based on an automatic method for optimal allocation and sizing of DG units on distribution network. The method is based on genetic algorithm techniques and uses the DG impact evaluation method described above for evaluating the potential candidates for the problem solution. The genetic algorithm plays the expert's part in the task of producing problem solution candidates in an automatic way.

The Cumulative Size Norm method shows that the best size for a DG would be that value where the value of the sum of the cumulative voltage deviations of the entire equal sized DG's is the least. It indicates that at that size the voltage profile has the least deviations considering the presence of the DG. [8]

Researchers in Ref [2-3], found that conventional load flow studies like Gauss-Seidal and fast decoupled load flow Newton-Raphson methods are not suitable for distribution system load flows because of high R/X ratio and unbalanced loads. These characteristic features make the distribution systems power flow computation different and somewhat difficult to analyze as compared to the transmission systems when the conventional power flow algorithms are employed. The losses of the system vary as the DG output changes. In general, the minimum losses occur when the size of the DG is equal to the feeder load. However, it can vary depending on the characteristics of the feeder such as loads on each phase, mutual impedance between phases etc. [12]

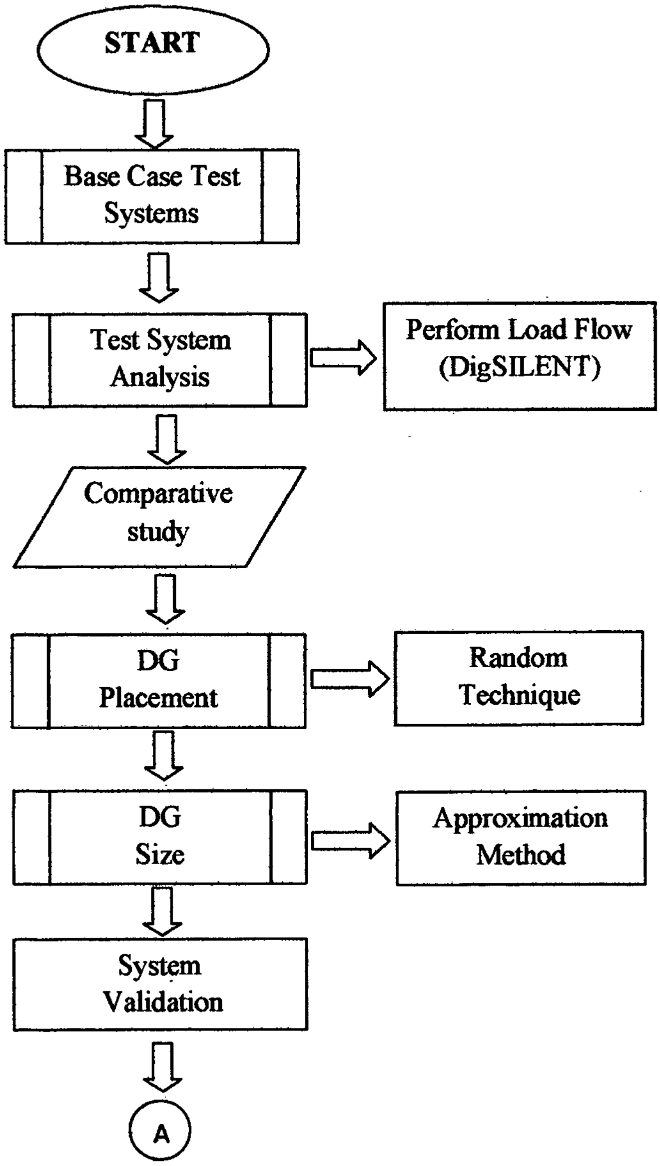
For all DG technologies the possibility of supplying reactive power has also been analyzed to quantify the impact on losses. This possibility depends on the technology of DG and so DG cannot supply reactive power in all the cases. Controlling reactive power supplied by DG has a big impact on distribution losses. This need a sophisticated control but a simple scheme can be implemented. In a competitive system it will be necessary that the DGs receive the suitable economic signal so that they are interested in supplying reactive power to the network. [14]

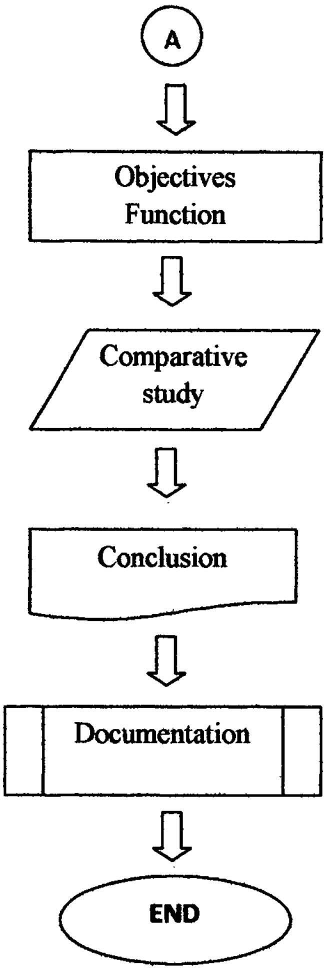
A study by N. Mithulananthan and Than Oo and Le Van Phu presents, the correct size of DG is playing an important role in minimizing the losses by decreasing the current drawn from the substation from a long distance. This study shows that the proper placement and size of DG units can have a significant impact on system loss reduction. It also shows how improper choice of size would lead to higher losses than the case without DG. However, in practice there will be many constraints to be considered in selecting the site. Given the choices, the correct sizes of DG units should be placed in the right location to enjoy the maximum technical benefits. [18]

