بسم الله الرحمن الرحيم

Sudan University of Science and Technology

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Impact of Distributed Generation in Power System Distribution Networks

أثر التوليد الموزع علي شبكات توزيع نظم القدرة الكهربائية

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BY: Nihad Mohammed Elatta

Supervised by:

Dr. Abdelaziz Yousif Mohamed Abbas

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الآيـة

بسم الله الرحمن الرحيم

قال تعالى :

﴿يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا

الْعِلْمَ دَرَجَاتٍ ۚ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ﴾

صدق الله العظيم

DEDICATION

First of all i dedicate this research to almighty God, who gave me strength and knowledge for my everyday life. I also dedicate this research to my mother, my brothers and sisters who always encouraged me to go on every adventure, have for all their support and putting me through the education possible and never left my side and are very special. A special feeling of gratitude to my loving parents.

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In the name of Allah, the Most Gracious and the Most Merciful Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this research. Special thanks should be given to Dr. Abdelaziz Yousif, research project supervisor for his professional guidance and valuable support. The door of his office was always open whenever I ran into a trouble spot or had a question about my research. He consistently allowed this research to be my own work, but steered me in the right the direction whenever he thought I needed it.

Besides thanking my thesis supervisor, I acknowledge other professors who have guided me along the way during my master's program.

Last but not the least; I must express my very profound gratitude to my dear mother and to my brothers and sisters for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Not forgotten, my appreciation to my colleagues at the office. My heartfelt thanks.

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ABSTRACT

The use of distributed generation (DG) within distribution systems has increased for the last two decades due to worldwide increase in demand for electricity and governmental policy change from “conventional” energy to renewable energy. The excessive growing needs for electricity force electrical researchers to implement new approaches through the electric system. DG constitutes one of the most important developments in modern electric power systems.

Integrating DG into an electricity network, especially close to load center’s, has many significant benefits but also brings with it many drawbacks such as voltage drop, and power losses. Introducing Distributed Generation (DG) in the distribution network is considered to be a promising new approach to solve these problems. DG is capable of providing some or all of the required power for the demand increase and simultaneously improves system’s performance.

This study presents the impact of DG in power system distribution system improve voltage profile and reduces power losses by installing DG at different locations on the distribution networks. A radial distribution system is simulated using NEPLAN software while changing the location of DG in the system. Finally, extensive studies in a distribution network have been conducted, with and without DGs are presented to confirm the proposed ideas. The simulation results obtained proposed for selecting the optimum size and location of DG in distribution networks.

المستخلص

إزداد استخدام نظام التوليد الموزع في أنظمة توزيع الكهرباء خلال العقدين الأخيرين بسبب الزيادة العالمية في الطلب على الكهرباء و توجه سياسة الحكومات إلى الطاقة المتجددة. والنمو المتزايد علي طلب الإمداد الكهربائي أدي لتشجيع الباحثين في مجال الطاقة تطبيق نهج جديد لتطوير النظام الكهربائي، يشكل نظام التوليد الموزع احد أهم التطورات في أنظمة الطاقة الكهربائية الحديثة. تكامل التوليد الموزع للشبكة الكهربائية خاصة المتعلقة بالحمولة المركزية،حيث له القدرة علي توفير بعض أو كل الطاقة المطلوبة لزيادة الطلب ويعتبر منهج واعد لتحسين أداء النظام من خلال حل مشاكل شبكة توزيع الكهرباء المتمثلة في انخفاض الجهد وفقودات الطاقة بإضافته بالقرب من مناطق إستهلاك الإمداد الكهربائي.

تتناول هذه الدراسة تأثير نظام التوليد الموزع علي شبكة توزيع الكهرباء و تحسين ملف الجهد وتقليل فقودات الطاقة عن طريق تركيب وحدة التوليد الموزع في مواقع مختلفة في الشبكة. تمت محاكاة نظام التوزيع بإستخدام برنامج ***NE-PLAN*** قبل و بعد إضافة وحدات التوليد الموزع مع تغيير موقع الوحدة لإختيار الحجم والموقع الأمثل لها و ذلك لتأكيد الأفكار المقترحة.

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LIST OF ABBREVIATION

DG	Distributed Generation
CHP	combined heat and power
PV	Photovoltaic
LTC	Load tap changer
EHV	extra-high voltage
UHV	ultra-high voltages

CHAPTER ONE
INTRODUCTION

1.1. Background:

Electric power systems have served well the consumers need for continuous, uninterrupted power supply of good quality and at the minimum possible cost. Distribution systems initially designed to operate without any generation on the distribution system or at customer loads. The introduction of generating sources in the distribution network is called distributed generation (DG) and can produce significant impact on power flow through the network. The severity of impact depends on the location (site) and size (penetration level) of the generating sources. It is small scale generation units are interconnected with the electric power system near load centers', thus, directly to the distribution network that mainly use renewable sources such as wind and solar energy, however, non-renewable sources also are employed such as diesel generators, natural gas generators, fuel cells. Although centralized large power stations located far away from load centers' have several benefits in terms of efficiency, they only require a small number of staff to operate the station and the bulk of electricity can be transferred over long distances with small losses, they also have their drawbacks such as environmental concerns related to emissions and the cost of expanding the electricity system because of the increased demand and concerns about fuel supply [1].

By producing power from distributed renewable sources leads to reduce the distribution losses and will help to reduce the output requirements from conventional plants which in turn reduce the greenhouse gas emissions.

Distributed generation can be based on alternative energy sources and hence participate in energy diversification. It also, helps to deliver backup power during times of increased electricity demand, avoiding the investment in large power plants. Furthermore DG improves voltage profiles and reduction power losses [2], which minimize the number of required voltage regulators, capacitors and their ratings and maintenance costs. The different DG power plant types may have different impact on power system distribution networks [1].

1.2. Problem:

Distribution system considered the most expensive part in the electric network [3]. As load demand densities increase the more complication and problems will occur in the distribution network. Voltage regulation and power losses are the main problems in the distribution network. This research focuses on introducing Distributed Generation (DG) in the distribution network is considered to be a promising new approach to solve these problems and simultaneously improves system's performance by installing DG in the distribution system.

1.3. Objectives:

The main objectives of this dissertation are:

- The main objective of this research is to improve the voltage profile and reduce the power losses.
- Analysis of the impact of distributed generation in voltage profiles and power losses of distribution networks.

1.4. Methodology:

Simulation of distribution system is performed in order to investigate the voltage profile and power loss using a computer programming (Ne-plan). The simulation results of distribution network with and without installation of DG unit is illustrated. The proposed methodology will be implementing on Sudan national grid.

1.5. Motivations:

Nowadays, the technological evolution, environmental policies, and also the expansion of the finance and electrical markets, are promoting new conditions in the sector of the electricity generation [5].

New technologies allow the electricity to be generated in small sized plants. Moreover, the increasing use of renewable sources in order to reduce the environmental impact of power generation leads to the development and application of new electrical energy supply schemes.

Taking Sudan into account with its electrification rate of 35% due to the scattered population across the large area of the country and distribution lines travel too long distance to reach the customers and then faces power stability issues presented significant voltage drop and high losses.

In this new conception, the generation is not exclusive to the centralized generation. Hence some of the energy-demand is supplied by the centralized generation and another part is produced by distributed generation. The electricity is going to be produced closer to the customers adding new electrical energy source and solving the problems of power quality.

1.6. Thesis Layout:

The current research dissertation is divided into four chapters. The first chapter introduces the objectives of this research work and motivation, as well as the outline of the dissertation. Chapter two presents the electric power systems' networks and configuration. Also provides distribution networks configurations. Furthermore, the concept of distributed generation (DG) is presented and the list is provided with the up today author's publications that were produced based on the research presented in this dissertation. Chapter three introduces the mathematical model for the load flow study.

Chapter four consists of the studies conducted on distribution networks with the aim to identify the impact of distributed generation in voltage profiles and power losses. Several simulations have been conducted on both under study with and without installation of distributed generation (DG) units in distribution networks. The simulation is implemented in NE-PLAN, one of the most reliable power systems software. Chapter five summarizes the conclusions and recommendations of this research.

CHAPTER TWO
LITERATURE REVIEW

2.1. Introduction:

This chapter presents the electric power systems' networks and configuration (generation, transmission and distribution network). Also provides distribution networks with special attention paid in the configurations of electricity distribution networks (radial, primary selective, secondary selective and loop system). Issues such as voltage drop and power loss are discussed. Furthermore, the concept of distributed generation (DG) is presented, providing information for a number of DG sizes and categories that have been reported worldwide and are connected to the distribution networks. Advantages and disadvantages related to DGs are also presented. Finally problems and issues arising from constant and increasing installation of distributed generation in distribution networks are described in detail.

2.2. Electricity Power System Networks:

The worldwide competition in the electricity market to reduce the prices' fluctuations, costs in the electric power prices and supply the best customer's service as possible. The structure of a traditional electric power system consists of three stages to be passed through before the power reaching the final user, i.e. generation, transmission and distribution. In the first stage the electricity is generated in large generation plants, located in non-populated areas away from loads to get round with the economics of size and environmental issues. Second stage is accomplished with the support of various equipment's such transformers, overhead transmission lines and underground cables. The last stage is the distribution, the link between the utility system and the end customers. This stage is the most important part of the power system, as the final power quality depends on its reliability. Nowadays, the technological evolution, environmental policies, and also the expansion of the finance and electrical markets, are promoting new conditions in the sector of the electricity generation [3].

The Ministry of Water Resources, Irrigation, and Electricity (MWRIE) is the prime body responsible for the Generation, Transmission and Distribution of electric power in Sudan. Recently it has undergone major structuring whereby the process of power generation, transmission and distribution were separated and each run and managed by a state-owned company in a first step to privatize the power sector in the country in future. Electric companies tried to maximize their profits and minimize their costs. This is done by reducing spending on the maintenance [4].

Sudan currently has a power generation capacity of about 3,000 MW, with no wind generation capacity and no grid-connected solar capacity. The Government owns 6,519 km of 220 kV transmission lines and 965 km of 500 kV transmission lines. In Sudan, approximately 38% of the population has access to electricity. Hydro-power is the largest share of energy generation. The potential to expand hydro-power to meet future needs is limited. Sudan does not have significant oil or gas production and as a result will have to turn to importation of fossil fuels to meet future energy needs. MWRIE has conducted many resource assessment studies such as country wide Wind energy, Solar energy and biomass resource. In meantime, meteorological data collection is underway in other potential areas covering the Northern State and Western Darfur which are the future targets in the long-term planning of wind power application and in the medium- term planning of solar power application in different states in Sudan. There are a few countries around the world that possess nuclear power stations for generating electricity (the required high pressure steam is produced by nuclear fission instead of burning fossil fuels), while almost all countries possess generating units that are using renewable energy sources (solar, wind, geothermal, biomass, etc.), since these technologies are considered more environmentally friendly than the traditional sources (coal, oil and natural gas). New technologies allow the electricity to be generated in small sized plants. Moreover, the increasing use of renewable sources in order to reduce the environmental impact of power generation leads to the development and application of new electrical energy supply schemes. The electricity is going to be produced closer to the customers [5].

Based on the international standards transmission voltage networks operate at 230 kV or higher voltage. The transmission networks above 230 kV are usually referred to as extra-high voltage (EHV). Finally voltages above 1000 kV are referred to as ultra-high voltages (UHV). Transmission consists mainly of an overhead transmission network (the percentage of underground and submarine cables is relative low). That transfers the electric power from generating units to distribution, which eventually supplies the load [3]. The transmission network is also interconnected with neighboring transmission networks for exchanging electric power due to electric power trading maintenance scheduling, sharing of generation reserves and emergencies, i.e., lack of sufficient electric power, assistance in the grid stability, etc. Used stepping-up transformers to raise the voltage of the generated power in order to transmission it to long distances. This has a result the reduction of current for a specific amount of transferred electric power, resulting in the reduction of power losses and in the more cost-effective construction of transmission network's infrastructure (size of conductors, type of towers). In Sudan the transmission voltage networks operate at 500KV.

Distribution network links the distribution transformers (stepping-down transformers) that distribute electricity to different consumers. The primary distribution lines range from 33 to 11 kV and supply the load in a well-defined geographical area. Some industrial customers are served directly by the primary feeders. The secondary distribution network reduces the voltage for utilization by commercial and residential consumers. It serves most of the customers at levels of 415V three-phase.

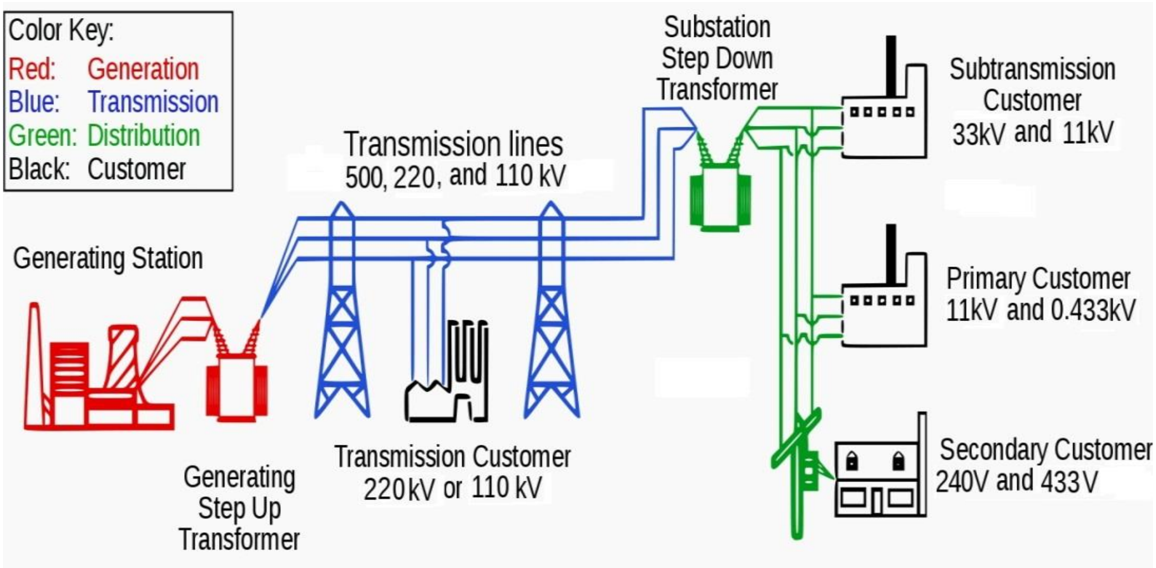

Figure 2.1 the electrical power system.

The electrical power system shown in Figure 2.1 is called the centralized model, has served well during the past decades its ultimate goal for uninterrupted power supply to consumers at the best achievable quality. The main characteristic of the centralized model is the unidirectional power flow from higher to lower voltage levels. However, the electric power system structure has undergone through major changes worldwide when privatization took place in the early nineties, resulting to the separation of generation from transmission and distribution. The main goal of such a movement was to accommodate competition in the electricity industry, to deliver better services for customers, decrease in electricity rates, and to improve efficiency. There were also significant environmental motives and the need exploit alternative energy sources. As a result, the electric power system has evolved from the centralized to the decentralized model, broadly observed and implemented nowadays, which consists of small scale distributed power stations, located closer to load centre's. This new decentralized model has introduced the bidirectional power flow, mainly in the distribution networks, but in the transmission networks as well, altering the philosophy and operation of networks and introducing many significant problems that need to be further studied and analyzed [6].

2.3. Distribution Networks:

The distribution network is a very important part of the electric power system. Electric power is transferred through this network to consumers. A distribution network makes use of both overhead lines and underground cables, and consists of many different elements such as bus bars, switches, circuit breakers and transformers. As electricity demand increases continuously over the past years, the distribution network is constantly expanding, causing its congestion. Distribution networks have been initially designed to serve an unidirectional power flow from higher to lower voltage levels. The number of Distribution substations is (165) substation and total numbers of distribution lines is 370 line of 33 KV and 909 line of 11 KV.

As load demand densities increase the more complication and problems will occur in the distribution network. Power losses and voltage regulation is the main problems in the distribution systems. Several techniques have been applied by implementing many devices in the distribution network to solve these problems. The most common devices and techniques used are transformer equipped by load tap changer (LTC), supplementary line regulators installed on distribution feeders, shunt capacitor switched on distribution feeders [7]. Four basic circuit arrangements are used for the distribution of electric power. They are the radial, primary selective, secondary selective and Loop Distribution configuration [8].

2.3.1. Radial System:

The radial system is the simplest that can be used, and has the lowest system investment. It is suitable for smaller installations where continuity of service is not critical. For the supply of low-load consumers and remote areas is widely used the radial distribution configuration. In order to reduce the duration of interruptions, overhead feeders can be protected by automatic devices located at the substation or at other locations on the feeder. These devices reenergize the feeder in cases of temporary faults. The main advantages of this configuration are the simplicity in operation and design and the reduced construction cost in contrast to the loop and network configurations. The main disadvantage of the radial configuration is its low reliability since in the case of a fault, downstream buses (nodes) will be isolated (buses are only supplied from one side) [9]. A radial configuration of a distribution network is shown in Figure 2.2.

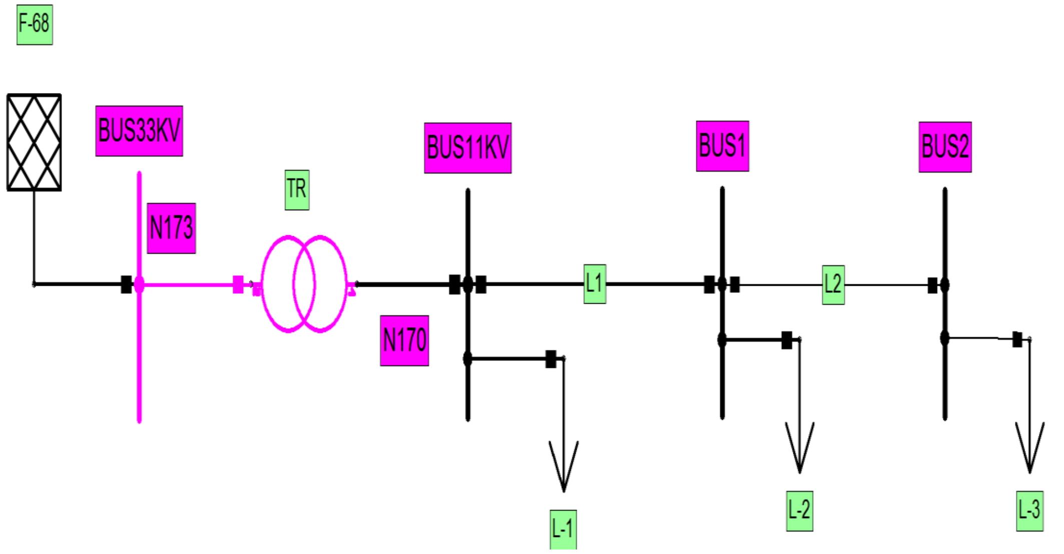

Figure 2.2: The Radial distribution configuration

2.3.2. Primary Selective System:

This operating feature is provided through the use of duplicate primary feeder circuits and load interrupter switches that permit connection of each secondary substation transformer to either of the two primary feeder circuits. Each primary feeder circuit must have sufficient capacity to carry the total load in the building. Under normal operating conditions, the appropriate switches are closed in an attempt to divide the load equally between the two primary feeder circuits. Then, should a primary feeder fault occur, there is an interruption of service to only half of the load. Service can be restored to all loads by switching the deenergized transformers to the other primary feeder circuit. The primary selective switches are usually manually operated and outage time for half the load is determined by the time it takes to accomplish the necessary switching. An automatic throw over switching arrangement could be used to avoid the interruption of service to half the load. However, the additional cost of the automatic feature may not be justified in many applications. If a fault occurs in a secondary substation transformer, service can be restored to all loads except those served from the faulted transformer. The higher degree of service continuity afforded by the primary selective arrangement is realized at a cost somewhat higher than a simple radial system due to the extra primary cables and switchgear [8]. A Primary Selective configuration of a distribution network is shown in Figure 2.3.

