Power System Transmission Modeling and Simulation.

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Electrical and Electronics Engineering Program
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(ELECTRICAL ENGINEERING

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

TUMISANG PENELOPE GABRIEL

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ABSTRACT

The project describes the plan for the extension of the transmission and distribution network to supply the Ledig and Bosok area in the North West Province in South Africa. The growth ramp in the area as a result of industrialization, commercialization and electrification will result in an overloading condition if supplied from the existing network. The objectives are to improve, rehabilitate, strengthen and extend the electrical power transmission system within the North West and to cater for the anticipated load growth for the next few years.

Power transmission planning starts with a forecast of anticipated future load requirements of both demand and energy. The detailed power survey for assessing category wise rate of growth of consumption is carried out for the residential, commercial and industrial loads.

It will start with a load study of the distribution system, to be able to anticipate how much power must be delivered. The design is inclusive of number of circuits for each route, power transformer configuration, high voltage and low voltage rating of the lines and the layout of the substation equipment like busbars, circuit breaker configuration, rating of all transformers, isolators, surge arrester and protective relay schemes that will be used. The data gathered will be consolidated by producing a schematic diagram (one line diagram) and station electric diagram of the substation. A load study will be conducted on the transmission network to see the impact of the extension on the existing grid. A voltage study will be conducted on the distribution network to ensure that all load a supplied with the specified limits, which is ± 5% of the rated voltage. If the impact on the rest of the network is too compromising or the load are supplied outside the given tolerance, the design will be re-engineered until we find a design that will lead to a efficient and effective system (old and new combined).

The starting point will be the load data which will be used to determine the total power that needs to be supplied to the area. The total MVA will help in selecting the system's voltages levels, kVA ratings of equipment and amount of power that needs to be delivered to the area under study.

The work starts with a transmission load study so as to be able to develop a methodology for power transmission quality value based model that will allow determining a reliable solution between utility side investment and customer side improvement.

TABLE OF CONTENT

ACKNOWLEDEGEMENT			i
ABSTRACT			ii
CERTIFICATE OF APPROVAL.			iii
CERTIFICATE OF ORIGINAL			iv
CHAPTER 1:	**INTRODUCTION**		1
	1.1	Background Study	1
	1.2	Problem Statement	3
	1.3	Objective and Scope of Work	3
	1.4	Significance of the Project	3
CHAPTER 2:	**LITERATURE REVIEW**		5
	2.1	Electrical Power System.	5
	2.2	Power and Distribution Transformer	8
	2.3	Simple Power System Equivalent Circuit	11
CHAPTER 3:	**METHODOLOGY**		12
	3.1	Procedural Identification	12
	3.2	Tools	15
CHAPTER 4:	**DISTRIBUTION DESIGN SIMULATION**		17
	4.1	Transmission Design Simulation.	.17
	4.2	Distribution Design Simulation	.22
	4.3	Substation.	.31
	4.4	Safety	.40
	4.5	Protection	.41

CHAPTER 4: CONCLUSION 50

4.1 Conclusion 50

APPENDIX I. 51

LIST OF FIGURES

Figure 1.1	Power system layout
Figure 2.1	Typical electrical power system
Figure 2.2	Typical load flow for a residential load
Figure 2.3	Star to Delta connection (step-down) and Delta to Star (step-up)
Figure 2.4	Power triangle
Figure 2.5	Autotransformer
Figure 2.6	Vector grouping for transformer
Figure 2.7	Simple power system equivalents circuit
Figure 3.1	Graph of loads connected with their power factor
Figure 4.1	Geographical locations of Tswane and Thabang substations.
Figure 4.2	Load study of system transmission before 400kV line
Figure 4.3	Load study of system transmission after 400kV line
Figure 4.4	Graph of Transmission load study before compared to after 400kV line is added
Figure 4.5	Tswane busbar with the distribution load connected
Figure 4.6	Distribution and Reticulation network
Figure 4.7	Distribution and reticulation lines
Figure 4.8	Distribution system voltage profile
Figure 4.9	Tswane 400/33kV transmission substation
Figure 4.10	How a line is divided into zones for distance protection
Figure 4.11	Impedance / distance relay operation

LIST OF TABLES

Table 3.1	Load connected to the system
Table 4.1	Transmission load study before compares to after 400kV line is added
Table 4.2	Distribution substation and mini-substation
Table 4.3	Loads connected to the distribution system
Table 4.4	Distribution and Reticulation lines
Table 4.5	Faults caused by voltage level deviations
Table 4.6	Cost estimation of all equipment required in the substation excluding labour

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

The main objective of this chapter is to provide a clear overview of what the project is about, and outline of what has to be done to fulfill the identified needs.