The major obstacle for the distributed generation has been the high cost. However, the costs have decreased significantly over the past 20 years. [12] DG can avoid paying for network system costs depending on the distribution and transmission tariff design. This is especially true in tariff designs where all network costs are recovered through kWh charges rather than as fixed demand charges. It is important to emphasize that the potential benefits from DG are contingent upon patterns of generation and end use. For a different generation and end use patterns, losses and usage would be different. In fact, losses may increase in the distribution network as a result of DG. [13]- [15]

CHAPTER 3

METHODOLOGY




A
Objectives Function
Comparative study
Conclusion
Documentation
END

3.1 Base Case Test Systems

The power flow used in this study was taken from Petronas at Kerteh, Terengganu. The DIgSILENT power factory software has been used in this study to simulate the load flow. The ratings and parameters needed are the transformer data, total load, size and type of cable, feeder size, type and size of motor and others. The power flow was merely balanced in terms of stability, losses, and also voltage deviations. Thus, it needs some modifications to create some problems to achieve the objectives of this study. This new system was quiet differ from the actual system. The DigSILENT software has limited number of point's connection between the components. Thus, in this new system, the numbers of bus bar were reducing from the actual system.

DG was injected at the chosen feeder to observe the characteristics and the impact. The losses are analyzed through the load flow calculation by using the DIgSILENT power factory software. The active and reactive power is obtain from this load flow calculation in order to analyze the influence in total losses. Other explanatory variables like voltage deviation and reliability can be obtained.

Table 3.1: Total of System Load

	S(MVA)	P(MW)	Q(MVar)
Total of the system load	56	42	36

3.2 Test System Analysis

3.2.1 Perform Load Flow

The load flow is designed by using DigSILENT software. All the parameters obtained from the industry were applied in this load flow after

3.2.2 Modeling of system components

There are different electrical components were used in this power flow study.

- Bus bar

  There are different types of distribution feeder which are slack bus, load bus and regulated bus. In this study, slack bus or known as swing bus is used where the magnitude and phase angle of the voltage are specified. This bus makes up the difference between the scheduled loads and generated power that are caused by the losses in the network. [1] The bus bars used in this power flow are 132 kV, 33 kV, 11 kV, 3.3 kV and 415 V.

- Induction Motor

  Modelling of motor is based on the data given with some modification in term of percentage of load used in certain time. In this study, the loads are assuming only use 50% of the total load given. As the power factor equal to 1, the value of real power, P and the complex power, S are same.

- Synchronous Generator

  The synchronous generators are used to generate electricity into the distribution network. Below, the functional details of both generator types are presented. [20]

  Synchronous generators are widely used because they allow independent control of real and reactive power. Variable wind turbines are commonly equipped with synchronous generators. Small generators that are connected to a utility distribution system have little control over its terminal voltage and none at all over the system frequency.

  For transient conditions, it can illustrate the potential benefit of fast acting excitation systems, as follows:

$$P = \frac{E_f' V}{X'} \sin \delta$$

Where Ef' is the transient internal voltage of the generator and X' is the transient reactance. The transient reactance is determined by the generator design, but the transient internal voltage can be increased by a fast acting excitation system. Therefore, by using a high response excitation system, the power transfer capability of the generator can be maintained even if the network voltage (V) is not constant due to a fault. Thus, the generator can remain stable for longer clearing times, or at higher loading conditions than would be possible with a slower AVR/exciter [20].

The excitation system of a synchronous generator consists of an exciter and a controller. The controller is also referred to as an AVR (automatic voltage regulator), and it regulates the voltage of the generator. The excitation and governor systems of a generator can significantly impact its performance during network disturbances. [20]

3.3 Placement of DG

The sizes will be test on the several cases which are different in placement of DG. Besides, the cases also include the comparison of power factor:

i. Case 1: Placement of DG at 11 kV bus bar
ii. Case 2: Placement of DG at 33 kV bus bar
iii. Case 3: Placement of DG at 3.3 kV bus bar
iv. Case 4: Power factor at 0.75
v. Case 5: Power factor at 0.85
vi. Case 6: Power factor at 1.0

3.4 Size of DG

To analyze the power losses in this distribution network, this study vary the size of DG with the random technique which known as approximation method. This technique applied by choosing the size of DG based on percentage of the load at the specific feeder (small-scale of DG) and percentage of load at overall system (large-scale of DG).

3.4.1 The small-scale DG

Total Load at feeder 33 kV= 33 MW, 28.89 MVar

Table 3.2: The size of DG at 33kV bus bar

PERCENTAGE OF LOAD	S(MVA)	P(MW)	Q(MVar)
5% of load at feeder 33kV	2	1.7	1.5
10% of load at feeder 33kV	4	3.3	2.9
20% of load at feeder 33kV	9	6.6	5.8
50% of load at feeder 33kV	22	16.5	14.5
100% of load at feeder 33kV	44	33.0	28.9

The size of DG in terms of percentage load at the 33kV bus bar varies from 2 MVA to 44 MVA (small-scale)

Total Load at feeder 11 kV = 4.3 MW, 3.31 MVar

Table 3.3: The size of DG at 11kV bus bar

PERCENTAGE OF LOAD	S(MVA)	P(MW)	Q(Mvar)
5% of load at feeder 11kV	0.3	0.2	0.2
10% of load at feeder 11kV	0.5	0.4	0.3
20% of load at feeder 11kV	1	0.9	0.7
50% of load at feeder 11kV	3	2.2	1.7
100% of load at feeder 11kV	5	4.3	3.3