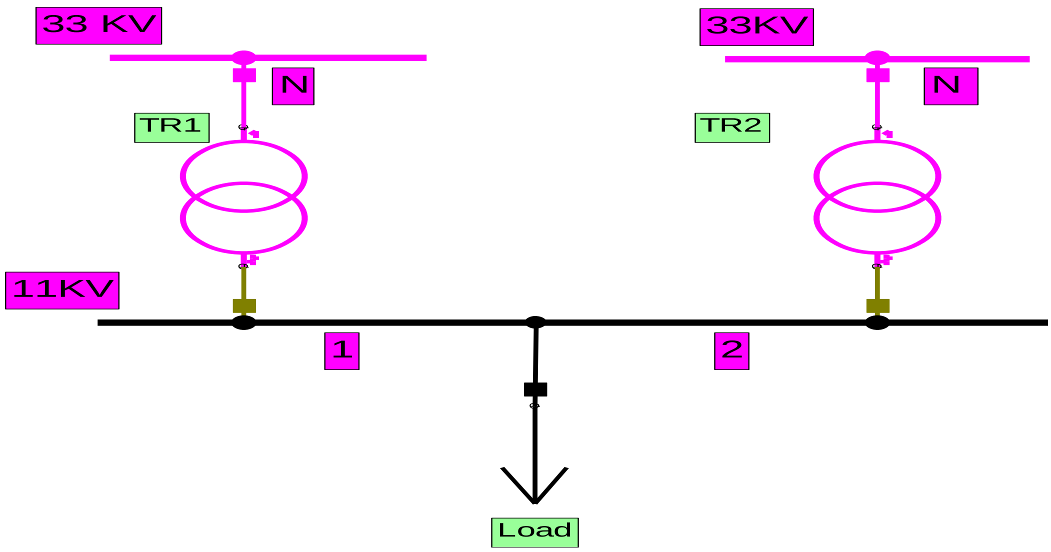

Figure 2.3: The Primary Selective system.

2.3.3. Secondary Selective System:

The secondary selective under normal conditions is operated as two separate radial systems. The secondary tie circuit breaker in each secondary substation is normally open. The load served from a secondary selective substation should be divided equally between the two bus sections. The cost of this system will depend upon the spare capacity in the transformers and primary feeders. The minimum transformer and primary feeder capacity will be determined by essential loads that must be served under emergency operating conditions. If service is to be provided for all loads under emergency conditions, then each primary feeder should have sufficient capacity to carry the total load, and each transformer should be capable of carrying the total load in each substation. This type of system will be more expensive than either the radial or primary selective system, but it makes restoration of service to all essential loads possible in the event of either a primary feeder or transformer fault. The higher cost results from the duplication of transformer capacity in each secondary substation. This cost may be reduced by shedding nonessential loads [8]. A secondary Selective configuration of a distribution network is shown in Figure 2.4.

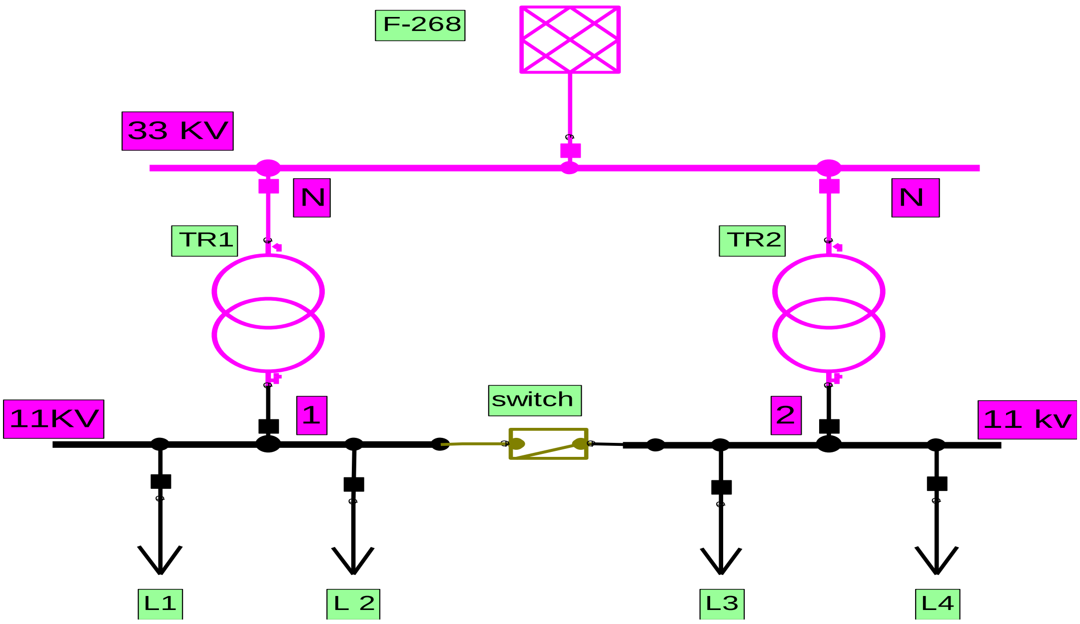

Figure 2.4: The Secondary Selective System

2.3.4. Loop Distribution Configuration:

Due higher level of service reliability and continuity of supply is necessary to use the loop system. Two primary feeders form a closed loop, in order all buses and loads to be supplied from one feeder or another in the event of a fault. One or more additional feeders along separate routes may be implemented for critical loads that cannot tolerate extended interruptions. Switching from one feeder to an alternative can be accomplished either manually or automatically with the help of circuit breakers and/or electrical interlocks, used to prevent the connection of a functional feeder with a faulted one [9]. The main disadvantages of this configuration are the higher cost and augmented complexity compared to the radial configuration. A loop configuration of a distribution network is shown in Figure 2.5.

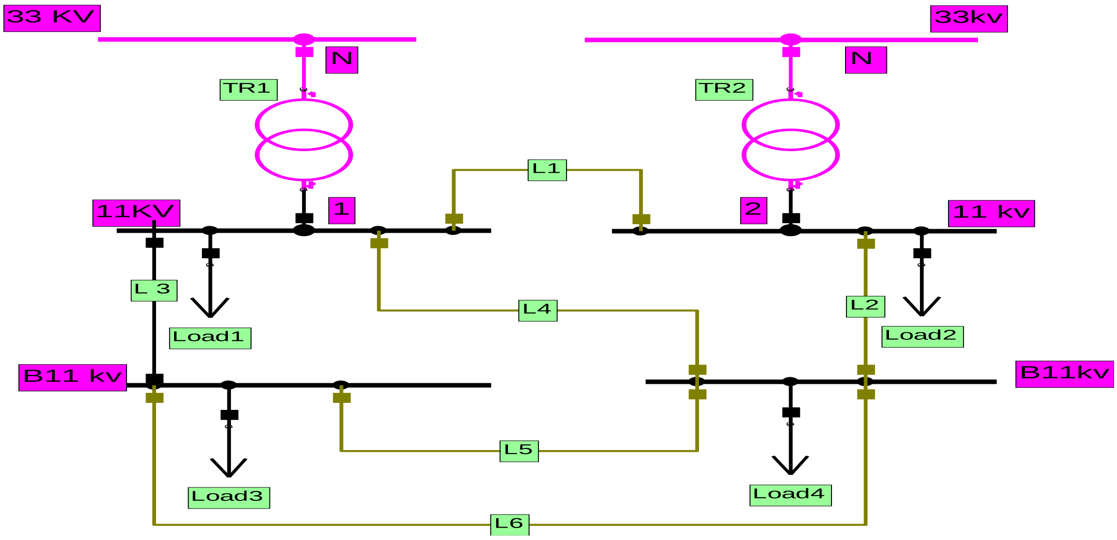

Figure 2.5: The loop distribution configuration

2.3.5. Network Distribution Configuration:

Network configuration is used to supply high-density load areas in downtown sections of cities, where the highest degree of reliability is needed. A group of radial and loop systems or the expansion of one of them will result in a network configuration distribution network. Such networks are supplied by two or more primary feeders through network transformers. These transformers are protected by devices that open to disconnect the transformer from the network if the transformer or supply feeder is faulted. Special current-limiting devices are also used at various locations to keep problems from spreading [9]. A network configuration of a distribution network is shown in Figure 2.6.

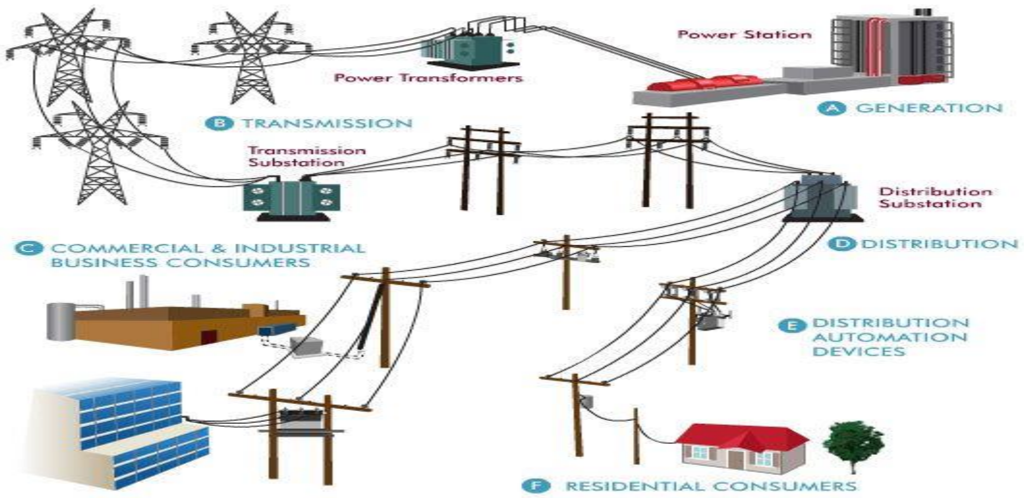

Figure 2.6: The network distribution configuration.

2.4. Voltage Drop:

Voltage drops in distribution networks are a common occurrence when different loads are connected to bus bars and across long distance lines. As the length of a line increases, its inductive reactance increases, and there is an increase in inductive reactive power. However, as inductive reactive power increases, the voltage drop across the line also increases and the voltage at the far or receiving end of the line drops. To reduce the voltage drop and support the voltage at the receiving end, more capacitive reactive power is needed to offset the inductive effect. The equipment that is usually used to regulate and provide voltage support is voltage regulators and capacitors. The recent years has been also observed that distributed generation has the potential to improve voltage if optimally is placed and sized in a distribution network [3].

2.5. Power Losses:

Electric energy passes from generation to transmission and distribution networks through overhead lines and underground cables. Losses are unavoidable as long as power is flowing in the power system. The distribution network's losses constitute the largest share of power losses within the electric power system. This is because it is constructed from many components such as lines, transformers, substations, capacitors, switches, circuit breakers.

Furthermore, the existence of different load capacities at different load profiles contributes significantly to these power losses.

Distribution networks present two types of energy losses, i.e., losses in the conductors due to the magnitude of the current and transformer core losses that are independent of current. Current related losses are equal to the current squared times the resistance of the conductor (I^2R). Accompanying these losses are reactive losses, which are related to the reactance of the conductor and are given by (I^2X). The core losses result from the energy used in transformer cores as a result of hysteresis and eddy currents. These losses depend on the magnetic material used in the core [3]. Reducing power losses is an environmental and economical concern. By producing power from distributed renewable sources and also reducing the distribution losses will help to reduce the output requirements from conventional plants which in turn reduce the greenhouse gas emissions.

2.6. Distributed Generation:

Distributed generation (DG) is related with the use of small generating units installed in strategic points of the electric power system close to load centers. It is one of the new trends in power systems used to support the increased energy-demand. There is not a common accepted definition of DG as the concept involves many technologies and applications.

Generally some distributed generation systems are geographically distributed and can be located near to region of power consumers. This reduces transmission and distribution losses by robust terms based upon the very large numbers of individual generators and statistical robustness of such a collection compared to centralized generation [10]. DG sources include small-scale, environmentally-friendly technologies (photovoltaic and wind) installed on and designed primarily to serve a single end user’s site. But when reliability and power quality issues are critical, DG most often includes more traditional fossil fuel fired reciprocating engines or gas turbines. However, the continuous increasing demand for electricity, the environmental concerns and the government policies have now made it an attractive option. In addition, technological advancement has made it possible to shift from large central generation stations powered by fossil fuels, or nuclear power (as is the case in some countries), to smaller generators most of which are connected to the distribution system. Such generator technologies can be based on alternative energy sources, with a concentration on renewable sources such as: wind and solar energy and on non-renewable sources such as: diesel and gas generator. The classification of these technologies has been made based on DG’s output power, categorising the DG units into “dispatchable” (generating units that can be turned on or off, or can adjust their power output on demand) and “non-dispatchable” units [11].

DG units can be used either in an isolated way, supplying power only for serving the consumer’s local demand, or in an integrated way, supplying power to the electric power system. In distribution systems, DG offer many advantages for both consumers and electric utilities, especially in cases where central generation is not feasible or in cases where there are serious issues/problems with the transmission network [2]. DG also poses an economic risk to incumbent utilities and their consumers unless appropriate rate structures or cost recovery mechanisms are put into place. Researchers from all over world are studying the former mentioned problems and have featured various techniques and methodologies for selecting the optimum sitting and sizing of DGs in an effort to improve voltage profiles and minimize or even eliminate power losses of modern distribution networks with distributed generation.

The authors in [12] have shown that if the customer interruptions due to any fault in the system are followed by some planned techniques, likely by injecting DG units to the distribution system will improve the reliability of the system. The results reveal that the reliability of the distribution network does improve by injecting DG to the system.

A new particle swarm optimization method has been proposed in [13] aiming to improve the power quality and the reliability of a distribution system by identifying the optimal number of DGs that must be connected and their suitable locations in the system. The proposed method was tested on the IEEE 30-bus system, producing results that have shown considerable reduction in the total power loss of the system and improvement in voltage profiles of the buses and in reliability.

Correspondingly in [14], genetic and particle swarm optimization algorithms have been exploited for optimal placement and sizing of both a DG and a capacitor. The performance of these algorithms has been tested by applying the proposed methodology to a 12-bus radial distribution system. The produced results have shown that the proposed methodology is more effective and capable of providing better results than other analytical methods.

In [15] a genetic optimization algorithm has been used in order to find the optimal location and size of different DG units in a radial distribution system.

Three main objectives have been selected, i.e., voltage, real and reactive power losses, and DG size, aiming to reduce the total power losses and improve the voltage profiles. A 69-bus radial distribution test system has been used in their study for testing and verification purposes. The proposed methodology suggested that the installation of three DG units of the same size in three different positions of the 69-bus radial distribution test system, resulted in the reduction of power losses and in voltage profiles enhancement.

Following two different approaches Parizad et al. [16] tried to determine the optimum location and size of DG by reducing losses and stabilizing voltage. The first approach targeted real power losses through the development of an exact loss formula by finding the best location for DG installation. In the second approach, a voltage stability index was used to position DG in the optimum location. Power flow was computed by applying the forward-backward sweep method. Two distribution systems of 33-bus (radial) and 30-bus (loop) systems have been exploited in the study. The proposed techniques revealed significant improvement in terms of voltage profiles and power losses reduction.

Jamian et al. in [17] used multiple types of optimization techniques to regulate the DG's output in order to compute its optimal size. Comparative studies of a new proposed rank evolutionary particle swarm optimization method with evolutionary particle swarm optimization and traditional particle swarm optimization were conducted. The implementation of evolutionary programming and particle swarm optimization allowed the entire particles to move toward the optimal value more rapidly. Their applied technique has shown a reduction in power losses which can be achieved when an optimal DG size is selected. Another conclusion made, was that evolutionary particle swarm optimization showed better results than the conventional particle swarm optimization due to its reduced iteration numbers and minor consumed computing time. The authors achieved with this approach to obtain the optimum values faster.

A relative simple analytical method for real power losses reduction, voltage profile improvement of a distribution system with a DG unit coupled and substation capacity release based on voltage sensitivity index analysis has introduced in [18]. They have chosen a 33-bus distribution system to apply their method on. Initially, a voltage sensitivity index was calculated for all the buses and then the bus with the lowest sensitivity index was chosen as the optimum place for the DG unit installation. Subsequently, several DG sizes were tested in order to identify the one that would result to the least possible power losses. In this study the forward-backward sweep algorithm was selected to perform the load flow analysis.

A very interesting study has been introduced in [19]. The authors explored the results of the penetration of mixed distributed generation technologies to a medium voltage power distribution network. Power flow and short-circuit analyses were carried out to determine the changes caused by the DG penetration to the currents, losses, voltage profiles and short-circuit levels of the examined network. Their general conclusion was that arbitrary DG accommodation leads not only to network sterilization, but also to the violation of technical constraints. The system's behavior was analyzed using NEPLAN software. It was found that losses fluctuated depending on the load factor with the major impact observed on the voltage profile

A similar technique that combines a genetic algorithm with particle swarm optimization method for the optimal location and sizing of DGs on distribution networks has been proposed in [20]. The suggested technique aimed at better voltage regulation and stabilization and power loss reduction in radial systems. The genetic algorithm has been used in order to locate the optimum place for DG installation while the particle swarm optimization method has been used so as to compute the DG's optimum size. A 33-bus radial system and a 69-bus radial system were used in order to test the proposed technique.

Balamurugan et al. in [21] conducted load flow and short circuit studies in an effort to investigate the impact of photovoltaic's on the distribution systems. DigSilent power factory software has been used for the analysis. They applied their analysis on the IEEE 34-bus system, with their main focus on total power losses, phase imbalances, fault levels and voltage profiles of the system. The authors found that the higher the penetration level the higher the positive impact of DG in terms of power losses and voltage profile. They have also observed that the same positive impact was sustained even when DG was installed in several different places within the distribution system.

An analytical technique to calculate the optimum size and to allocate DG units in the optimal place has presented in [22]. The technique that aimed to reduce the power losses and to improve the voltage profiles of distribution systems has used a sensitivity index to identify the best location for the connection of the DG. The 13-bus IEEE radial distribution test system has been used for verification purposes and the main conclusion of this work was that minimum losses and a better voltage profile can be achieved with integrating a single DG unit of optimum size and in an optimum location rather the integration of several DG units.

In [23] the authors used The Newton-Raphson method in order to calculate power losses and voltages across the network. Similarly particle swarm optimisation for the placement of DG in radial distribution systems reducing the active power losses and improving the voltage profile. In this work Power System Analysis Toolbox (PSAT), an open source MATLAB software package for analysis and design of electric power systems have been used for the power flow calculation.

Finally in [24], have used fuzzy logic for finding the optimum placement of a single DG unit and proposed a new analytical expression for DG sizing implemented in radial networks. The aim of this study was to improve voltage profile and minimize real and reactive power losses. Three different distribution systems (12-bus, 33-bus and 69-bus) were utilized in order to verify that the proposed methodologies could be applied in radial distribution systems of different sizes and arrangements. The results disclosed that an optimal size and location of a DG unit with significant reduction in real and reactive power losses was realizable. Furthermore, a noteworthy voltage profile improvement was attained. It must be declared that a forward-backward sweep algorithm was applied for load flow analysis in contrast to the majority of other researchers that use the Newton-Raphson method.

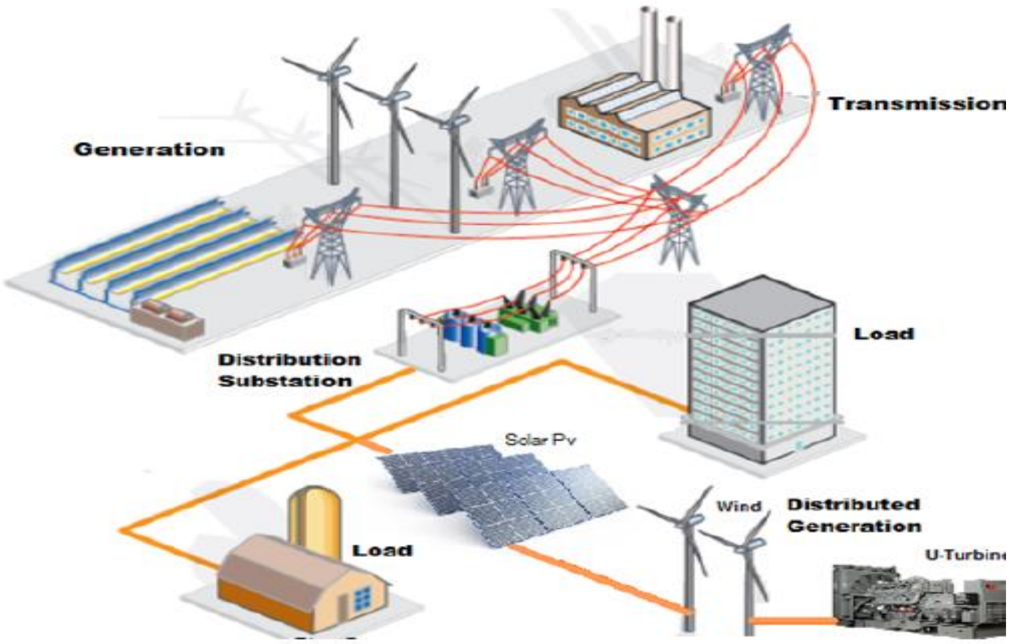

Figure 2.7: Distribution System with Distributed Generation

2.6.1. Term of DG:

Distributed generation is small scale power plant and environmentally friendly due to its “friendly” technologies. These “friendly” technologies include photovoltaic (PV), fuel cells, small wind turbines, or more conventional technologies such as micro turbines and reciprocating engines that are fueled by renewable fuels, for instance, landfill gas. DG encompasses generation built near to a consumer’s load despite size or energy source. The latter definition could include diesel-fired generators with significant emissions [25].