1.1 Background Study

In home, electricity is used for lighting, operating vacuum cleaner, television sets, cooking, heating and other appliances to make our lives comfortable.

The production of electricity to supply power for all these things is carried out by means of generators. Isolated building in rural areas, such as farms house, may have small generators fuelled by petrol to make electricity they need. But in most industrialized nations, the making of electricity is done on a huge scale at vast electric power stations. At these locations generators are used to change some natural resources of energy into electrical energy. Generators are apparatus that convert mechanical energy to electrical energy. After production electricity flows through switching gear with transformer, which steps up the generated voltage high as 765kV, making it high enough for sending by transmission lines over long distances. High voltage enables relatively thin overhead transmission lines, to carry large amounts of electricity over long distance. Somewhere near a district where the power is used there is a substation with other transformers, this time to reduce the voltage and more controlling switch-gear, instruments and meters to measure the power supplied.

From the substation the electricity is distributed at 11kV by distribution lines. Still more transformers and switch gear serve to reduce the voltage for use in houses and shops. The voltage supplied to houses is 220V, in each building to which electricity is supplied; there is a main switch and meter to measure how many units are used, circuit breaker and fuses that instantly cut off the electricity if the current become too great for the wiring to carry it safely.

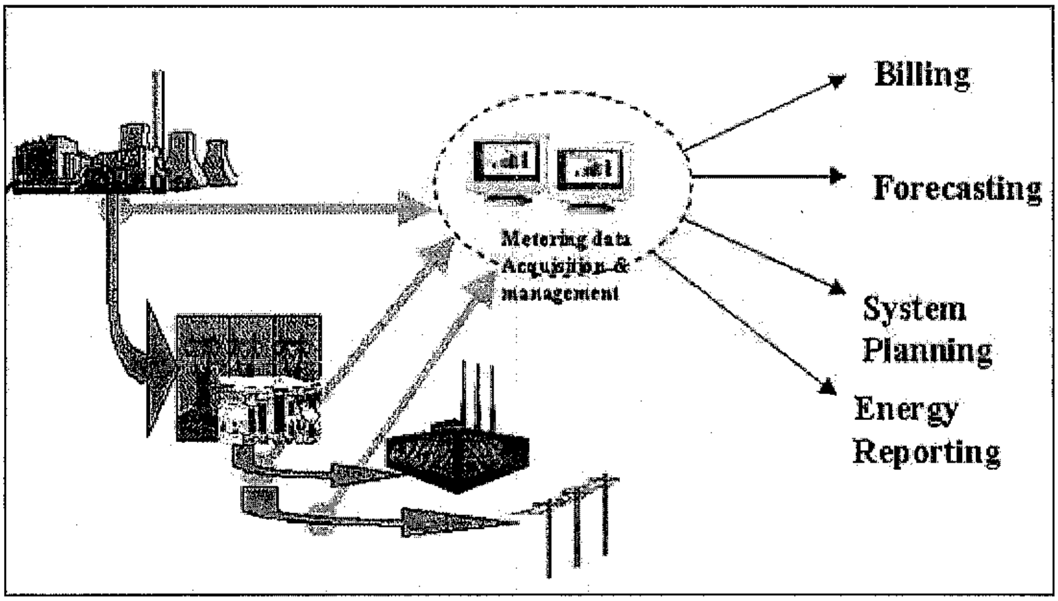


Figure 1.1: Power system layout.

The electrical power system should serve all its customers and interconnected partners economically and reliably. Thus the electrical utility industry has developed planning principles and criteria to ensure that the transmission system reliably performs this basic function. They have provided definitions of the term reliability, which is the degree to which the performances of the elements of the system result in power being delivered to customers with the accepted standards and in the desired amount. Adequacy which is the ability of the system to supply the aggregate electric energy and power requirement of customers at all times taking into account scheduled and unscheduled outages of system components. Security is the ability to withstand sudden disturbances such as electric short circuit unanticipated loss of system components especially overloading.