In general, there is Different countries use different notations like “distributed generation” (DG) or its definition. In some countries it may be referred as “embedded generation”, while in others it is known as “dispersed generation” or “decentralized generation”. The International Energy Agency has introduced all existing different terms in order to describe DG providing also their relevant descriptions (Table2.1). Some of the DG technologies, which are available at the present: photovoltaic systems, wind turbines, fuel cells, micro turbines, synchronous and induction generators are introduced. DG technology is available in a wide capacity range (i.e., from 1 kW up to 300 MW), giving the possibility to DG units to be easily installed on distribution networks, both medium and low voltage [26].

Table 2.1: Different terms for DG and their description.

Term	Description
Distributed generation	DG technologies connected close to load Centre's with the exception of wind turbines
Distributed power	DG and energy storage
Distributed energy resources	DG and demand side management
Decentralized power	DG connected to the distribution system
Dispersed generation	DG including wind turbines (stand alone or grid connected)

Many a variety of definitions may be found in the literature that relate to size, location or the underlying technology. Ackermann et al. in [27] approached this problem by reviewing a number of different issues so that a more subtle definition for DG could be reached. The issues were: location, technology, purpose, mode of operation, ownership, size, power delivery area, DG penetration and environmental impact. Their definition for DG was: DG can be defined as an electric power generation source connected directly to the distribution network or on the customer site of the meter. Table 2.2 below shows Ackermann's et al classification for DG based on the size.

Table 2.2: Ratings categories of DG

Ratings	Categories
1W < 5kW	Micro-distributed generation
5kW < 5MW	Small distributed generation
5MW < 50MW	Medium distributed generation
50MW < 300MW	Large distributed generation

2.6.2. Types of Distributed Generation:

DG can be classified into two major groups, inverter based DG and rotating machine DG. Normally, inverters are used in DG systems after the generation process, as the generated voltage may be in DC or AC form, but it is required to be changed to the nominal voltage and frequency.

Therefore, it has to be converted first to DC and then back to AC with the nominal parameters through the rectifier [28].

1. Photovoltaic Systems:

PV systems generate DC voltage then transferred to AC with the aid of inverters. There are two general designs that are typically used: with and without battery storages. This system, converts the light received from the sun into electric energy. The cells are placed in an array that is either fixed or moving to keep tracking the sun in order to generate the maximum power [29]. These systems are environmental friendly without any kind of emission, easy to use, with simple designs and it does not require any other fuel than solar light. On the other hand, they need large spaces and the initial cost is high.

1. Wind Turbines:

Wind turbines transform wind energy into electricity. The wind is a highly variable source, which cannot be stored, thus, it must be handled according to this characteristic. In the most common system, the generator system gives an AC output voltage that is dependent on the wind speed. As wind speed is variable, the voltage generated has to be transferred to DC and back again to AC with the aid of inverters. However, fixed speed wind turbines are directly connected to grid [29].

2. Fuel Cells:

Fuel cells operation is similar to a battery that is continuously charged with a fuel gas with high hydrogen content; this is the charge of the fuel cell together with air, which supplies the required oxygen for the chemical reaction. The fuel cell utilizes the reaction of hydrogen and oxygen with the aid of an ion conducting electrolyte to produce an induced DC voltage. The DC voltage is converted into AC voltage using inverters and then is delivered to the grid [29].

Advantage of a fuel cell is that there are no moving parts, which increase the reliability of this technology and no noise is generated. Moreover, they can be operated with a width spectrum of fossil fuels with higher efficiency than any other generation device. On the other hand, it is necessary to assess the impact of the pollution emissions and ageing of the electrolyte characteristics, as well as its effect in the efficiency and life time of the cell. A fuel cell also produces heat and water along with electricity but it has a high running cost, which is its major disadvantage [28].

3. Micro-Turbines:

A micro-turbine is a mechanism that uses the flow of a gas, to covert thermal energy into mechanical energy. The output voltage from micro-turbines cannot be connected directly to the power grid or utility, it has to be transferred to DC and then converted back to AC in order to have the nominal voltage and frequency of the utility. The main advantage of micro-turbines is the clean operation with low emissions produced and good efficiency. On the other hand, its disadvantages are the high maintenance cost and the lack of experience in this field. Very little micro-turbines have been operated for enough time periods to establish a reliable field database. Furthermore, methods of control and dispatch for a large number of micro turbines and selling the remaining energy have not been developed yet [28].

4. Induction and Synchronous Generators:

Induction and synchronous generators are electrical machines which convert mechanic energy into electric energy then dispatched to the network or loads. A generator connected to a very large (infinite bus) electrical system will have little or no effect on its frequency and voltage, as well as, its rotor speed and terminal voltage will be governed by the grid. Synchronous generator is a source or sink of reactive power. Nowadays, synchronous generators are also employed in distribution generator systems, in thermal, hydro, or wind power plants. Normally, they do not take part in the system frequency control as they are operated as constant power sources when they are connected in low voltage level. These generators can be of different ratings starting from kW range up to few MW ratings [30].

2.6.3. The Impact of DG in Voltage Profile and Power Losses:

1. Voltage Profile:

Distributed generation is supposed to support and improve the system's voltage but the question that is raised is up to what extent is this statement accurate, since it has been demonstrated that the penetration of DGs in the distribution system may cause overvoltage or under voltage. Furthermore, specific DG technologies vary their output power level over time, as in the case of photovoltaic and wind generators. As a consequence, voltage fluctuations occur that in turn deteriorate the power quality delivered to consumers. Moreover, overvoltage and under voltages in distribution networks with DG have been reported due to the incompatibility of DGs with the existing voltage regulation methods [31].

In general, the distribution networks are regulated with the help of voltage regulators, capacitors and the tap changing of transformers. These methods were designed for radial (unidirectional) power flow and have been proved to be very reliable and efficient in the past. However, nowadays, the installation of DGs in distribution networks had a substantial impact on the voltage regulation methods performance due to the meshed (bidirectional) power flow, introduced by DGs to the networks. On the other hand, the implementation of DG had a positive impact on the distribution networks for the reason that they contribute to the reactive compensation for voltage control, to frequency regulation and they operate as spinning reserve in the case of main system's fault indices [31].

2. Power Losses:

DG units should be allocated in places where they provide a higher reduction of losses. This process of DG allocation is minimize the power losses (both real and reactive) of distribution networks due to their installation near the load centers. Several studies, most of which were presented earlier, demonstrated that the location and size of a DG unit play an important role in the power losses elimination. Consequently, the specific location of a DG in a distributed network and DG's specific capacity resulting in minimum power losses is in general identified as the optimum location. The DG allocation process is very similar to the capacitor allocation procedure aiming at the power losses reduction. The main difference between the two processes is that DG units exhibit impact upon both real and reactive power, while the capacitor banks influence only the reactive power flow. It has been proven, that in the case of networks with increased power losses, installing a relative small distributed generation unit strategically connected to the network, may result in substantial power losses reduction [32].

2.6.4. Benefits and Drawbacks of the DG:

An overview of some common benefits and drawbacks of the DG are presented below:

1. Benefits of DG [33-35]:

Many benefits have been derived from integration of DG units into the distribution networks by power system planners and policy makers [36]. These benefits depend upon the characteristics of DG units such as photovoltaic (PV), wind generating system and reciprocating engines, type of loads, local renewable sources and network pattern.

a. The Connection of DG is intended to increase the reliability of power supply provided to the customers, using local sources, and if possible, reduce the losses of the transmission and distribution systems.

b. The integration of DG to the power system is injected of real power and consumption of reactive power could improve the voltage profile, power quality and support voltage stability, which minimizes the number of required voltage regulators, capacitors and their ratings and maintenance costs. It must be mentioned that the amount of improvement depends on the sitting and sizing of DG units. Therefore, the system can withstand higher loading situations.

c. DG units are usually installed near the load site on the radial distribution networks. Thus, part of the transmission power is replaced by the injected DG power, causing a reduction in transmission and distribution line losses, which minimizes costs related to loss.

d. Some DG technologies have low pollution and good overall efficiencies like combined heat and power (CHP) and micro-turbines. Besides, renewable energy based DG like photovoltaic and wind turbines contribute to the reduction of greenhouse gases.

e. The increasing power demands, due to load growth, can be covered by DG units without the need to increase existing traditional generation capacity. This has also as a result the reduction or delay for building new transmission and distribution lines and for upgrading the present power systems.

f. DG units require a short period of time to install and pose less of an investment risk due to their modular characteristics, which enables them to be easily, assembled anywhere. Each DG unit is totally independent of the others, can generate electricity immediately after its installation and cannot be affected by other units' operation failure.

g. DGs are flexible devices that can be installed at load centres rather than at substations, where difficulties due geographical constraints or scarcity of land availability may occur. In addition, DG locations are not restricted by the government's choice for potential locations, as is the case when selecting new substation locations.

h. DG technologies produce electric power with few emissions (and sometimes zero emissions).This feature makes them more environmentally friendly compared to traditional power plants.

2. Drawbacks of DG:

The integrating of DG units into electrical distribution systems may also lead to negative impacts, especially for large scale installations if they are not optimally handled. The main drawbacks of DG are summarized as follows: [33-34-35]

a. The connection of DGs might cause over voltages and disturbances to the system's voltage profile, mainly due to mismatched synchronization with the electrical supply utilities.
b. Many DG are connected to the grid using power converters, which injects harmonics into the system.
c. Short circuit levels are changed when a DG is connected to the network. Therefore, relay settings should be changed and if there is a disconnection of DG, relay should be changed back to its previous state.
d. Depending on the network configuration, the penetration level and the nature of the DG technology, the power injection of DG results in the reduction of power losses, may increase the power losses in the distribution system.
e. Although the continuous connection of DGs results to a more complex power system. The control, operation, protection and security of the system changes that result the need for the conduction of new studies and the development of new techniques.

3. Issues Arising from Distributed Generation use [2]:

The impact that the increasing connection of distributed generation (DG) plants has in the electric power systems, can be summarized in the following issues:

a. **Stability issues:** The stability of distribution network is important for DG installations. The DG should be able to remain synchronized after a major fault. Furthermore, a massive implementation of DG leads to the inertia of the entire system to decrease. Unless fast acting primary control is applied, the system frequency will become significantly sensitive to disturbances.
b. **Distribution system reliability performance:** DG affects significantly the reliability and operational indices of existing distribution networks. The operation of DG in parallel with the transmission supply system and its performance during abnormal conditions, such as power supply outages must be taken into account.

c. **Regulation and balancing issues.** Larger penetration of renewable energy sources, in the form of DG, from the strictly technical point of view, depends on two major issues: i) grid connection issues, and ii) power system regulation issues. The first issue addresses the need for network reinforcements, which is more a question of feasibility and economics, while the second relates to complex balancing issues. Regulation and balancing issues can only be addressed in coordination between all power system players on a national and international (interconnection) level.

d. **Islanding effect:** When the main line of a utility system, which contains DG, is disconnected, more than one DG continues to operate in the isolated section (island), thus leading to the islanding effect. Unintended islanding is of paramount importance for the general public, maintenance personnel and installed equipment, since the distribution lines remain energized.

e. **Management of micro-grids in the new market environment.**
The micro-grid is a low voltage network which usually operates interconnected with the main medium voltage network. In case of emergency the micro-grid can run autonomously being a solution to the structure for the coordination of the DG units. The investigation of control approaches, possible configurations and security issues related to the micro-grids operation is of high importance.

f. **Optimum sitting and sizing of DG:** Today there is no specific plan, neither for the sitting the sizing of DG units, in almost all electric power systems worldwide. This can result voltage fluctuations, causing currents that exceed the line's thermal limit, harmonic problems and instability of the voltage profile of some electricity consumers. In addition, the bi-directional power flows can lead to voltage profile fluctuation and change the short circuit levels sufficiently to cause fuse-breaker discoordination. Studies have shown that the installation of DG units in distribution networks can improve the voltage profiles and contribute significantly in the minimization of both real and reactive power losses. The specific location and size of DG units play an important role in both voltage profile and power losses, since significant penetration of DGs has been shown that it may cause over voltages or under voltages.

g. **Selective protection coordination issues:** The connection of DG increases the complexity of selective protection coordination. From a technical point of view, the DG presence in distribution networks may result to conflicts in the normal operation of the current networks. This is mainly because, unlike the meshed transmission system, the distribution system is designed as a “passive” radial system, without generators operating in parallel, or power flow control. In addition, the connection of DG can alter the fault current during a grid disturbance, which leads to incorrect operation of the protective system and causes fault detection problems and selectivity problems.

2.7. Decision Making Algorithm for the Optimum Size and Placement of DG in Distribution Networks

A decision making algorithm for the optimum size and placement of a DG unit in distribution networks has been developed. The algorithm that is relative simple, flexible to changes and modifications can estimate the optimum DG size and can define the optimal location for a DG unit (of any type) to be installed, based on the improvement of voltage profiles and the reduction of the network’s total real and reactive power losses. The algorithm has been implemented in MATLAB and the load flow analysis is performed with the use of NEPLAN, one of the most reliable power systems software.

The following structure:

1. Define Network Model, Distributed Generation (DG) parameters, and number of test DGs.
2. Perform Load Flow analysis to obtain steady-state base case parameters for Bus voltages and line losses.
3. Sort Buses in ascending order of voltage deviation from nominal voltage for DG placement in the same order.

4. For each test DG, connect DG at given Bus, Perform Load flow analysis and store results as a scenario.
5. Repeat Step 4 for every Bus in ordered list.
6. Sort all Load flow scenario results for all DGs placed at all buses according to lowest line losses or best voltage profile.
7. Select scenario with lowest line losses or best voltage profile for optimum DG size and placement.

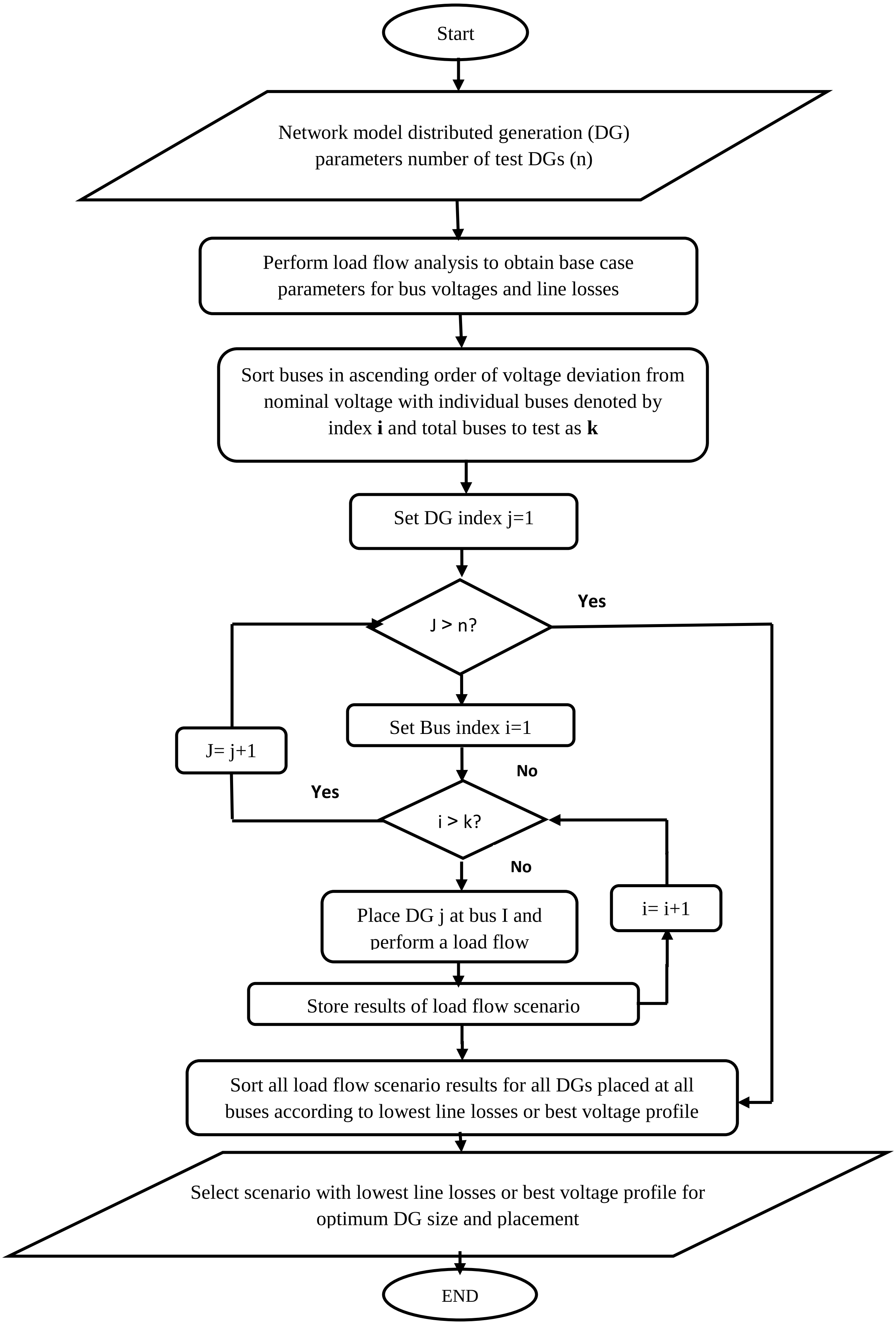

Figure 2.8: The flow chart of the proposed decision making algorithm

CHAPTER THREE
MATHEMATICAL MODEL AND SOFTWARE PROGRAM

3.1. Introduction:

This chapter discusses the mathematical model used to calculate load flow analysis and brief description of software program (NEPLAN) which has different methods available for the analysis. In this research the newton-Raphson method is adopted.

Load flow analysis is probably the most important of all network calculations since it concerns the network performance in its normal operating conditions. It is performed to investigate the magnitude and phase angle of the voltage at each bus and the real and reactive power flows in the system components.

Load flow analysis has a great importance in future expansion planning, in stability studies and in determining the best economical operation for existing systems. Also load flow results are very valuable for setting the proper protection devices to insure the security of the system. In order to perform a load flow study, full data must be provided about the studied system, such as connection diagram, parameters of transformers and lines, rated values of each equipment, and the assumed values of real and reactive power for each load [37].

3.2. Bus Classifications:

Each bus in the system has four variables: voltage magnitude, voltage angle, real power and reactive power. During the operation of the power system, each bus has two known variables and two unknowns. Generally, the bus must be classified as one of the following bus types [37]:

3.2.1. Slack or Swing Bus:

This bus is considered as the reference bus. It must be connected to a generator of high rating relative to the other generators. During the operation, the voltage of this bus is always specified and remains constant in magnitude and angle. In addition to the generation assigned to it according to economic operation, this bus is responsible for supplying the losses of the system.

3.2.2. Generator or Voltage Controlled Bus:

During the operation the voltage magnitude at this the bus is kept constant. Also, the active power supplied is kept constant at the value that satisfies the economic operation of the system. Most probably, this bus is connected to a generator where the voltage is controlled using the excitation and the power is controlled using the prime mover control Sometimes, this bus is connected to a VAR device where the voltage can be controlled by varying the value of the injected VAR to the bus.

3.2.3. Load Bus:

This bus is not connected to a generator so that neither its voltage nor its real power can be controlled. On the other hand, the load connected to this bus will change the active and reactive power at the bus in a random manner. To solve the load flow problem we have to assume the complex power value (real and reactive) at this bus.

3.3. Load Flow Equations:

Assuming a system having n buses, the injected current to the bus (node) k can be expressed as [38]:

$$I_k = \sum_{n=1}^{N} Y_{kn} V_n \tag{3.1}$$

Where:

I_k≡ is current in bus (k).

Y_{kn}≡ is admittance between bus (k) and bus (n).

V_n≡ is voltage in bus (n).

And,

$$Y_{kn} = |Y_{kn}|\angle\theta_{kn} \tag{3.2}$$

$$V_n = |V_n|\angle\delta_n \tag{3.3}$$

Where:

θ_{kn}≡ is voltage angle, δ_n≡is load angle

The complex power at bus k (k = 1, 2... n) is given as:

$$S_k^* = V_k^* I_k = P_k - jQ_k \tag{3.4}$$

So that;

$$P_k - jQ_k = V_k^* \sum_{n=1}^{N} Y_{kn} V_n \tag{3.5}$$

This gives the two power balance equations:

$$P_k = |V_k| \sum_{n=1}^{N} \{|Y_{kn}||V_n| \cos(\delta_n - \delta_k + \theta_{kn})\} \tag{3.6}$$

$$Q_k = |V_k| \sum_{n=1}^{N} \{|Y_{kn}||V_n| \sin(\delta_n - \delta_k + \theta_{kn})\} \tag{3.7}$$

Where, P_k and Q_k are the active and reactive power injection at bus k respectively. Thus, at each bus we have two equations and four variables (P, Q, δ, V). Note that Y's and θ's are known from network data.

Actually, at each bus we have to specify two variables and solve for the remaining two unknowns. Thus, for an N bus system 2N equations are solved. These 2N equations are nonlinear equations as they involve products of variables as well as sine and cosine functions.

3.4. Methods of Solving Power Balance Equations

Because of the nonlinearity and the difficulty involved in the analytical expressions for the power flow equations (3.6) and (3.7), numerical iterative methods must be used such as [38]:

3.4.1. Gauss – Seidel Method

This is one of many techniques for solving the nonlinear load flow problem. It should be pointed out that this solution technique, while straightforward to use and easy to understand, has a tendency to use a lot of computation, particularly in working large problems. It is also quite capable of converging on incorrect solutions (that is a problem with nonlinear systems). As with other iterative techniques, it is often difficult to tell when the correct solution has been reached. Despite these short comings, Gauss–Seidel can be used to get a good feel for load flow problems without excessive numerical analysis baggage.

To find the voltage in specific bus (k) in load bus equation (3.6) is used

$$V_k = \frac{1}{Y_{kk}}\left(\frac{P_k - jQ_k}{V_k^*} - \sum_{\substack{i=1 \\ i\neq k}}^{n} Y_{ki}V_i\right) \tag{3.8}$$

Where:

V_k ≡ is voltage is bus k.

Y_{kk} ≡ is the self-admittance in bus k.

P_k, Q_k ≡ is the active and reactive power in bus k.

V_i ≡ is the voltage in bus i.

This equation can be used in a numerical iterative scheme to update V_k as follows.

$$V_k(j+1) = \frac{1}{Y_{kk}}\left(\frac{P_k - jQ_k}{V_k^*(j)} - \sum_{\substack{i=1 \\ i\neq k}}^{n} Y_{ki}V_i(j)\right) \tag{3.9}$$

The letter j here is the iteration count, j+1 is the next iteration count.

For a voltage-controlled bus, Q_k is unknown, but can be calculated using equation (3.10)

$$Q_k = \sum_{i=1}^{n} |V_k||V_i|(G_{ki}\sin\delta_{ki} - B_{ki}\cos\delta_{ki}) \tag{3.10}$$

If the calculated value of Q_k does not exceed its limits, then Q_k is used to calculate

$$V_k(j+1) = V_k(j+1)\angle\delta_k(j+1) \tag{3.11}$$

Then the magnitude V_k (j+1) is changed to V_k, which is input data for the voltage-controlled bus. Thus we use the equation (3.11) only to compute the angle δ_k(j+1) for voltage-controlled buses.

But if the calculated value exceeds its limit (Q_{kmax} or Q_{kmin}) during any iteration, then the bus type is changed from a voltage-controlled bus to a load bus.

3.4.2. Newton Raphson Method:

Newton Raphson is another method used for solving power balance equations the advantages of Newton Raphson method over Gauss – Seidel method is that in Newton-Raphson converges in many cases where Gauss-Seidel diverges, also the number of iterations required for convergence is independent of the dimension N for Newton-Raphson, but increases with N for Gauss-Seidel. And the last advantage is that most of Newton-Raphson power-flow problems converge in fewer than 10 iterations [39].

Power Balance Equations:

$$S_i = P_i + jQ_i = V_i\left(\sum_{j=1}^{n} Y_{ij}V_j\right)^* = \sum_{j=1}^{n}|V_i||V_j|e^{j\theta_{ik}}\left(G_{ij} - jB_{ij}\right)$$
$$S_i = \sum_{j=1}^{n}|V_i||V_j|\left(\cos\theta_{ij} + j\sin\theta_{ij}\right)\left(G_{ij} - jB_{ij}\right) \quad (3.12)$$

Resolving into the real and imaginary parts:

$$P_i = \sum_{j=1}^{n}|V_i||V_j|\left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) = P_{Gi} - P_{Li}$$
$$Q_i = \sum_{j=1}^{n}|V_i||V_j|\left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) = Q_{Gi} - Q_{Li} \quad (3.13)$$

The swing (slack) bus variables δ_1 and V_1 are omitted since they are already known.

$$y_i = P_i = P_i(x) = V_i\sum_{\substack{j=1\\ j\neq i}}^{n} Y_{ij}V_j\cos\left(\delta_i - \delta_j - \theta_{ij}\right)$$
$$P_i = |V_i|^2 G_{ii} + \sum_{\substack{j=1\\ j\neq i}}^{n}\left|V_iV_jY_{ij}\right|\cos\left(\theta_{ij} + \delta_j - \delta_i\right)$$
$$y_i = Q_i = Q_i(x) = V_i\sum_{\substack{j=1\\ j\neq i}}^{n} Y_{ij}V_j\sin\left(\delta_i - \delta_j - \theta_{ij}\right) \quad (3.14)$$
$$Q_i = -|V_i|^2 B_{ii} - \sum_{\substack{j=1\\ j\neq i}}^{n}\left|V_iV_jY_{ij}\right|\sin\left(\theta_{ij} + \delta_j - \delta_i\right)$$

Where: V, P and Q terms in per-unit

δ Terms are in radians

j = 2, 3…n

If j = i -→ $\left(\delta_j - \delta_i\right) = 0$

For load bus:

The known values are: real power demand to load at bus i = P_{Li}

Reactive power demand to load at bus i = Q_i

$$\begin{aligned}\Delta P_i &= P_{i,sch} - P_{i,calc} \\ \Delta Q_i &= Q_{i,sch} - Q_{i,calc}\end{aligned} \qquad (3.15)$$

Each non slack bus of the system has two equations like those for ΔPi and ΔQi.

Generally, for system with n bus collecting the mismatch equations into vector-matrix form yields.

$$\begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \cdots & \frac{\partial P_2}{\partial \delta_n} & |V_2|\frac{\partial P_2}{\partial |V_2|} & \cdots & |V_n|\frac{\partial P_2}{\partial |V_n|} \\ \vdots & J_{11} & \vdots & \vdots & J_{12} & \vdots \\ \frac{\partial P_n}{\partial \delta_2} & \cdots & \frac{\partial P_n}{\partial \delta_n} & |V_2|\frac{\partial P_n}{\partial |V_2|} & \cdots & |V_n|\frac{\partial P_n}{\partial |V_n|} \\ \frac{\partial Q_2}{\partial \delta_2} & \cdots & \frac{\partial Q_2}{\partial \delta_n} & |V_2|\frac{\partial Q_2}{\partial |V_2|} & \cdots & |V_n|\frac{\partial Q_2}{\partial |V_n|} \\ \vdots & J_{21} & \vdots & \vdots & J_{22} & \vdots \\ \frac{\partial Q_n}{\partial \delta_2} & \cdots & \frac{\partial Q_n}{\partial \delta_n} & |V_2|\frac{\partial Q_n}{\partial |V_2|} & \cdots & |V_n|\frac{\partial Q_n}{\partial |V_n|} \end{bmatrix} \begin{bmatrix} \Delta\delta_2 \\ \vdots \\ \Delta\delta_n \\ \frac{\Delta|V_2|}{|V_2|} \\ \vdots \\ \frac{\Delta|V_n|}{|V_n|} \end{bmatrix} = \begin{bmatrix} \Delta P_2 \\ \vdots \\ \Delta P_n \\ \Delta Q_2 \\ \vdots \\ \Delta Q_n \end{bmatrix} \qquad (3.16)$$

For the slack bus:

1. Mismatches cannot include because ΔP1 and ΔQ1 are undefined when P_1 and Q_1 are not scheduled.
2. All terms involving $\Delta\delta_1$ and $\Delta|V_1|$ are omit from Eq (3.16) because those corrections are both zero at the slack bus.

The partitioned form of Eq (3.16) emphasizes the four different types of partial derivatives which enter into the Jacobian J.

The solution of Eq (3.16) is found by iteration as follow;

1. Estimate values $\delta_i^{(0)}$ and $|V_i|^{(0)}$ for the state variables.
2. Use the estimates to calculate:

$P_{i,calc}^{(0)}$ and $Q_{i,calc}^{(0)}$ from Eq (3.14), mismatch $\Delta P_i^{(0)}$ and $\Delta Q_i^{(0)}$ from Eq (3.15), and the partial derivative elements of the Jacobian J.

3. Solve Eq (3.16) for the initial estimates to obtain

$$\delta_i^{(1)} = \delta_i^{(0)} + \Delta\delta_i^{(0)}$$
$$|V_i|^{(1)} = |V_i|^{(0)} + \Delta|V_i|^{(0)} = |V_i|^{(0)}\left(1 + \frac{\Delta|V_i|^{(0)}}{|V_i|^{(0)}}\right) \tag{3.17}$$

4. Use the new values $\delta_i^{(1)}$ and $|V_i|^{(1)}$ as starting values for iteration 2 and continue.

In more general terms, the update formulas for the starting values of the state variables are:

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)}$$
$$|V_i|^{(k+1)} = |V_i|^{(k)} + \Delta|V_i|^{(k)} = |V_i|^{(k)}\left(1 + \frac{\Delta|V_i|^{(k)}}{|V_i|^{(k)}}\right) \tag{3.18}$$

The elements of the sub matrix J_{11}:

The diagonal elements:

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{\substack{j=1 \\ j\neq i}} |V_i V_j Y_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i) = -\sum_{\substack{j=1 \\ j\neq i}}^{n} \frac{\partial p_i}{\partial \delta_j} = -Q_i - |V_i|^2 B_{ii} \tag{3.19}$$

The off-diagonal elements:

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i V_j Y_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i) \tag{3.20}$$

The elements of the sub matrixJ_{21}:

The diagonal elements:

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{\substack{j=1 \\ j\neq i}} |V_i V_j Y_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i) = -\sum_{\substack{j=1 \\ j\neq i}}^{n} \frac{\partial Q_i}{\partial \delta_j} = -P_i - |V_i|^2 G_{ii} \tag{3.21}$$

The off-diagonal elements:

$$\frac{\partial Q_i}{\partial \delta_j} = -\left|V_i V_j Y_{ij}\right| \cos\left(\theta_{ij} + \delta_j - \delta_i\right) \quad (3.22)$$

The elements of the sub matrixJ_{12}:

The diagonal elements:

$$\left|V_i\right| \frac{\partial P_i}{\partial \left|V_i\right|} = \left|V_i\right| \left[2\left|V_i\right| G_{ii} + \sum_{\substack{j=1 \\ j \neq i}}^{n} \left|V_j Y_{ij}\right| \cos\left(\theta_{ij} + \delta_i - \delta_i\right) \right] = \frac{\partial Q_i}{\partial \delta_i} + 2\left|V_i\right|^2 G_{ii} = -P_i + \left|V_i\right|^2 G_{ii} \quad (3.23)$$

The off-diagonal elements = The off-diagonal elements J21:

$$\left|V_i\right| \frac{\partial P_i}{\partial \left|V_j\right|} = -\frac{\partial Q_i}{\partial \delta_j} = \left|V_i V_j Y_{ij}\right| \cos\left(\theta_{ij} + \delta_j - \delta_i\right) \quad (3.24)$$

The elements of the sub matrixJ_{22}:

The diagonal elements:

$$\left|V_i\right| \frac{\partial Q_i}{\partial \left|V_i\right|} = -\frac{\partial P_i}{\partial \delta_i} - 2\left|V_i\right|^2 B_{ii} = Q_i - \left|V_i\right|^2 B_{ii} \quad (3.25)$$

The off-diagonal elements:

$$\left|V_j\right| \frac{\partial Q_i}{\partial \delta_j} = -\left|V_j Y_{ij}\right| \sin\left(\theta_{ij} + \delta_j - \delta_i\right) = \frac{\partial P_i}{\partial \delta_j} \quad (3.26)$$

3.4.3. Fast Decoupled Power Flow:

It is type of Newton-Raphson method it used for contingencies purpose the algorithm give the solution in second or less by neglecting J_2 a (i) and J_3 a (i) in jacobian matrix and reduced it to set of equations (3.35) and (3.36):

Power Balance Equations

$$\begin{aligned} S_i = P_i + jQ_i = V_i \left(\sum_{j=1}^{n} Y_{ij} V_j \right)^* &= \sum_{j=1}^{n} \left|V_i\right| \left|V_j\right| e^{j\theta_{ik}} \left(G_{ij} - jB_{ij}\right) \\ &= \sum_{j=1}^{n} \left|V_i\right| \left|V_j\right| \left(\cos\theta_{ij} + j\sin\theta_{ij}\right) \left(G_{ij} - jB_{ij}\right) \end{aligned} \quad (3.27)$$

Resolving into the real and imaginary parts:

$$P_i = \sum_{j=1}^{n} |V_i||V_j|\left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) = P_{Gi} - P_{Li}$$
$$Q_i = \sum_{j=1}^{n} |V_i||V_j|\left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) = Q_{Gi} - Q_{Li} \quad (3.28)$$

We have the system of equation with two separated, and we called the Decoupled power-flow method because:

1. the voltage-angle corrections $\Delta\delta$ are calculated using only real power mismatches ΔP,
2. while the voltage-magnitude corrections are calculated using only ΔQ mismatches

In a few assumption and approximation properly operated power transmission system:

1. The angular differences $(\delta_i - \delta_j) \cong 0$ between typical buses of the system are very small, so:

   $$\cos(\delta_i - \delta_j) \cong 1 = 1 \quad \text{And} \quad \sin(\delta_i - \delta_j) \cong 0 = 0$$

2. The line susceptances B_{ij} a are many times larger than the line conductances G_{ij} so during normal operation: $Q_i << |V_i|^2 B_{ii}$ which would flow if all lines from that bus were short-circuited to reference.

With approximation above we have the elements of the Jacobian sub matrix J_{11} and J_{22} a as:

Elements off-diagonal:

$$\frac{\partial P_i}{\partial \delta_j} = |V_j|\frac{\partial Q_i}{\partial |V_j|} \cong -|V_i V_j| B_{ij} \quad (3.29)$$

Elements diagonal:

$$\frac{\partial P_i}{\partial \delta_i} \cong |V_i| \frac{\partial Q_i}{\partial \delta_i} \cong -|V_i|^2 B_{ii} \tag{3.30}$$

Substitution Eq (3.29) and (3.30) in the coefficient matrix J11 and J22 we have:

$$\begin{bmatrix} -|V_2V_2|B_{22} & \cdots & -|V_2V_n|B_{2n} \\ \vdots & J_{11} & \vdots \\ -|V_2V_n|B_{n2} & \cdots & -|V_nV_n|B_{nn} \end{bmatrix} \begin{bmatrix} \Delta\delta_2 \\ \vdots \\ \Delta\delta_n \end{bmatrix} = \begin{bmatrix} \Delta P_2 \\ \vdots \\ \Delta P_n \end{bmatrix} \tag{3.31}$$

And

$$\begin{bmatrix} -|V_2V_2|B_{22} & \cdots & -|V_2V_n|B_{2n} \\ \vdots & J_{22} & \vdots \\ -|V_2V_n|B_{n2} & \cdots & -|V_nV_n|B_{nn} \end{bmatrix} \begin{bmatrix} \frac{\Delta|V_2|}{|V_2|} \\ \vdots \\ \frac{\Delta|V_n|}{|V_n|} \end{bmatrix} = \begin{bmatrix} \Delta Q_2 \\ \vdots \\ \Delta Q_n \end{bmatrix} \tag{3.32}$$

By manipulation mathematic from Eq (3.31) and (3.32) we have:

$$\underbrace{\begin{bmatrix} -B_{22} & \cdots & -B_{2n} \\ \vdots & J_{11} & \vdots \\ -B_{n2} & \cdots & -B_{nn} \end{bmatrix}}_{B} \begin{bmatrix} \Delta\delta_2 \\ \vdots \\ \Delta\delta_n \end{bmatrix} = \begin{bmatrix} \frac{\Delta P_2}{|V_2|} \\ \vdots \\ \frac{\Delta P_n}{|V_n|} \end{bmatrix} \tag{3.33}$$

And

$$\underbrace{\begin{bmatrix} -B_{22} & \cdots & -B_{2n} \\ \vdots & J_{11} & \vdots \\ -B_{n2} & \cdots & -B_{nn} \end{bmatrix}}_{B} \begin{bmatrix} \Delta V_2 \\ \vdots \\ \Delta V_n \end{bmatrix} = \begin{bmatrix} \frac{\Delta Q_2}{|V_2|} \\ \vdots \\ \frac{\Delta Q_n}{|V_n|} \end{bmatrix} \tag{3.34}$$

Short equation is:

$$\Delta \mathrm{P(i)} = \mathrm{J}_{11}\,\mathrm{(i)}\,\Delta\delta\mathrm{(i)} \tag{3.35}$$

$$\Delta \mathrm{Q(i)} = \mathrm{J}_{22}\mathrm{(i)}\,\Delta \mathrm{V(i)} \tag{3.36}$$

Usually, matrix B is:

1. symmetrical and sparse with nonzero elements,
2. which are constant,
3. real numbers exactly equal to the negative of the susceptances of Y bus

This method was called Fast-Decoupled Method, because Fast in solution and Decoupled between mismatches of real power and reactive power.

The computer time required to solve the decoupled equations is significantly less than that required to solve for the complete Jacobian matrix equations [39].

3.4.4. The DC Power Flow:

The DC load flow simplifies the AC load flow to a linear circuit problem. Consequently, it makes the steady state analysis of the power system very efficient. The main shortcoming of the DC load flow model is that it cannot be used in checking voltage limit violations. Because the DC load flow uses a linear model, it is not only suitable to efficiently treat the problem of line outages, but is also suitable to form linear optimization problems. Therefore, the DC load flow method has been widely used in power system planning and operating problems [39].

The node active power equations of an AC load flow are given by:

$$P_i = V_i \sum_{j=1}^{n} V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) \ldots\ldots\ldots (i = 1,2,\ldots\ldots, n) \tag{3.37}$$

Branch active power is:

$$P_i = V_i V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) - t_{ij} G_j V_i^2 \tag{3.38}$$

Where $t_{ij}$is the circuit transformer ratio per unit of branch ij, Y_{ij} is the phase angle difference across branch ij, G_{ij}, B_{ij} are the real and imaginary parts of corresponding elements of the node admittance matrix, respectively.

$$\theta_{ij} = \theta_i - \theta_j \tag{3.39}$$

When $i = j$:

$$G_{ii} = -\sum_{\substack{j \in i \\ j \neq i}} G_{ij}$$

$$B_{ii} = -\sum_{\substack{j \in i \\ j \neq i}} B_{ij}$$

Under assumptions applied in the fast decoupled method, the above AC load flow equations can be simplified to the following equations.

$$P_i = \sum_{j \in i} B_{ij}\theta_{ij} \;\ldots\ldots\ldots (i = 1,2,\ldots\ldots, n) \qquad (3.40)$$

This can be rewritten as,

$$P_i = \sum_{j \in i} B_{ij}\theta_i - \sum_{j \in i} B_{ij}\theta_j \;\ldots\ldots\ldots (i = 1,2,\ldots\ldots, n) \qquad (3.41)$$

We know the first term in the right hand of the above equation is 0, thus we have,

$$P_i = -\sum_{j \epsilon i} B_{ij}\Theta_j \; (i = 1, 2, \ldots, n) \qquad (3.42)$$

The DC flow model usually has no negative sign, thus we redefine B_{ij} as,

$$B_{ij} = -\frac{1}{x_{ij}} \qquad (3.43)$$

Thus,

$$B_{ii} = \sum_{\substack{j \epsilon i \\ j \neq i}} \frac{1}{x_{ij}} \qquad (3.44)$$

Finally, we establish the DC flow equation,

$$P_i = \sum_{j \epsilon i} B_{ij}\Theta_j \qquad (i = 1, 2, \ldots, n) \qquad (3.45)$$

Or in matrix form,

$$\boldsymbol{P} = \boldsymbol{B\theta} \qquad (3.46)$$

where P is u the node injection power vector and its *i*th element is given by $P_i = P_{Gi} - P_{Di}$ here P_{Gi} and P_{Di} are the generator output and load at node i, respectively; is the phase angle vector and B is the matrix whose elements are defined by (3.34) and (3.44).