1.2 Problem Statement

A transmission and distribution network design to supply the Ledig and Bosok area, in the North West Province, South Africa. The growth ramp (relatively rapid growth rates because of new constructions) in the area as a result of industrialization, commercialization and electrification require an extension of the current network. The objective is to design a power transmission system using the load data, work backwards to choose appropriate voltage levels. The network will improve, rehabilitate, strengthen and extend the electrical power transmission system within the North West so to be able to cater for the anticipated load growth.

1.3 Significance of the Project

The project can be used to study and analyse the power transmission system behavior before the implementation stage. One can simulate the power flow, load flow, system faults and unanticipated power system failure so as to be able to be proactive. All loop holes can be picked up during the simulation and solutions can be generated to counter act these flaws, using power factor as an illustration one can think of different methods, that can be used to improve the customer load factor thus leading to higher system performance. Data collected from the study will also help in selecting the protection schemes which will be able to detect and correct the fault conditions on the network.

1.4 Overview and Scope of Work

The objective of the project is to design and simulate a power transmission and distribution system to accommodate the sudden load growth in the North West area. It will start with a load study of the distribution system, to be able to anticipate how much power must be delivered. The design is inclusive of number of circuits for each route, power transformer configuration, high voltage and low voltage rating of the lines and the layout of the substation equipment like busbars, circuit breaker configuration, rating of all transformers, isolators, surge arrester and protective relay schemes that will be used. The data gathered will be consolidated by producing a schematic diagram (one line diagram) and station electric diagram of the substation. A load study will be conducted on the transmission network to see the impact of the extension on the existing grid. A voltage study will be conducted on the distribution network to ensure that all loads are supplied with the specified limits, which is ± 5% of the rated voltage. If the impact on the rest of the network is too compromising or the load are supplied outside the given tolerance, the design will be re-engineered until we find a design that will lead to a efficient and effective system (old and new combined).

CHAPTER 2

LITERATURE REVIEW

2.1 Electrical Power System

Electrical power system consists of three major parts, namely:-

- Generation

Electric power is generated at power station using generators that are operated by coal, pump storage, nuclear reaction or hydro electric. Generation happens at relatively small number of location but the power needs to be transmitted from these points to loads in the country, thus forming a wide integrated network. Power stations are connected to loads by transmission lines.

- Transmission

The power is transported to distant parts of the network, by transmission line thus transmission is said to be the heart of any power utility system. Power lines can be defined as a three phase power transmission media consisting of bare, overhead strung conductors, supported by physical structure called towers with suitable phase spacing, sufficient height above ground and insulated from the support structures. The power lines combined are called tie lines because they join generation to load distributed in the country. Before the power is delivered to customers it must be reduced to lower voltage, this leads to distribution.

- Distribution

Distribution systems connect transmission line to loads, which are classified into three groups residential, commercial and industrial. A typical distribution substation will serve from one to as many as ten feeder circuits. A typical feeder circuit may serve numerous loads of all types. A light to medium industrial customer may take service from distribution feeder circuit primary, while a large industrial load complex may take service directly from the bulk transmission system. All other customers, including residential and commercial are typically served from the secondary side of the distribution transformer.

Figure 2.1 shows a typical power system network (not the system of the project), the different voltage level define the difference between power plant (generation), transmission ≤33kV, ≥725kV. and distribution ≤33kV. Transmission and distribution consist of substation that serves to step-down the voltage using step-down transformers.