Equation (3.46) can also be expressed as follows:

$$\theta = \mathrm{XP} \qquad (3.47)$$

Where X is the inverse of matrix B,

$$\boldsymbol{X} = \boldsymbol{B}^{-1} \qquad (3.48)$$

Similarly, substituting the simplifying conditions into (3.38), one obtains the active power flowing into branch ij,

$$P_{ij} = -B_{ij}\Theta_{ij} = \frac{\Theta_i - \Theta_j}{x_{ij}} \qquad (3.49)$$

Or in matrix form,

$$P_I = B_l \Phi \qquad (3.50)$$

If the number of branches is l, B_l is an $l*l$ diagonal matrix whose elements are branch admittance; P_I is the branch active power vector; Φ the end terminal phase angle difference vector.

Assuming that the network incidence matrix is **A**, then one arrives at;

$$\Phi = A\theta \qquad (3.51)$$

Equations (3.46), (3.47), and (3.50) are basic DC load flow equations which are linear. Under given system operation conditions, the state variable y may be obtained through triangularizition or matrix inversion from (3.47), and then branch active power can be obtained from (3.50).

3.5. Neplan Software:

NEPLAN is a software tool to analyze, plan, optimize and simulate networks. The user-friendly graphical interface allows the user to perform study cases very efficiently. The customizable software has a modular concept and covers all electrical aspects in transmission, distribution, generation and industrial networks. It suits best for Renewable energy system and Smart Grid application, because all necessary models and simulation methods are integrated with a very high accuracy and performance. Besides steady state calculations, power quality and optimization aspects and protection design, the NEPLAN simulator allows to model wind and solar power plants.

After simulation it reports power flows, losses, power factor, reactive power flows for all equipments, length of single phase, two phase and three phase lines can also be determined in the network [32].

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 System Description:

This chapter presents studies that have been conducted on distribution networks in order to identify the impact of distributed generation (DG) in voltage profiles and real and reactive power losses. A methodology has been applied in order to serve the studies that have been conducted. Simulations have been carried out using the power systems software NEPLAN. NEPLAN software is programmed to analyze, plan, improve and simulate electricity systems [2]. It consists of a very friendly graphical user interface and it allows the user to make modifications to the network's elements according to specific needs with the help of its extensive library. Finally, the cost of DG and profit money after few years is presented.

The system under study is shown in Figure (4.1) and constitutes a part of a distribution network. This system is built from 59 bus bars and 58 lines 33 kV. One central station is feeding the system which consists of a network feeder (NETF) connected to the 33kV, The maximum and minimum voltage limits for all buses are considered at (±6%). The system has been designed such that there are no overloaded lines, while it is loaded by total 14.56 MW and 11.44 Mvar connected to bus bars and of different power factors.

Two different types of DGs have been connected to the selected buses on the examined distribution network in order to study their under different scenarios four cases were analyzed which shows diverse impacts DGs on voltage profile and power losses (active and reactive). Firstly, the simulation of the examined distribution network is carried out without connecting any DG into the network. For each bus bar the voltage profile and for each line the active and reactive power losses are calculated. Secondly several simulations are carried out connecting each time a different type of DG at specific locations recording each time for each bus bar the voltage profile and for each line the active and reactive power losses. It must be mentioned that for the load flow analysis, the extended Newton-Raphson method has been used. The elements of network are presented in Table (4.1).

Table 4.1: Network components

Elements	Number Of Elements
Line	**58**
Load	**43**
Synchronous Machine	**2**
Network Feeder	**1**
2W Transformer	**45**
Node	**104**
Total	***253***

4.2 Simulation Results:

The distribution network system was modeled with the help of NEPLAN software. The single line diagram of the network in NEPLAN is presented in Figure 4.1.

4.2.1 Analysis of distribution network without DG (base case):

Load flow analysis has been performed in the examined radial distribution network without connecting any DG (base case load flow) in order to calculate voltage profiles at each bus and both real and reactive power losses at each line. Table 4.2 and Table 4.3 present the bus bars data and lines data of the examined system. Six nodes were chosen in different location in system to calculate Voltage results presented as (u/kV) and percentage of the node voltage (u/%) (node1, node2, node3, node4, node5, node6) are listed in Table 4.4.The total active power losses (Ploss) is **5.45** MW and the total reactive power losses (Qloss) is **10.16** Mvar are presented in Table 4.5 for each line. Figure 4.2 presents the Voltage profile of network without DG and Figure 4.3 presents the total network real and reactive power losses.

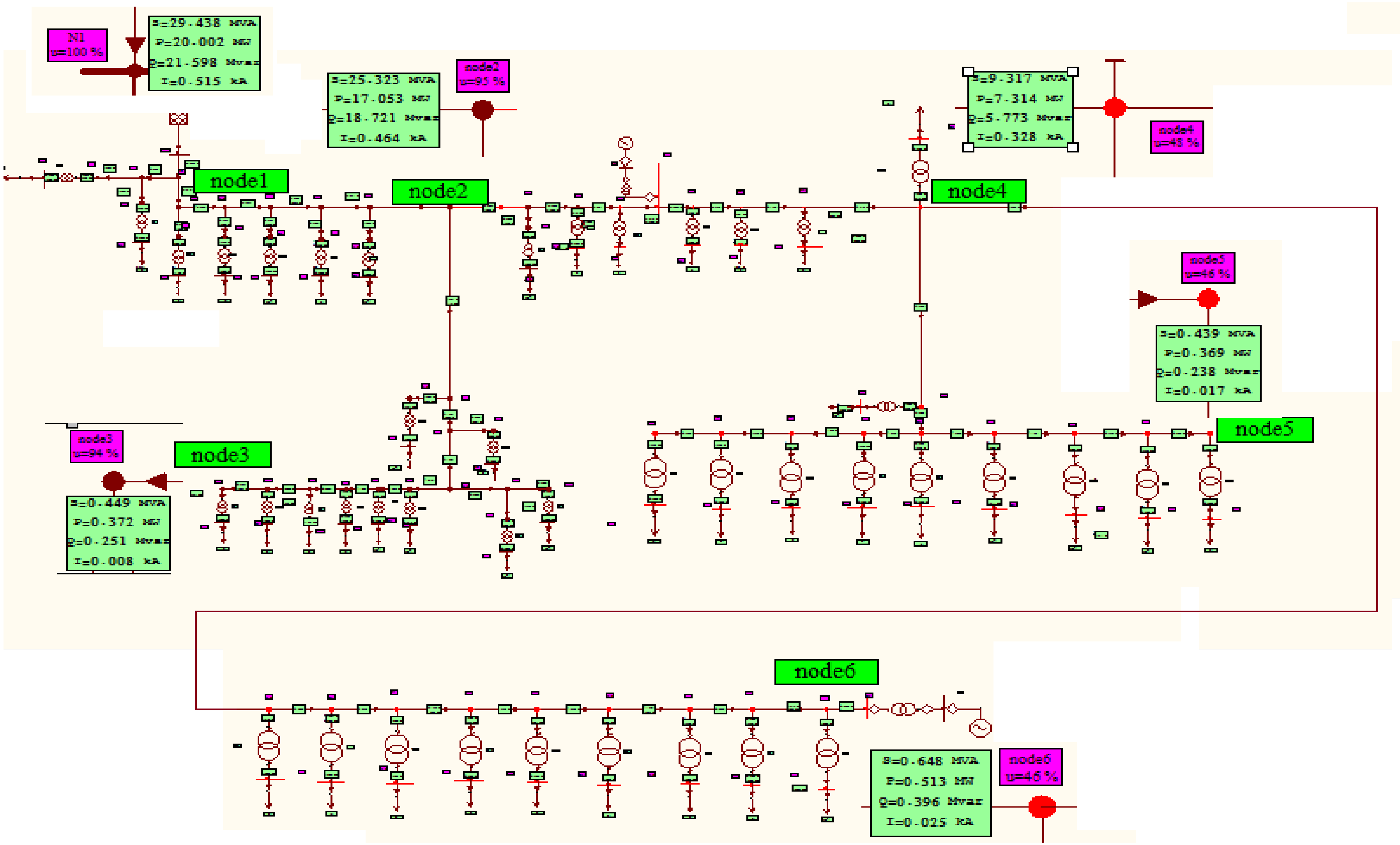

Figure 4.1: Single line diagram of radial distribution system in NEPLAN.

1. Bus bar data of Network System (with no DG):

A load flow analysis has been performed without connecting any DG (base case load flow) in order to calculate the voltage profiles at each bus. As it can be observed 26 buses violate acceptable tolerance provided by the network as presented in Table 4.2,

Table 4.2: Bus bar data of distribution network (base case).

Bus bar name	U(KV)	U(%)	Busbar name	U(KV)	U(%)
N1	33	100%	N31	32.183	97.5%
N2	32.795	99.4%	N32	31.997	97.0%
N3	32.501	98.5%	N33	31.615	95.8%
N4	32.195	97.6%	N34	31.504	95.5%
N5	31.998	97.0%	N35	31.215	94.6%
N6	31.617	95.8%	N36	31.21	94.6%
N7	31.505	95.5%	N37	31.211	94.6%
N8	31.15	94.4%	N38	31.211	94.6%
N9	30.993	93.9%	N39	31.178	94.5%
N10	30.057	91.1%	N40	31.168	94.5%
N11	28.456	86.2%	N41	31.162	94.4%
N12	22.894	69.4%	N42	31.158	94.4%
N13	22.784	69.0%	N43	31.157	94.4%
N14	17.384	52.7%	N44	31.155	94.4%
N15	16.411	49.7%	N45	31.232	94.6%
N16	15.697	47.6%	N46	31.175	94.5%
N17	15.615	47.3%	N47	31.172	94.5%
N18	15.541	47.1%	N48	31.175	94.5%
N19	15.476	46.9%	N49	30.992	93.9%
N20	15.419	46.7%	N50	15.387	46.6%
N21	15.37	46.6%	N51	15.265	46.3%
N22	15.329	46.5%	N52	15.193	46.0%
N23	15.297	46.4%	N53	15.137	45.9%
N24	15.273	46.3%	N54	15.1	45.8%
N25	15.179	46.0%	N55	15.081	45.7%
N26	15.179	46.0%	N56	15.193	46.0%
N27	32.795	99.4%	N57	15.137	45.9%
N28	32.795	99.4%	N58	15.099	45.8%
N29	32.791	99.4%	N59	15.08	45.7%
N30	32.5	98.5%	Total bus bars= 59		

2. Line data of Network System (with no DG):

A load flow analysis has been performed without connecting any DG (base case load flow) in order to calculate the active and reactive power for each line. The network feeder injects total power of 20 MW and 21.6 MVar to network under study as presented in Table 4.3.

Table 4.3: Lines data of distribution network (base case)

Element	P(MW)	Q(MVar)	Element	P(MW)	Q(MVar)
LINE1	20.002	21.598	LINE30	0.372	0.24
LINE2	19.219	20.905	LINE31	0.372	0.25
LINE3	18.838	20.489	LINE32	0.326	0.295
LINE4	18.343	20.033	LINE33	0.326	0.295
LINE5	17.894	19.647	LINE34	2.551	2.117
LINE6	17.421	19.091	LINE35	2.178	1.869
LINE7	17.053	18.721	LINE36	0.372	0.247
LINE8	14.399	16.425	LINE37	0.313	0.226
LINE9	13.997	15.988	LINE38	2.178	1.87
LINE10	13.401	15.13	LINE39	1.618	1.37
LINE11	12.514	13.995	LINE40	1.377	1.153
LINE12	10.834	10.865	LINE41	1.144	0.945
LINE13	10.238	10.403	LINE42	0.889	0.715
LINE14	8.19	6.923	LINE43	0.698	0.543
LINE15	7.314	5.773	LINE44	0.372	0.247
LINE16	3.05	2.746	LINE45	0.558	0.501
LINE17	2.74	2.421	LINE46	0.326	0.294
LINE18	2.432	2.101	LINE47	0.232	0.208
LINE19	2.127	1.787	LINE48	0.326	0.295
LINE20	1.757	1.555	LINE49	3.786	2.384
LINE21	1.454	1.249	LINE50	3.384	2.09
LINE22	1.153	0.947	LINE51	1.479	0.945
LINE23	0.853	0.647	LINE52	1.108	0.708
LINE24	0.513	0.396	LINE53	0.738	0.472
LINE25	0.513	0.396	LINE54	0.369	0.236
LINE26	0.697	0.541	LINE55	1.526	0.893
LINE27	0.372	0.249	LINE56	1.132	0.684
LINE28	0.326	0.291	LINE57	0.739	0.474
LINE29	0.262	0.205	LINE58	0.369	0.237

3. Voltage profile of Network System (with no DG):

The results show the voltage profiles of the understudy network buses (base case). This is demonstrate the high voltage drop in some of the selected nodes (node4, node5 and node6) provided by the simulation while in the actual situation will lead to voltage collapse as shown in Table 4.4.

Table 4.4: voltage profile of network (base case)

Node	voltage(kv)	voltage%
node1	***32.501***	***98.49***
node2	***31.232***	***94.64***
node3	***31.15***	***94.4***
node4	***15.697***	***47.57***
node5	***15.08***	***45.7***
node6	***15.179***	***46***

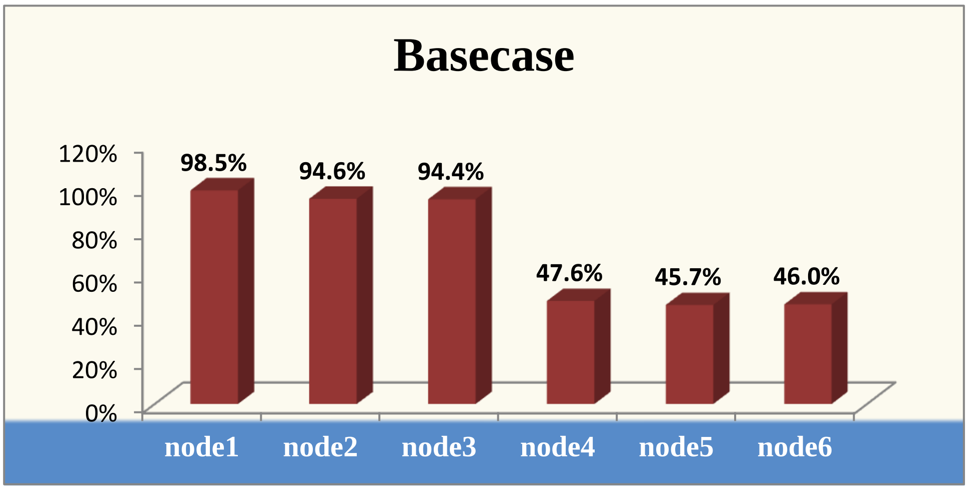

Figure 4.2 Voltage profile of network without DG

4. Total power of Network System (with no DG):

The active and reactive power flow of the network is calculated by the software program (Ne-plan) for the generation, load and losses. The total active power losses (Ploss) is **5.45** MW and the total reactive power losses (Qloss) is **10.16** Mvar are presented in Table 4.5 for each line.

Table 4.5: Total active and reactive power of network (base case)

Power	P(MW)	Q(MVar)
Generation	***20.00***	***21.6***
Load	***14.56***	***11.44***
Losses	***5.45***	***10.16***

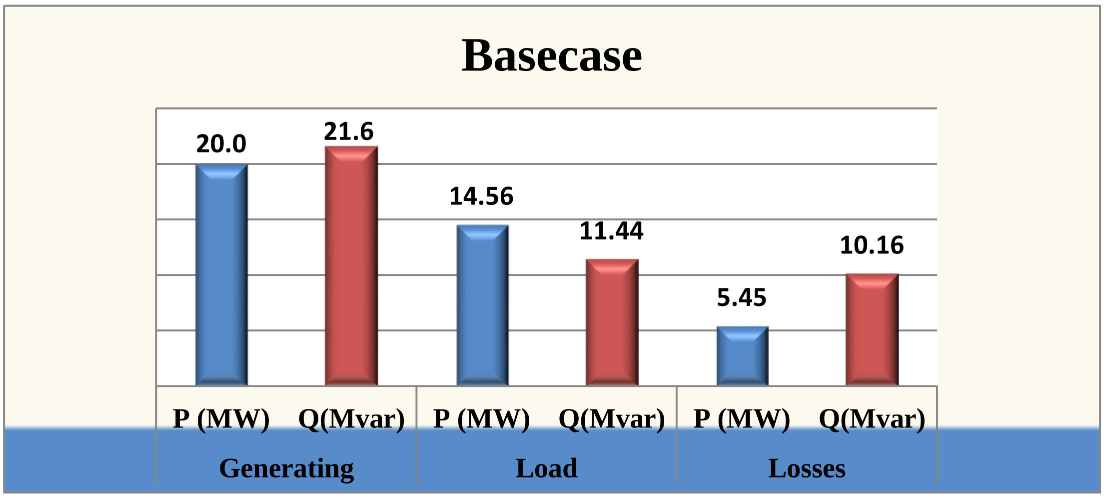

Figure 4.3: Total network real and reactive power without DG

4.2.2 Analysis of distribution network with DG1:

The single line diagram for this case is shown in Figure 4.4. Bus bars with low voltages have been chosen locations to install distributed generation. Although there are many week points in the network, More specifically the examined DG units have succeeded to reduce both real and reactive power losses when they have been connected in bus 12 (first week point of the network) was chosen to install DG1 (1MW) and load flow analysis was performed. The obtained voltage profiles results for all bus bars of the examined distribution network after the installation of DG1 presented as (u/kv) and percentage of the node voltage (u/%) (node1, node2, node3, node4, node5, node6) are listed in Table 4.6. Active and reactive power losses have been calculated for all lines. The total active and reactive power losses after the installation of DG1 injecting power into the system to drop to **2.02**MW and **4.98** Mvar are presented in Table 4.7 for each line. Figure 4.5 presents the Voltage profile of all buses of the network system with DG1 and Figure 4.6 presents the total network real and reactive power losses with DG1.

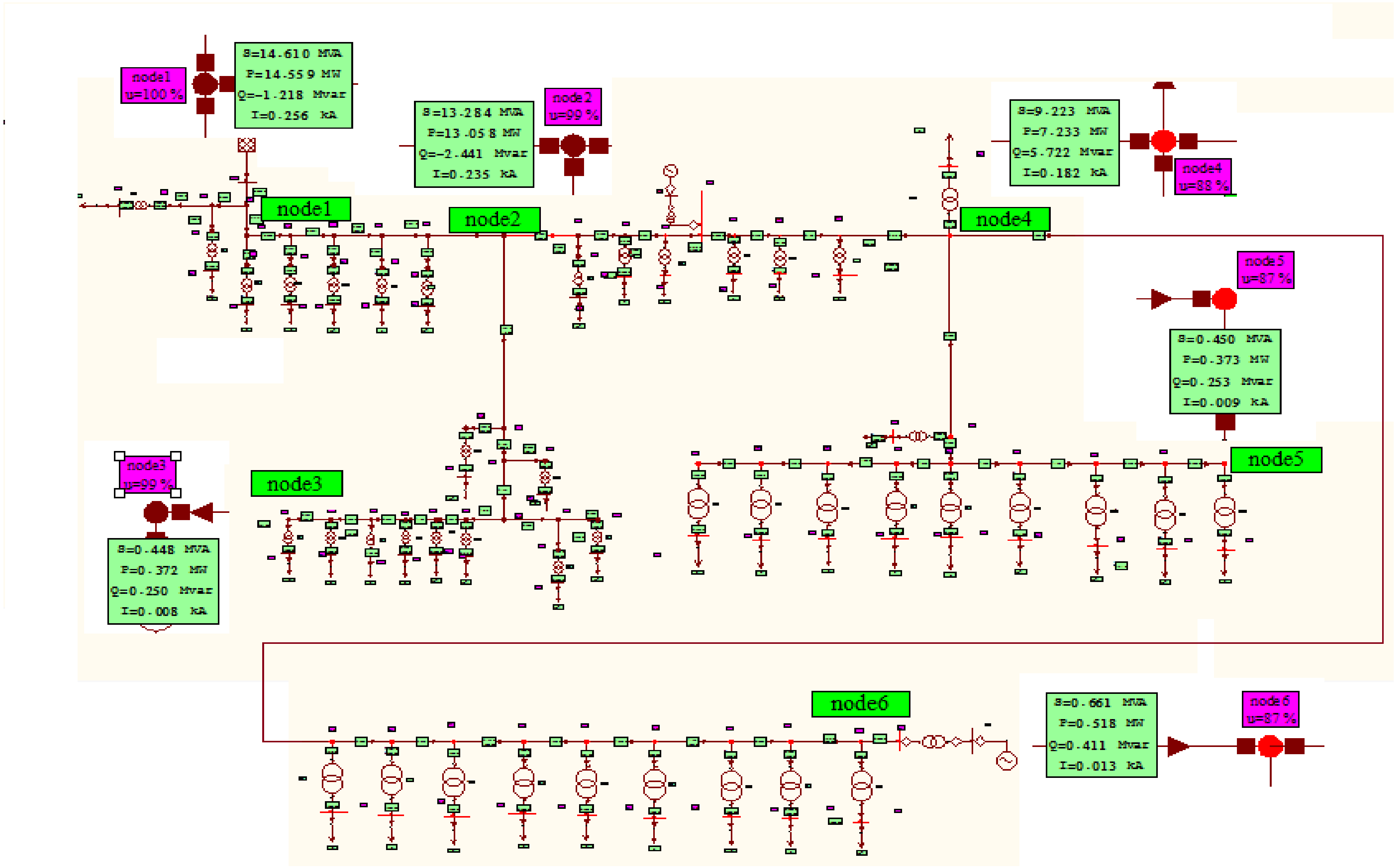

Figure 4.4: Single line diagram of radial distribution system with DG1

1. Voltage profile of Network System:

The results show that DG1 installing at bus 11kv and connected at N12 has a very large impact to the voltage profiles of the buses, resulted in voltage degradation which was a slightly better case than this without DG installed. This is demonstrate by improvement in the voltage level in node5 40.8% to reach 86.5% of the nominal voltage 33KV (this node has the lowest voltage level), which is near acceptable tolerance in the Sudanese distribution network (12%) as shown in Table 4.6.