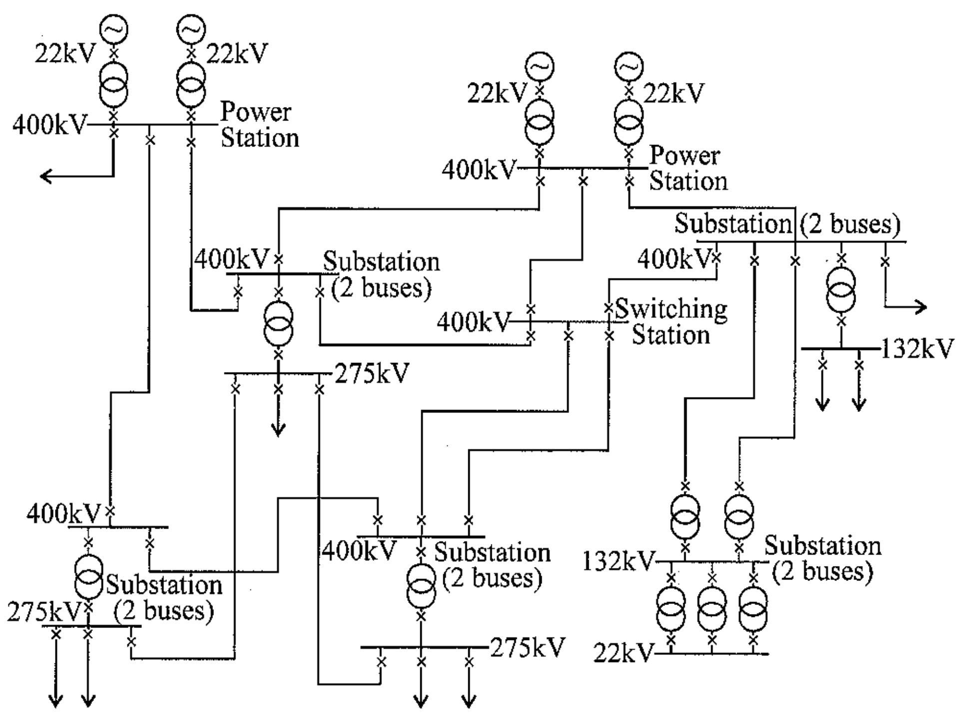


Figure 2.1: Typical electrical power system.

2.1.1 Load Characteristics

Power system loads are classified into three groups, residential, commercial and industrial loads. The general nature of loads is characterized by load factor, demand factor, diversity factor, utilization factor and power factor. All these factors are used to calculate the maximum demand of each load type. The loads in the area will be used to compute the total power to be consumed; in turn will be able to choose the voltage level of the lines feeding the loads. Having obtained the value of power and voltage, the current can be calculated, which will dictate the selection of transmission conductor material, transformer and other related devices. Different materials handle different current ratings, thus the material choose will be based on the current that will be carried to the loads. Care is taken in choosing conductors that will also be able to maintain supply even under maximum demand and not only under average demand.

$$\textbf{Load Factor} = \frac{\textbf{Average Demand}}{\textbf{Maximum Demand}}$$

The load factor is the ratio of the average load to the peak load. The average value is the total energy used during the entire period load was measured (day or month). Load factor gives the extent to which the peak load is maintained during the period of study. High load factor means the load is near peak a good portion of the time.

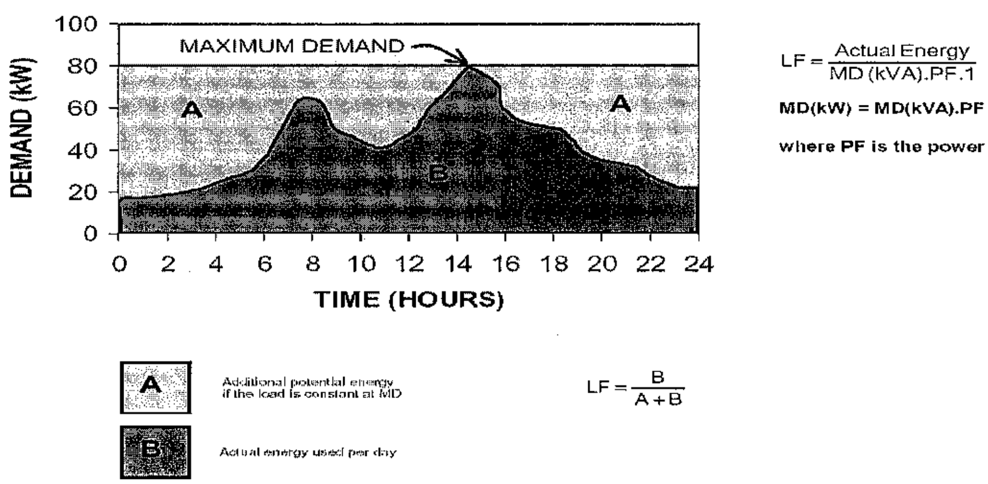


Figure 2.2: Typical Load flow for a residential load.