Table 4.6: voltage profile of network with DG1

node	voltage(kv)	voltage%
node1	32.886	99.65
node2	32.653	98.95
node3	32.575	98.71
node4	28.884	87.53
node5	28.555	86.53
node6	28.596	86.66

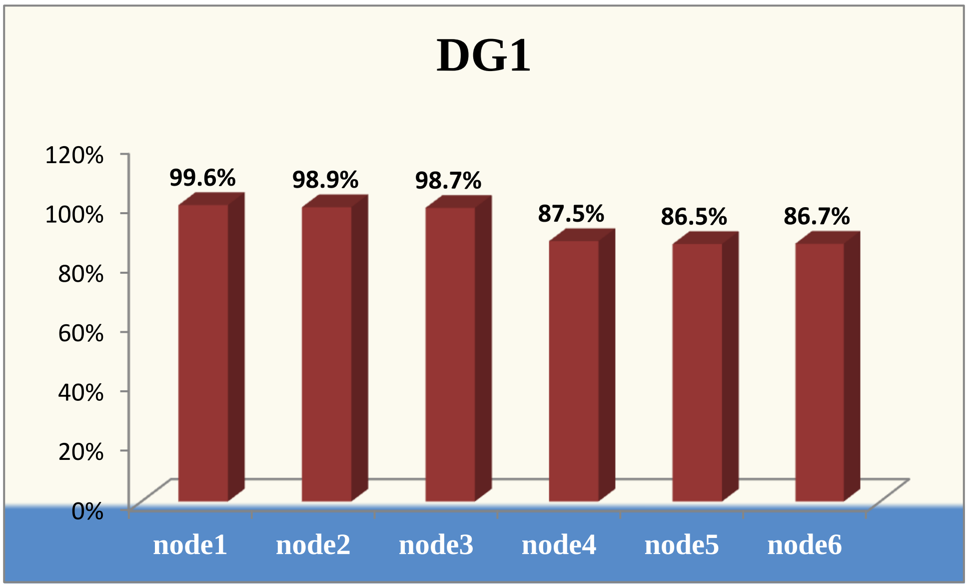

Figure 4.5: Voltage profile of network with DG1

2. Total power of Network System :

The impact of distributed generation on power losses in the network is shown in Table 4.7; there was a significant reduction in total active and reactive losses of 3.43MW and 5.18 MVar respectively after DG1 installation.

Table 4.7: Total active and reactive power of network with DG1

Power	P(MW)	Q(MVar)
Generation	*16.58*	*16.42*
Load	*14.56*	*11.44*
Losses	*2.02*	*4.98*

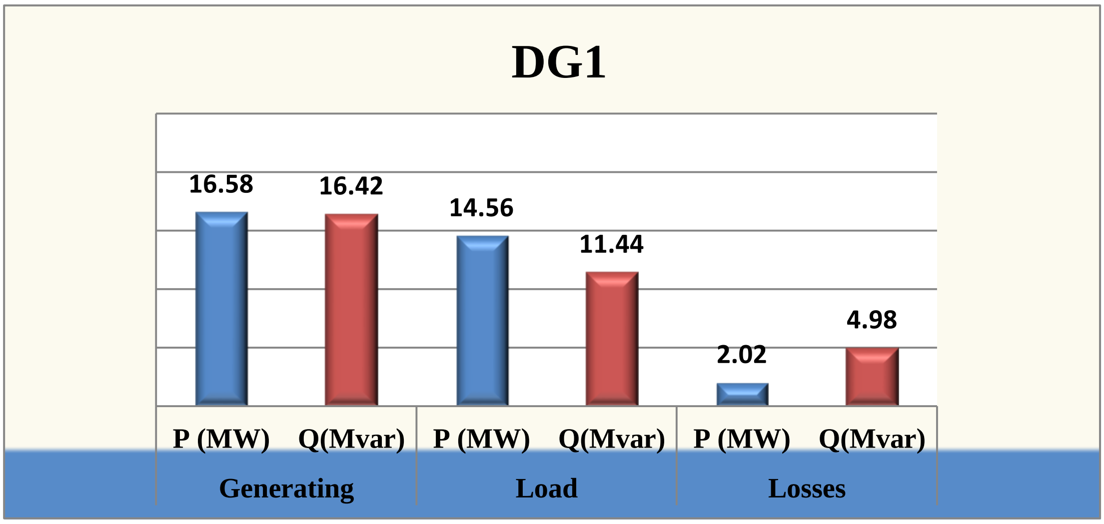

Figure 4.6: Total network real and reactive power with DG1

4.2.3 Analysis of distribution network with DG2:

The single line diagram is shown in Figure 4.7. In this case was chosen last bus bar to install distributed generation. More specifically the examined DG units have succeeded to reduce both real and reactive power losses when they have been connected in bus 26 (last week point of the network) was chosen to install DG2 (1MW) and load flow analysis was performed. The obtained voltage profiles results for all bus bars of the examined distribution network after the installation of DG2 presented as (u/kv) and percentage of the node voltage (u/%) (node1, node2, node3, node4, node5, node6) are listed in Table 4.8. Active and reactive power losses have been calculated for all lines. The total active and reactive power losses after the installation of DG2 injecting power into the system to drop to **1.55**MW and **3.39**Mvar are presented in Table 4.9 for each line. Figure 4.8 presents the Voltage profile of network with DG2 and Figure 4.9 presents the total network real and reactive power losses with DG2.

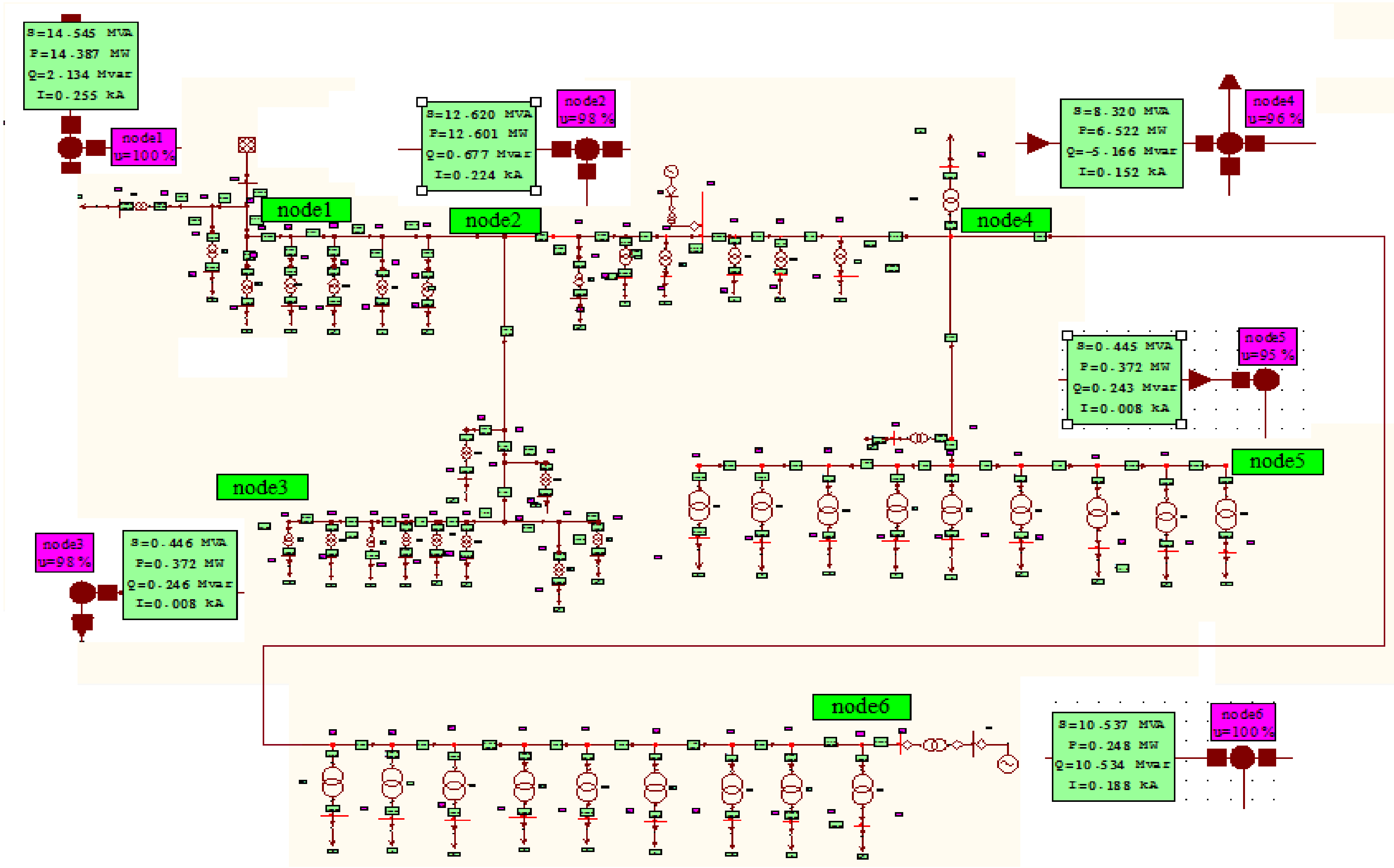

Figure 4.7: Single line diagram of radial distribution system with DG2

1. Voltage profile of Network System:

The installation of DG2 at bus 11kv and connected at N26 (end bus) and used step up transformer11/33kv had as a result the improvement of the voltage profiles of the buses. Resulted in voltage degradation which was a slightly better case than this without DG installed. This is demonstrate by improvement in the voltage level in node5 49.6% to reach 95.3% of the nominal voltage 33KV (this node has the lowest voltage level), which is near acceptable tolerance in the Sudanese distribution network (12%) as shown in Table 4.8.

Table 4.8: voltage profile of network with DG2

Node	voltage(kv)	voltage%
node1	*32.84*	*99.52*
node2	*32.484*	*98.44*
node3	*32.406*	*98.2*
node4	*31.728*	*96.15*
node5	*31.432*	*95.25*
node6	*33*	*100*

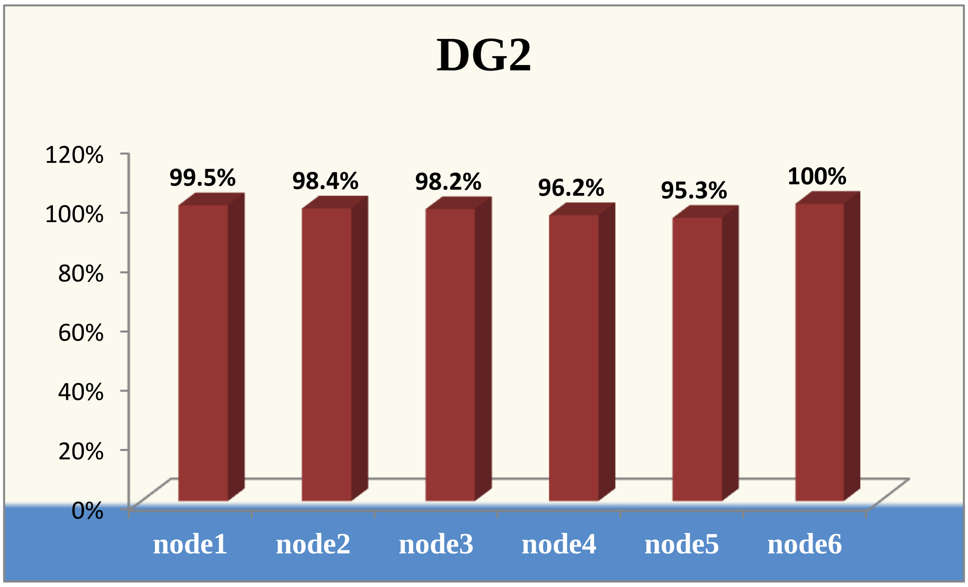

Figure 4.8: Voltage profile of network with DG1

2. Total power of Network System:

The total active and reactive power losses have decreased comparing to these obtained without the installation of DG2 is shown in Table 4.9; there was a significant reduction in total active and reactive losses of 3.9MW and 6.77 MVar respectively after DG1 installation.

Table 4.9: Total active and reactive power of network with DG2

Power	P(MW)	Q(MVar)
Generation	*16.11*	*14.84*
Load	*14.56*	*11.44*
Losses	*1.55*	*3.39*

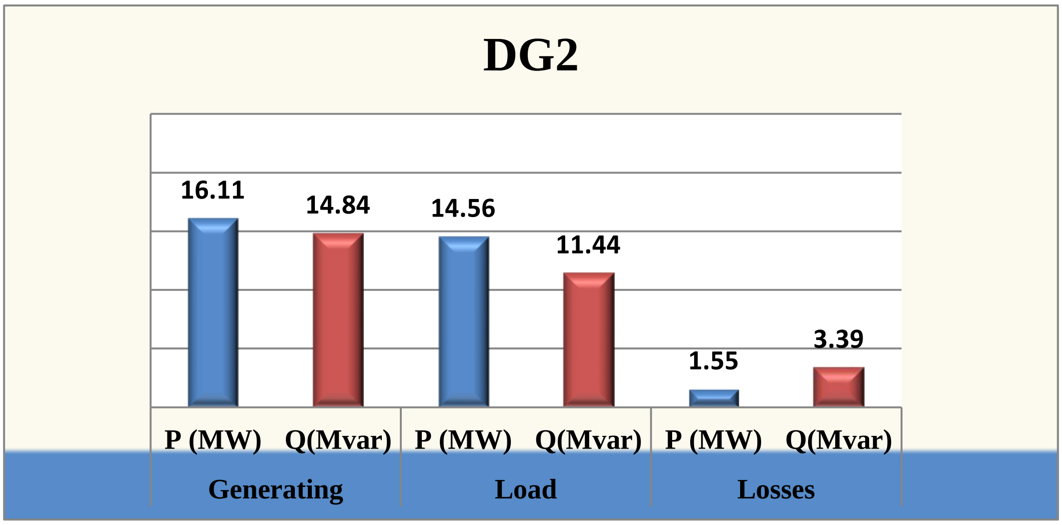

Figure 4.9: Total network real and reactive power with DG2

4.2.4 Analysis of distribution network with DG1& DG2:

The line data of network is show in Table 4.10 and single line diagram is shown in Figure 4.10. Each distributed generation was installed at time and load flow analysis was performed. More specifically the examined DG units have succeeded to reduce both real and reactive power losses when they have been connected in bus 12 and bus 26 was chosen to install both DGs (DG1&DG2) (2MW). The obtained voltage profiles results for all bus bars of the examined distribution network after the installation of both DGs presented as (u/kV) and percentage of the node voltage (u/%) (node1, node2, node3, node4, node5, node6) are listed in Table 4.11. Active and reactive power losses have been calculated for all lines. The total active and reactive power losses after the installation of both DGs injecting power into the system to drop to **1.24**MW and **2.59**Mvar are presented in Table 4.12 for each line.

Figure 4.11 presents the Voltage profile of network with both DGs and Figure 4.12 presents the total network real and reactive power losses with both DGs.

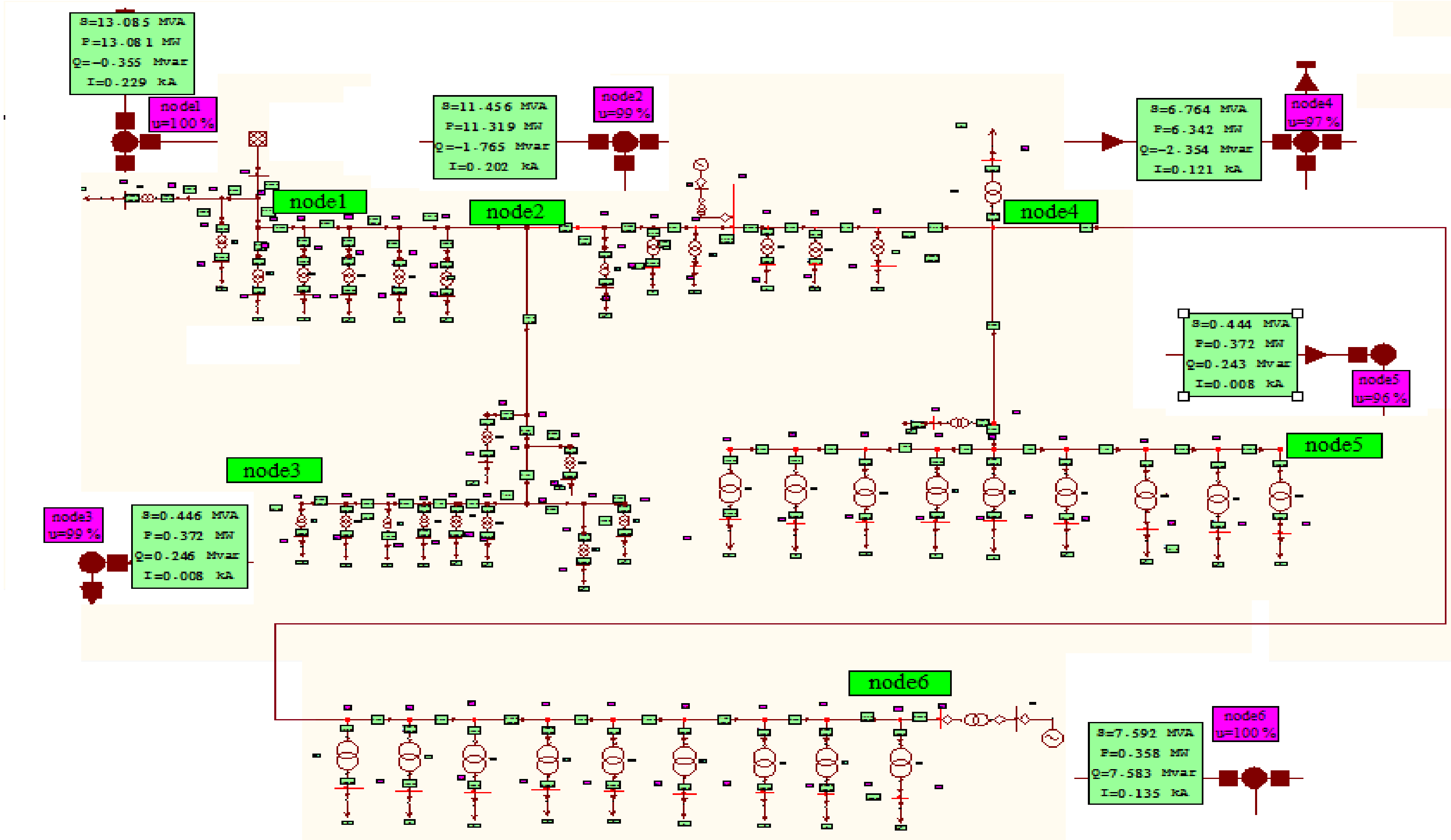

Figure 4.10: Single line diagram of radial distribution system with DG1 and DG2

1. Line data of Network System (with DG1 and DG2):

A load flow analysis has been performed with connecting DG1 and DG2 in order to calculate the active and reactive power for each line. The network feeder contributes total power of 13.8 MW of the total generation injected to the network as presented in Table 4.10.