2.2 Power and Distribution transformers

Transfomers allow relatively low voltage from the generators to be raised to a very high level for efficient power transmission and high voltage reduces the current allowing the use of smaller conductor area. At the user, at the end of the system transformers reduce the voltage to values most suitable for utilization. Δ-Y or Y-Δ transformer is more suitable for unbalance loads and if the Y connection is used on the high voltage side the insulation cost can be reduced. The Y-Δ transformer connection is commonly used to step down the high voltage to a lower voltage. The neutral point on the high voltage side can be grounded, which is a desirable condition. Δ-Y transformer connection is used for stepping up to a higher the voltage.

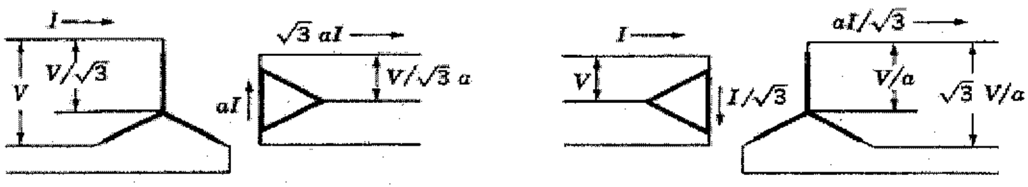


Figure 2.3: Star to Delta connection (step-down) and Delta to Star (step-up)

Transformer turn ratio

$\mathbf{k = N_2 / N_1 = V_2 / V_1 = I_1 / I_2}$

Ratio of line voltage magnitude for Y-Δ transformer is

$\mathbf{V_{2L} / V_{1L} = \sqrt{3}a}$

Transformation between line-line and per phase quantities;

Delta (Δ) connection $\mathbf{I_l = \sqrt{3}\, I_{ph}}$ $\mathbf{V_l = V_{ph}}$

Star (Y) connection $\mathbf{V_l = \sqrt{3}\, V_{ph}}$ $\mathbf{I_l = I_{ph}}$

Where

$\mathbf{V_l}$ and $\mathbf{I_l}$ = line Voltage and current

$\mathbf{V_{ph}}$ and $\mathbf{I_{ph}}$ = **phase Voltage and current**

power factor (PF): Is the real active power in kW divided by the apparent power in kVA i.e.

$$PF = \frac{P(kW)}{S(kW)} = COS(\Phi)$$

$$S(kVA) = p(kW) + jQ(kVAr)$$

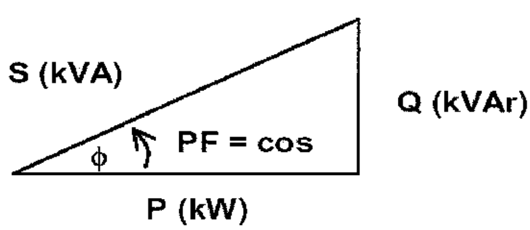


Figure 2.4: Power triangle

Power is the same for both connections

Apparent power	$\mathbf{S = 3V_{ph}\, I_{ph} = \sqrt{3}\, V_l\, I_l}$
Active power	$\mathbf{P = 3V_{ph}\, I_{ph}\, Cos\, \theta = \sqrt{3}\, V_l\, I_l\, Cos\, \theta}$
Reactive power	$\mathbf{Q = 3V_{ph}\, I_{ph}\, Sin\, \theta = \sqrt{3}\, V_l\, I_l\, Sin\, \theta}$

Autotransformers are used on the transmission network; they have a winding which is common to both primary and secondary sides. There is only one neutral connection, which is connected to earth. Tertiary windings, connected in delta, are provided for reasons as already explained above. The high voltage, common and tertiary winding are peer phase on the same leg of the core. Eskom (company used to design my network) and the projects transmission network make use of three phase autotransformers. An added advantage of autotransformers is that the primary and secondary voltages are in phase.