Table 4.10: Total active and reactive power of network with DG1 and DG2

Element	P(MW)	Q(MVar)	Element	P(MW)	Q(MVar)
LINE1	13.797	0.211	LINE30	0.372	0.239
LINE2	13.081	-0.355	LINE31	0.372	0.249
LINE3	12.793	-0.593	LINE32	0.326	0.294
LINE4	12.396	-0.864	LINE33	0.326	0.294
LINE5	12.008	-1.132	LINE34	2.549	2.107
LINE6	11.653	-1.461	LINE35	2.176	1.862
LINE7	11.319	-1.765	LINE36	0.372	0.246
LINE8	8.75	-3.895	LINE37	0.313	0.224
LINE9	8.41	-4.211	LINE38	2.176	1.863
LINE10	8.054	-4.61	LINE39	1.617	1.365
LINE11	7.568	-4.977	LINE40	1.376	1.149
LINE12	8.234	-0.469	LINE41	1.143	0.941
LINE13	7.671	-0.855	LINE42	0.888	0.712
LINE14	6.987	-1.664	LINE43	0.697	0.54
LINE15	6.342	-2.354	LINE44	0.372	0.246
LINE16	2.226	-5.11	LINE45	0.557	0.499
LINE17	1.918	-5.429	LINE46	0.326	0.293
LINE18	1.611	-5.749	LINE47	0.232	0.208
LINE19	1.303	-6.069	LINE48	0.326	0.294
LINE20	0.925	-6.327	LINE49	3.785	2.403
LINE21	0.616	-6.648	LINE50	3.401	2.145
LINE22	0.307	-6.971	LINE51	1.49	0.975
LINE23	0.011	7.307	LINE52	1.117	0.73
LINE24	0.411	7.66	LINE53	0.744	0.486
LINE25	0.928	8.083	LINE54	0.372	0.243
LINE26	0.697	0.54	LINE55	1.536	0.917
LINE27	0.372	0.249	LINE56	1.14	0.701
LINE28	0.326	0.291	LINE57	0.744	0.486
LINE29	0.262	0.205	LINE58	0.372	0.243

2. Voltage profile Network System:

The installation of DG1 and DG2 at bus 11kv and connected at N12 and N26 and used step up transformer11/33kv had as a result the improvement of the voltage profiles of the buses. Resulted considerable in improvement of voltage profile without DGs installed (all node voltage values are located between 96.5% and 100%) as shown in Table 4.11.

Table 4.11: voltage profile of network with DG1 and DG2

Node	voltage(kv)	voltage%
node1	32.891	99.67
node2	32.669	99
node3	32.592	98.76
node4	32.121	97.34
node5	31.829	96.45
node6	33	100

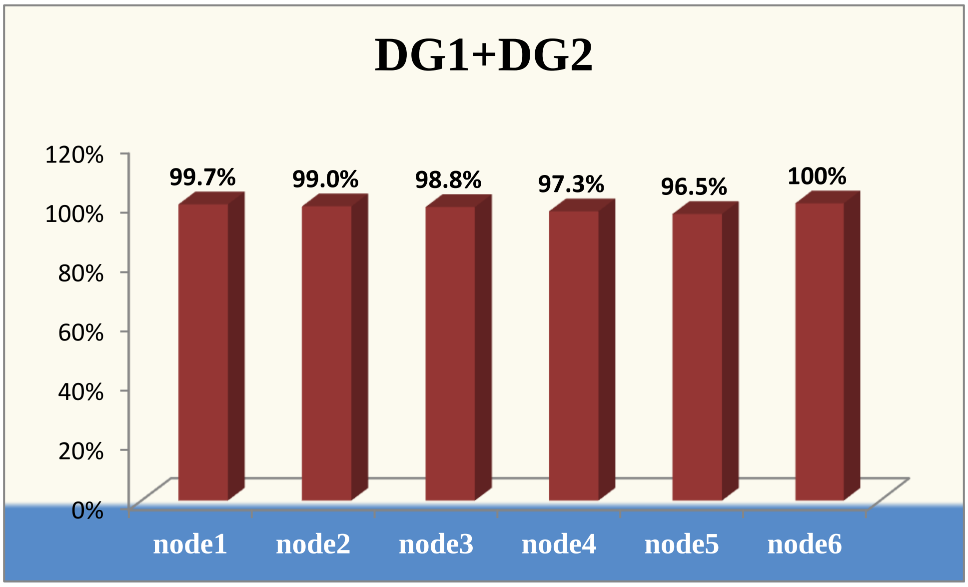

Figure 4.11: Voltage profile of network with DG1&DG2

3. Total power of Network System:

Installation of DG1 and DG2 in the system under study has resulted in decreasing the line consumption share of the generation from 20MW to 15.8MW and reducing the total active and reactive power losses to reach 1.24 MW and 2.59MVar respectively as shown in Table 4.12.

Table 4.12: Total active and reactive power of network with DG1 and DG2

Power	P(MW)	Q(MVar)
Generation	15.80	14.03
Load	14.56	11.44
Losses	1.24	2.59

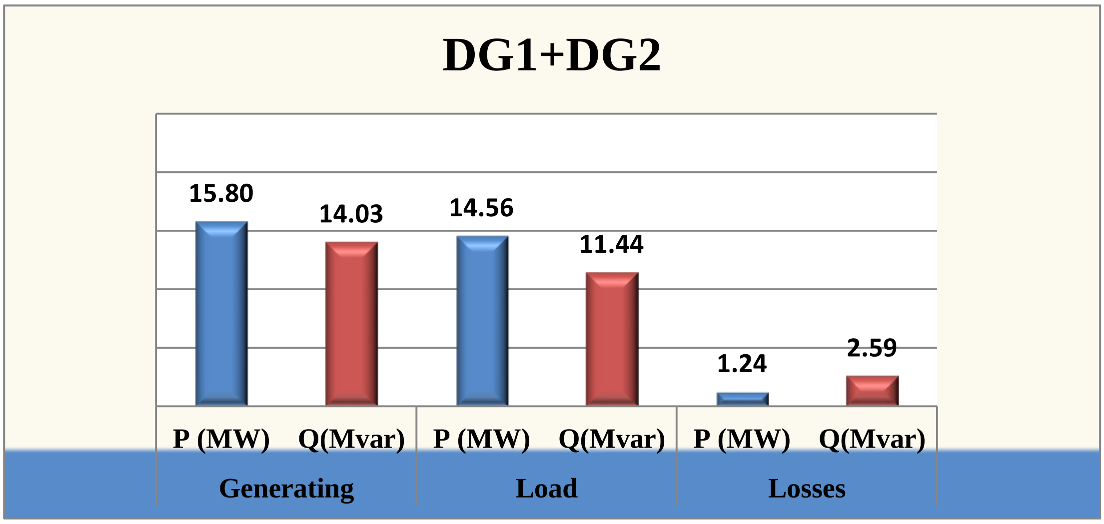

Figure 4.12: Total network real and reactive power with DG1 and DG2

4.2.5 Comparisons Analysis:

Comparison between solving DGs sizing and siting using NEPLAN software in this research is illustrated in Tables 4.13 and 4.14. As a final attempt to improve the voltage levels of the system, all DGs were connected at the same time. On running a load flow analysis this resulted in a notable voltage support. As far concerning the power losses in the lines, it is clear that with the installation of DGs at the selected locations, losses were much less than compared to no DGs. The lowest active and reactive power losses were observed when all DGs were installed at once.

The best solution is found that the optimum solution achieved when installing two DG’s (1.24 Mw and 2.59 Mvar) installed at nodes 12 and 26 and that all nodes voltages increased while voltage constraint are satisfied (all node voltage values are located between 96.5% and 100%).

Table 4.13: voltage profile of network with and without DGs

Node	Base case	DG1	DG2	DG1+DG2
node1	***98.5%***	***99.7%***	***99.5%***	***99.7%***
node2	***94.6%***	***99.0%***	***98.4%***	***99.0%***
node3	***94.4%***	***98.7%***	***98.2%***	***98.8%***
node4	***47.6%***	***87.5%***	***96.2%***	***97.3%***
node5	***45.7%***	***86.5%***	***95.3%***	***96.5%***
node6	***46.0%***	***86.7%***	***100%***	***100%***

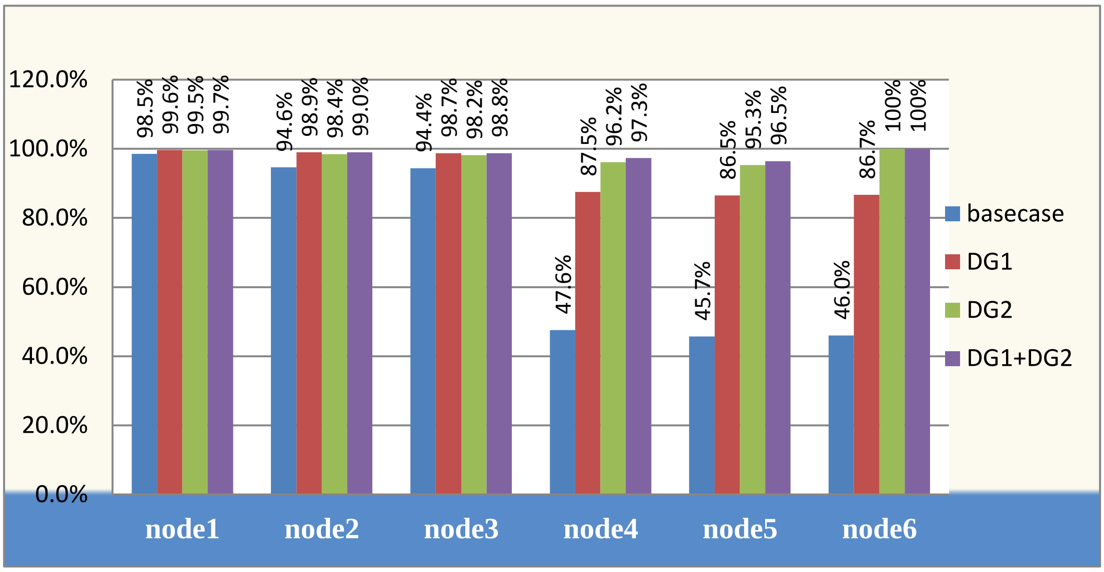

Figure 4.13: Voltage profile of network

Table 4.14: Total active and reactive power losses of network with and without DGs

POWER	Losses	
	P (MW)	Q(Mvar)
Base case	***5.45***	***10.16***
DG1	***2.02***	***4.98***
DG2	***1.55***	***3.39***
DG1+DG2	***1.24***	***2.59***

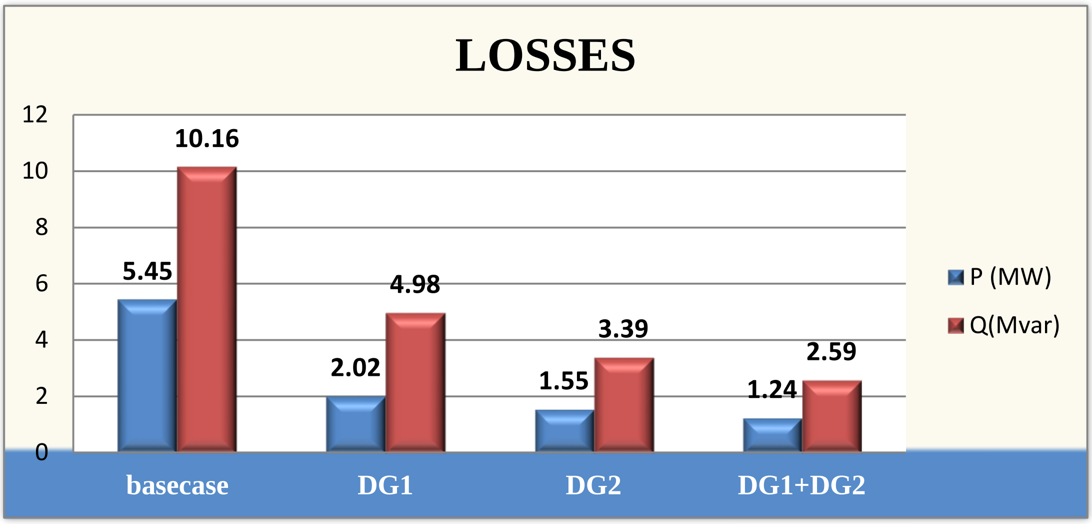

Figure 4.14: Total network real and reactive power

The results have shown that the size of the connected DG, independently from the DG type, plays an important role in the total network power losses since it has been observed that the bigger the size of the DG the bigger the impact on the total network power losses of the system. Furthermore, the position that is installed the DG unit (of any type) is of paramount importance, since its influence on the total power losses of the network (both real and reactive) is totally different. Moreover it has been observed that the impact to the total power losses is proportional to the size and location of the DG unit.

4.3 The Compound Interest and Present Value:

Table 4.15: Total active and reactive power losses (MW) and saving

Case	Losses		Saving		
	P (MW)	Q (Mvar)	P (MW)/Hr	P (MW)/month	SDG/month
base case	***5.45***	***10.16***	**-**	**-**	**-**
DG1	***2.02***	***4.98***	***3.43***	***2467.44***	***789,580.80***
DG2	***1.55***	***3.39***	***3.89***	***2803.68***	***897,177.60***
DG1+DG2	***1.24***	***2.59***	***4.21***	***3027.6***	***968,832.00***

The problem in Table 4.15 demonstrates the situation that equal amounts of money, *A*, are invested at each time period for *n* number of time periods at interest rate of *i* (given information are *A*, *n*, and *i*) and the future worth (value) of those amounts needs to be calculated.

In this case, Equation (4.1) can determine the future value of uniform series of equal investments as:

$$F = A * [(1 + i)^{n-1}]/i \quad (4.1)$$

The factor $[(1 + \mathrm{i})^{\mathrm{n}-1}]/\mathrm{i}$: is called "Uniform Series Compound-Amount Factor"

This factor is used to calculate a future single sum, "F", that is equivalent to a uniform series of equal end of period payments, "A".

i=interest rate (equal1.5%)

n =number of time periods at interest rate of i.

It able to deposit *A* million SDG every month (at the end of the year, starting from month1) the DG cost that gives *i* percent interest and repeat this for *n* years (depositing A million SDG at the end of the year). Finally calculated how much will have at the end of year n^{th}.

Table 4.16: Cash Flows (million SDG).

POWER	DG COST	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
DG1	30.0	(27.6)	(25.1)	(22.5)	(19.7)	(16.8)	(13.8)	(10.7)	(7.4)	(4.0)	(0.4)	3.4	7.3	11.4	15.7	20.2	28.2
DG2	30.0	(27.3)	(24.4)	(21.4)	(18.3)	(15.0)	(11.6)	(8.0)	(4.3)	(0.4)	3.7	7.9	12.4	17.1	22.0	27.1	36.1
DG1+DG2	60.0	(57.0)	(54.0)	(50.7)	(47.4)	(43.8)	(40.1)	(36.3)	(32.3)	(28.0)	(23.6)	(19.0)	(14.2)	(9.2)	(3.9)	1.6	11.4

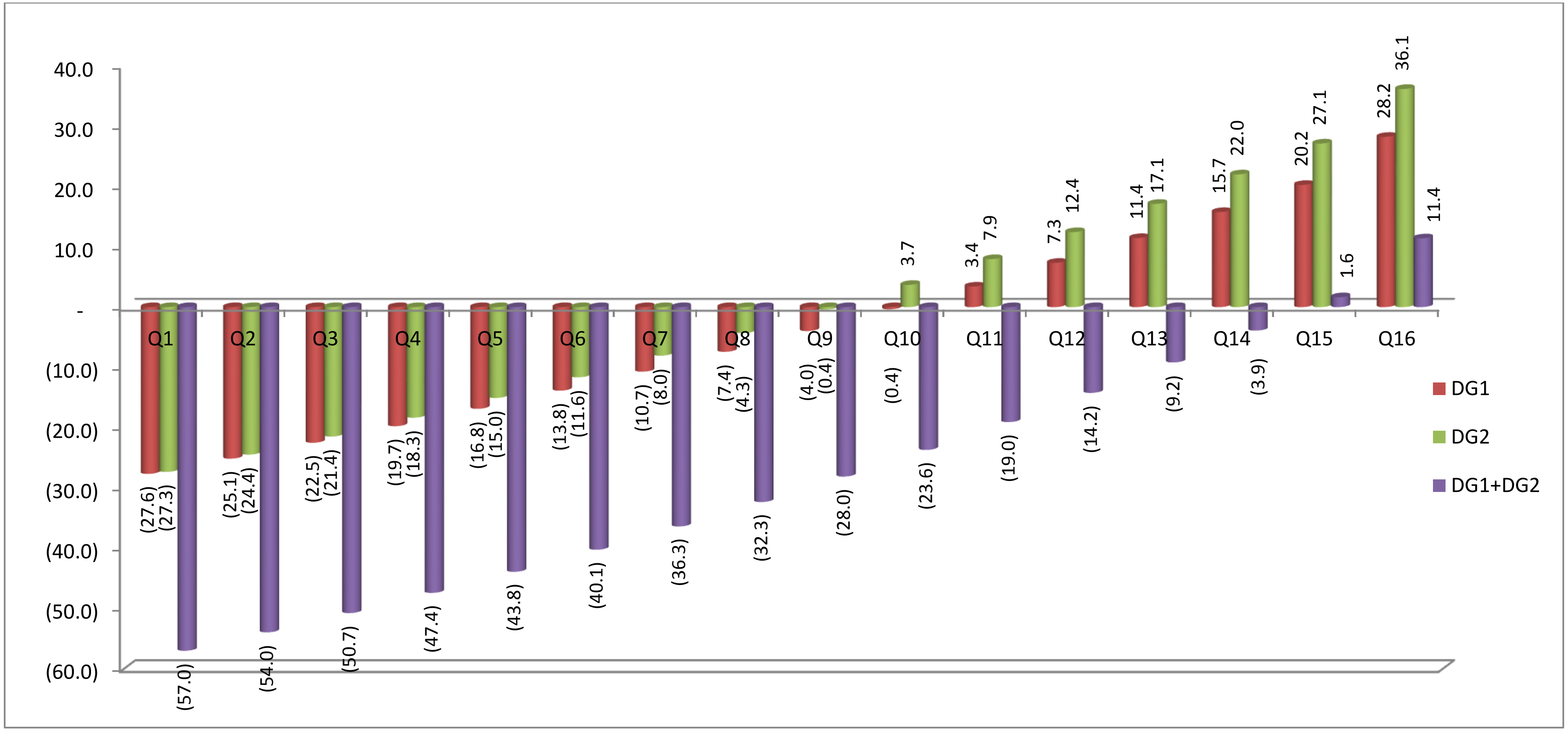

Figure 4.15: Cash Flows (million SDG).

In this case the total cash returns are the different value and time, the present value of money is lower for one DG than total DG1and DG2. With DG1, the money is returned after 32 month (Quarter11) and after four years the earning money is about (28.2 million SDG).With DG2, the money is returned sooner, after 29 month (Quarter10) and after four years the earning money high is about (36.1 million SDG). Also, when installed DG1 and DG2 the present value is high, the money is returned to late after 44 month (Quarter15) compared to the first and second cases and after four years the earning money low is about (11.4 million SDG). Finally, all result presented is allowing for enhanced using distributed generation opportunities.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion:

This research proves that the DG implementation as a source of active power in the distribution network will change the electric distribution system operation's map. DG mainly provides part of the required demand in the distribution network. In addition to its main purpose, DG has a great positive impact on improving the voltage profiles and reduction in the network's total power losses.

A methodology has been applied to radial distribution networks where two different DG units of different type have been installed at selected positions for networks; their impact on voltage profiles and power losses has analyzed. For the analysis NE-PLAN software and the extended Newton-Raphson method have been used. The obtained results have shown that different types of DG influence differently the distribution network and that their precise location and size are vital in reducing power losses and improving the voltage stability and most importantly injecting only 2MW of DGs has resulted in saving more than 4 MW ready for supplying other consumers

The obtained results have demonstrated that the size of a DG unit is strongly associated with the type of the examined network and with its installation location. Finally, the cost of DG and profit after four years is presented.

5.2 Recommendations:

- The simulations conducted in this dissertation are performed using solar and wind generation; they can be repeated using different type of DG to investigate its impact on the voltage profile and total power losses and other problems of the network.
- In this dissertation the size of the DGs, equal for all simulations. Capacity of the DG sources may be increased to observe its impact on the short circuit levels and analyze if protection coordination can be attained.

- This research work can help distribution companies to evaluate the reliability of a real distribution network and also helps them to inject distributed generation with most appropriate type, size and in proper location to enhance reliability of distribution system.
- In future several DG technologies renewable energy sources can be modeled as voltage sources and uninterrupted power sources, the Supervisory Control and Data Acquisition (SCADA) system may help to integrating DG into existing distribution networks.
- Reconfiguration, capacitors placement and DG placement are three major methods for loss reduction in distribution networks. It is interesting to investigate network reconfiguration with simultaneous placement of DGs, capacitors, and protection devices, which are dependent on each other.
- Traditional planning options, that is, the addition or expansion of substations and lines should be also simultaneously considered. Such a coordinated planning can provide maximum benefits for the network owner and/or the network users.