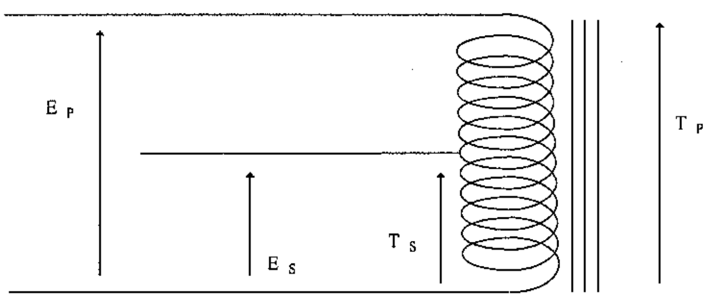


Figure 2.5: Autotransformer

Apart from voltage ratio, the phase shift between the corresponding primary and secondary voltages of a transformer depend on the primary and secondary connections. Some of the most important connections of primary and secondary windings of transformers are tabulated below, with their standard designations and phase shifts.

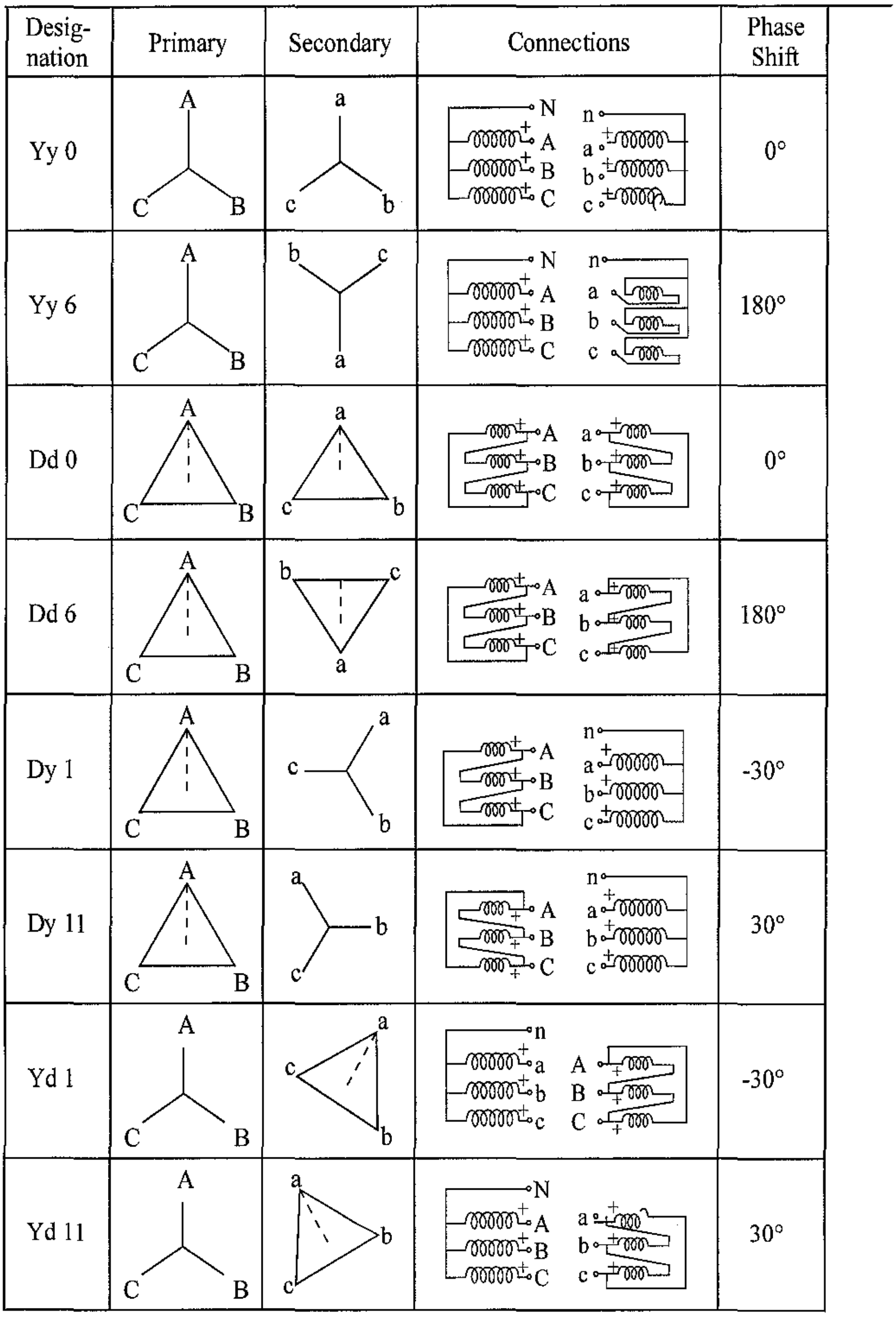


Figure 2.6 Vector grouping for transformers

Note that in the case of 180° phase shift, the polarities of the corresponding secondary phases (relative to primary) are reversed. Phase shift of the phases is obviously important when transformers are situated in a network. Thus, it is essential that there be no intentional phase shift when a transformer is either paralleled with others or is installed in an interconnection between parts of a network.