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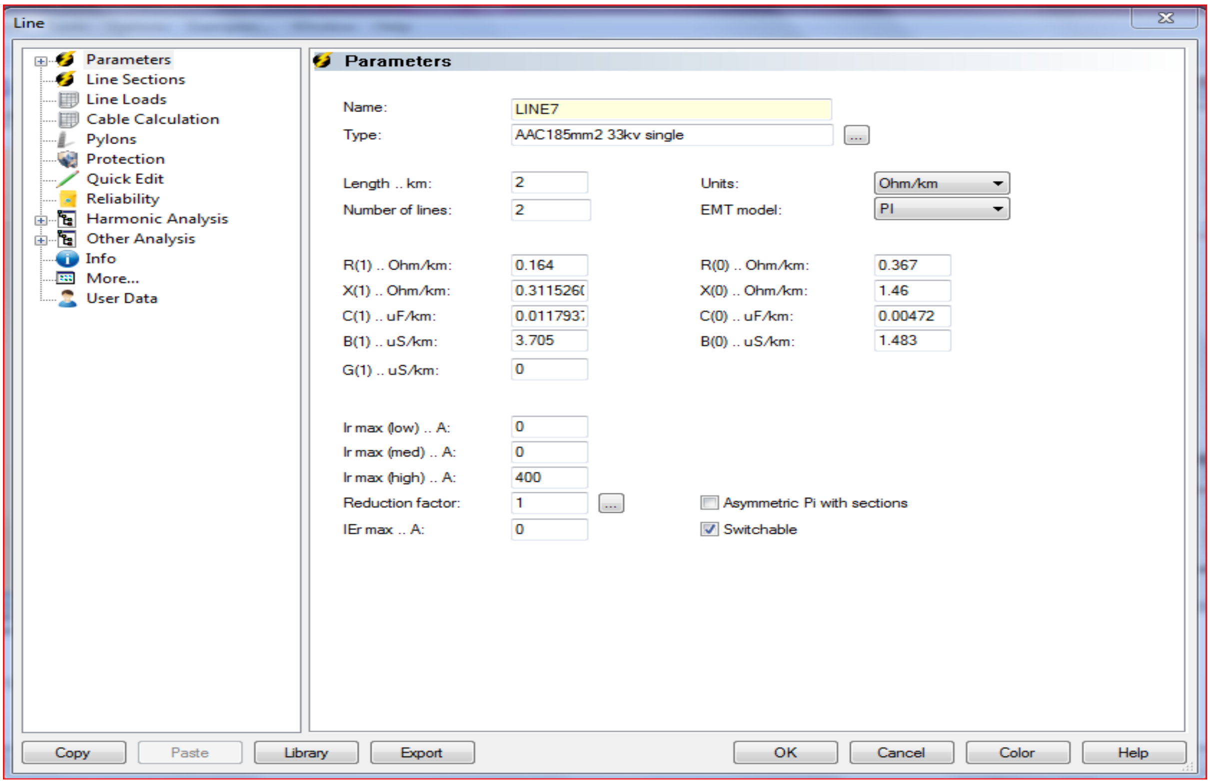
Appendices

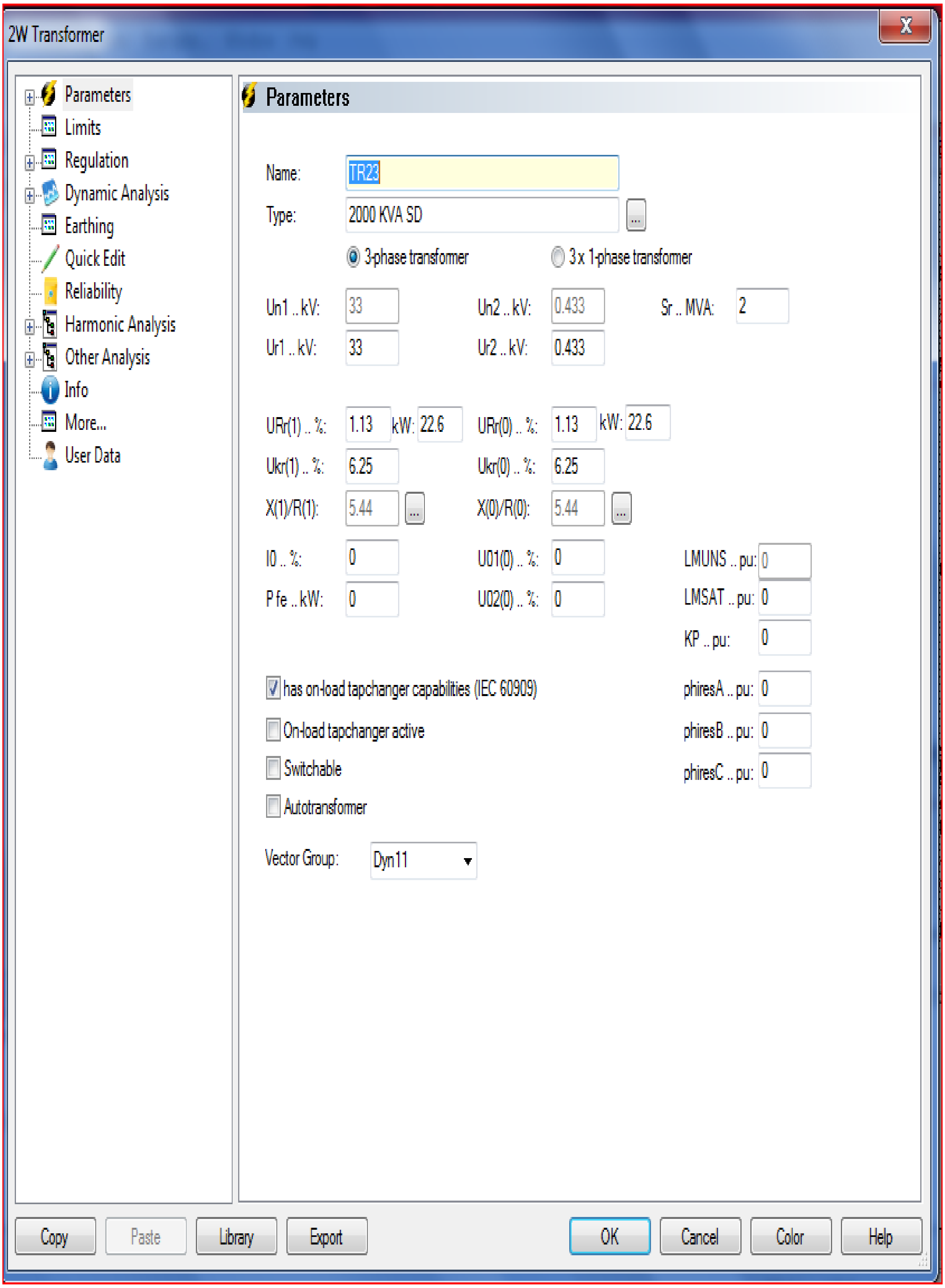
Appendix: A: Line Parameters

No.	Name	Type	Length km	R Ohm	X Ohm	C uF	From	To
1	LINE1	AAC185mm2 33kv single	1.35	0.164	0.311526	0.011794	N1	N2
2	LINE3	AAC185mm2 33kv single	2.1	0.164	0.311526	0.011794	node1	N4
3	LINE2	AAC185mm2 33kv single	2.0	0.164	0.311526	0.011794	N2	node1
4	LINE5	AAC185mm2 33kv single	2.7	0.164	0.311526	0.011794	N5	N6
5	LINE4	AAC185mm2 33kv single	1.37	0.164	0.311526	0.011794	N4	N5
6	LINE6	AAC185mm2 33kv single	0.8	0.164	0.311526	0.011794	N6	N7
7	LINE7	AAC185mm2 33kv single	2.0	0.164	0.311526	0.011794	N7	node2
8	LINE8	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	N9	node2
9	LINE9	AAC185mm2 33kv single	4.0	0.164	0.311526	0.011794	N9	N10
10	LINE10	AAC185mm2 33kv single	7.0	0.164	0.311526	0.011794	N10	N11
11	LINE11	AAC185mm2 33kv single	25.0	0.164	0.311526	0.011794	N11	N12
12	LINE12	AAC185mm2 33kv single	0.5	0.164	0.311526	0.011794	N13	N12
13	LINE13	AAC185mm2 33kv single	25.8	0.164	0.311526	0.011794	N13	N14
14	LINE14	AAC185mm2 33kv single	5.0	0.164	0.311526	0.011794	N14	N15
15	LINE15	AAC185mm2 33kv single	4.0	0.164	0.311526	0.011793	N15	node4
16	LINE16	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	node4	N17
17	LINE17	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	N17	N18
18	LINE18	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	N18	N19
19	LINE19	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	N19	N20
20	LINE20	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	N20	N21
21	LINE21	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	N21	N22
22	LINE22	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	N22	N23
23	LINE23	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	N23	N24
24	LINE24	AAC185mm2 33kv single	6.0	0.164	0.311526	0.011794	N24	node6
25	LINE25	AAC185mm2 33kv single	0.1	0.164	0.311526	0.011794	node6	N26
26	LINE26	AAC185mm2 33kv single	0.03	0.164	0.311526	0.011794	N2	N27
27	LINE27	AAC185mm2 33kv single	0.1	0.164	0.311526	0.011794	N27	N28
28	LINE28	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	N27	N29
29	LINE29	AAC185mm2 33kv single	0.1	0.164	0.311526	0.011794	node1	N30
30	LINE30	AAC185mm2 33kv single	2.82	0.164	0.311526	0.011794	N4	N31
31	LINE31	AAC185mm2 33kv single	0.18	0.164	0.311526	0.011794	N5	N32
32	LINE32	AAC185mm2 33kv single	0.25	0.164	0.311526	0.011794	N6	N33
33	LINE33	AAC185mm2 33kv single	0.19	0.164	0.311526	0.011794	N7	N34
34	LINE34	AAC185mm2 33kv single	0.5	0.164	0.311526	0.011794	node2	N35
35	LINE35	AAC185mm2 33kv single	0.12	0.164	0.311526	0.011794	N35	N37
36	LINE36	AAC185mm2 33kv single	1.0	0.164	0.311526	0.011794	N35	N36
37	LINE37	AAC185mm2 33kv single	0.31	0.164	0.311526	0.011794	N37	N38
38	LINE38	AAC185mm2 33kv single	1.1	0.164	0.311526	0.011794	N37	N39

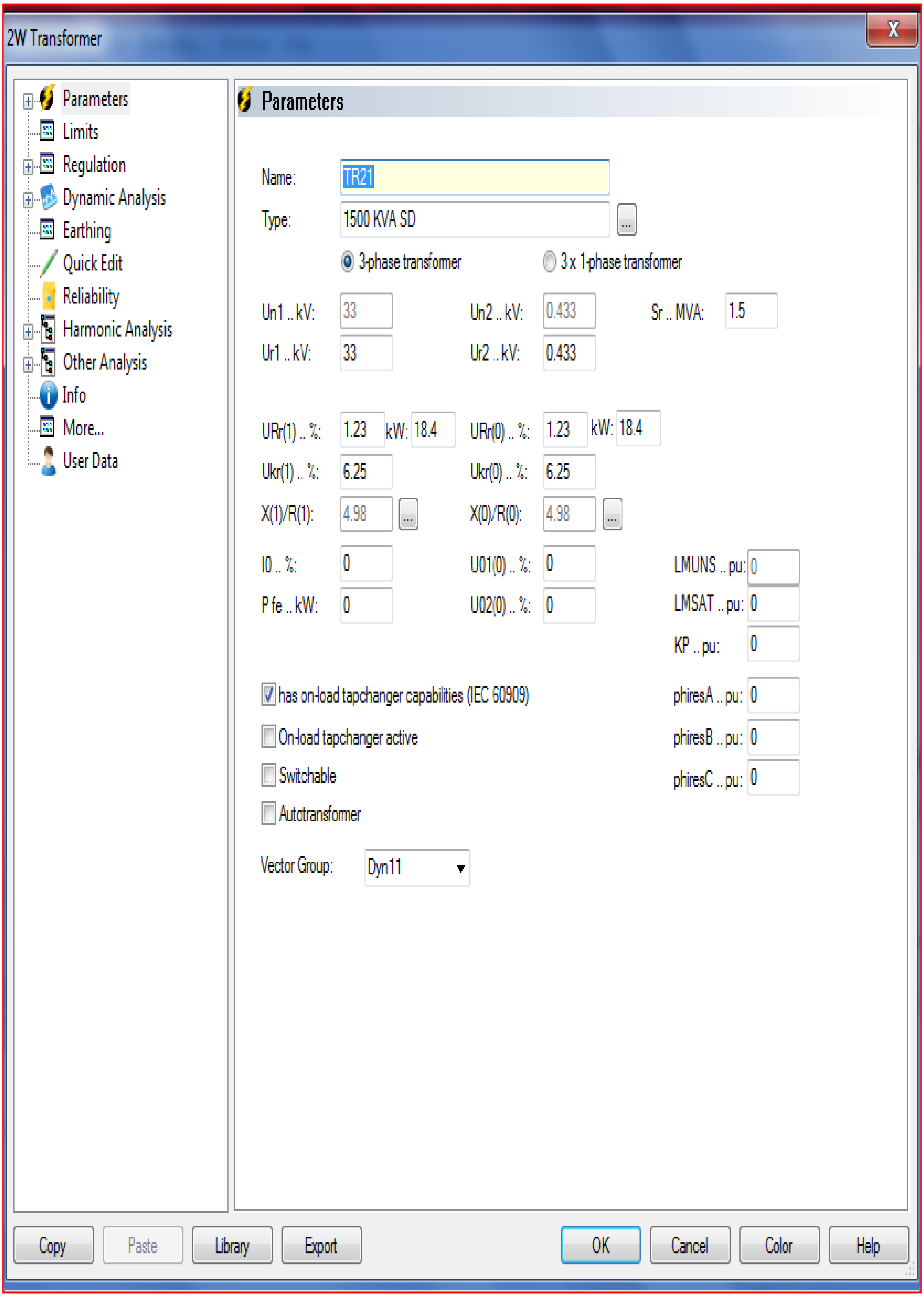
No.	Name	Type	Length km	R Ohm	X Ohm	C uF	From	To
39	LINE39	AAC185mm2 33kv single	0.44	0.164	0.311526	0.011794	N39	N40
40	LINE40	AAC185mm2 33kv single	0.31	0.164	0.311526	0.011794	N40	N41
41	LINE41	AAC185mm2 33kv single	0.3	0.164	0.311526	0.011794	N41	N42
42	LINE42	AAC185mm2 33kv single	0.04	0.164	0.311526	0.011794	N42	N43
43	LINE43	AAC185mm2 33kv single	0.2	0.164	0.311526	0.011794	N43	N44
44	LINE44	AAC185mm2 33kv single	1.11	0.164	0.311526	0.011794	N44	node3
45	LINE45	AAC185mm2 33kv single	0.31	0.164	0.311526	0.011794	N39	N46
46	LINE46	AAC185mm2 33kv single	0.7	0.164	0.311526	0.011794	N46	N47
47	LINE47	AAC185mm2 33kv single	0.14	0.164	0.311526	0.011794	N46	N48
48	LINE48	AAC185mm2 33kv single	0.29	0.164	0.311526	0.011794	N49	N9
49	LINE49	AAC185mm2 33kv single	3.5	0.164	0.311526	0.011794	node4	N50
50	LINE50	AAC185mm2 33kv single	1.5	0.164	0.311526	0.011794	N50	N51
51	LINE51	AAC185mm2 33kv single	2.0	0.164	0.311526	0.011794	N52	N51
52	LINE52	AAC185mm2 33kv single	2.0	0.164	0.311526	0.011794	N53	N52
53	LINE53	AAC185mm2 33kv single	2.0	0.164	0.311526	0.011794	N54	N53
54	LINE54	AAC185mm2 33kv single	2.0	0.164	0.311526	0.011794	N55	N54
55	LINE55	AAC185mm2 33kv single	2.0	0.164	0.311526	0.011794	N51	N56
56	LINE56	AAC185mm2 33kv single	2.0	0.164	0.311526	0.011794	N56	N57
57	LINE57	AAC185mm2 33kv single	2.0	0.164	0.311526	0.011794	N57	N58
58	LINE58	AAC185mm2 33kv single	2.0	0.164	0.311526	0.011794	N58	node5



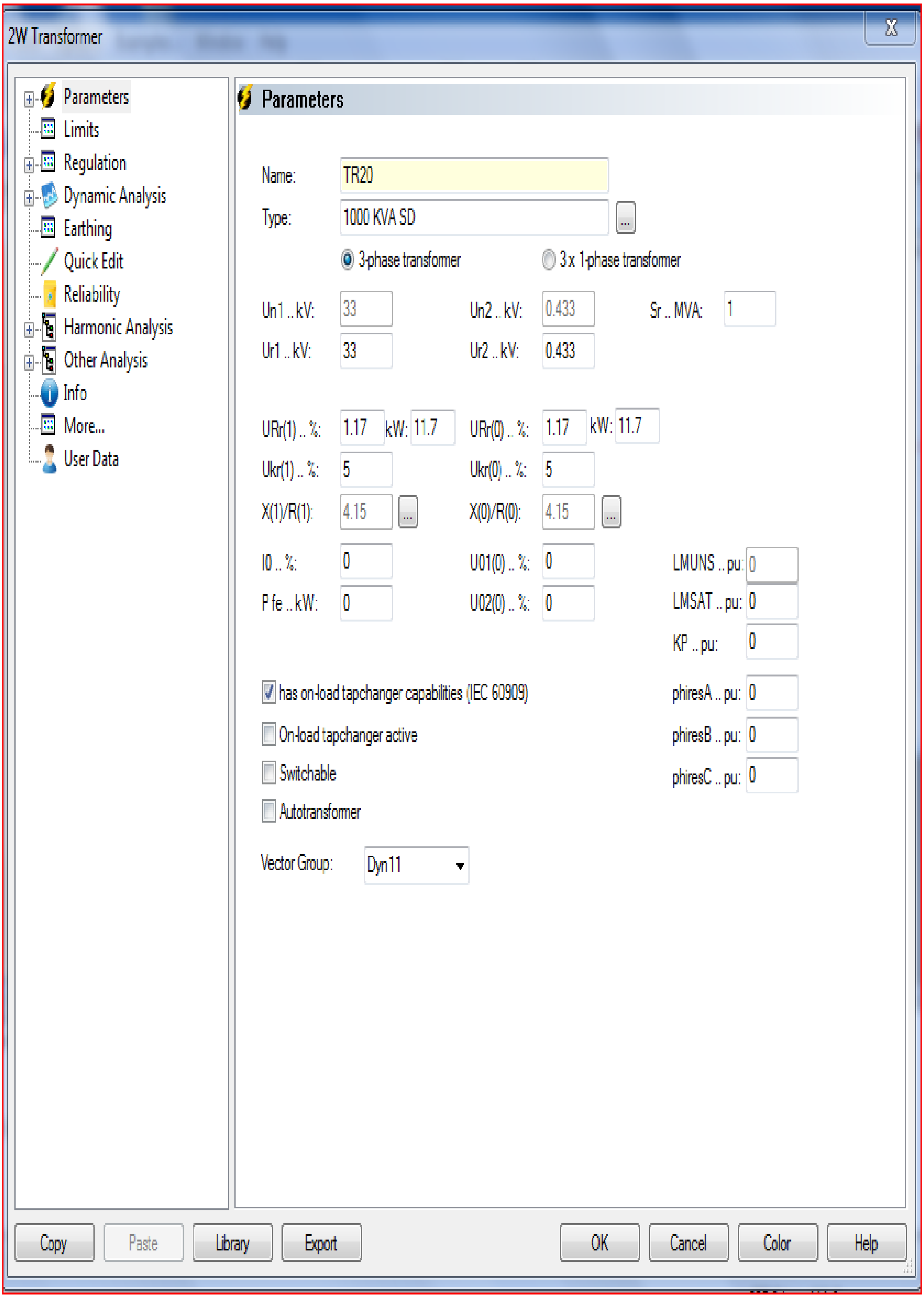
Appendix: B1: Transformer (2000) KVA 33/0.433 KV.



Appendix: B2: Transformer (1500) KVA 33/0.433 KV.



Appendix: B3: Transformer (1000) KVA 33/0.433 KV.



Appendix: C: Generation Parameters.