2.3 Simple Power System Equivalent Circuit

All transmission lines exhibits the electrical properties of resistance, inductance, capacitance and conductance. The capacitance and inductance are due to effect of magnetic and electric field around the conductor. These parameters are essential for the development of the transmission line models used in power system analysis. The shunt conductance accounts for leakage current flowing across the insulators and ionized path in air. The leakages are negligible compared to the current flowing in the transmission lines and thus may be neglected. Our design is based on a three phase transmission line.

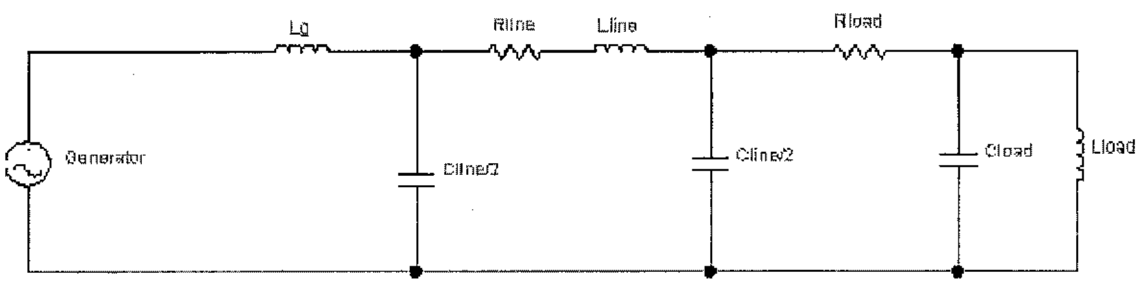


Figure 2.7: Simple power system equivalent circuit

The formulas chosen are for Equispaced three phase transmission lines.

Thus distance between the phase: d1=d2=d3=d

Resistance per phase $\mathbf{R = \rho\ell / A}$ **Ω**

Where

ρ = resistivity

ℓ = length of the conductor

A = area of the cross section of the conductor

Inductance per phase $\mathbf{L = 2 \times 10\text{-}7 \ \log_e \frac{d}{r'}}$ **H/m**

Where

r' = geometric mean radius = 0.7788r

d = d_1= d_2 = d_3 distance between the phases

Capacitance per phase $\quad C_1 = C_2 = C_3 = \dfrac{2\pi\varepsilon_0}{\log_e (d/r)}$ F/m

Where

$d = d_1 = d_2 = d_3$ = distance between the phases

r = radius of the conductor

CHAPTER 3

METHODOLOGY

1. Methodology

The project is carried out by doing a research to obtain information on:

- How load studies are conducted
- Transmission lines are designed
- Transmission substations are designed
- Distribution network are designed
- Protection schemes implemented and why

Based on the findings the transmission and distribution network is designed and modeled. The information is obtained from many resource especially, Eskom (transmission South Africa) manuals and software, power system design books and technical information from engineer and technicians, so to understand power distribution and transmission modeling

3.1 Procedure Identification

3.1.1 Load Study

The loads that are connected to the Ledig and Bosok grid and will be used to compute the total power consumed, these values are then used to work backwards to select rating that will be sufficient to supply the load, taking into account growth of the load that has occurred. See Table 3.1.

Load type	Name	Power (MW)	Power factor
Industrial	Granite mine	10MVA	0.8
Commercial	North gate	1MVA	0.9
Agriculture	Farmer1	1.7MVA	0.9
Agriculture	Farmer 2	815kVA	0.9
Agriculture	Farmer3	315kVA	0.9
Residential	House 1	9kVA	0.95
Residential	House 2	9kVA	0.95
Residential	House 3	9kVA	0.95
Residential	House 4	9kVA	0.95

Table 3.1: Loads connected to the system

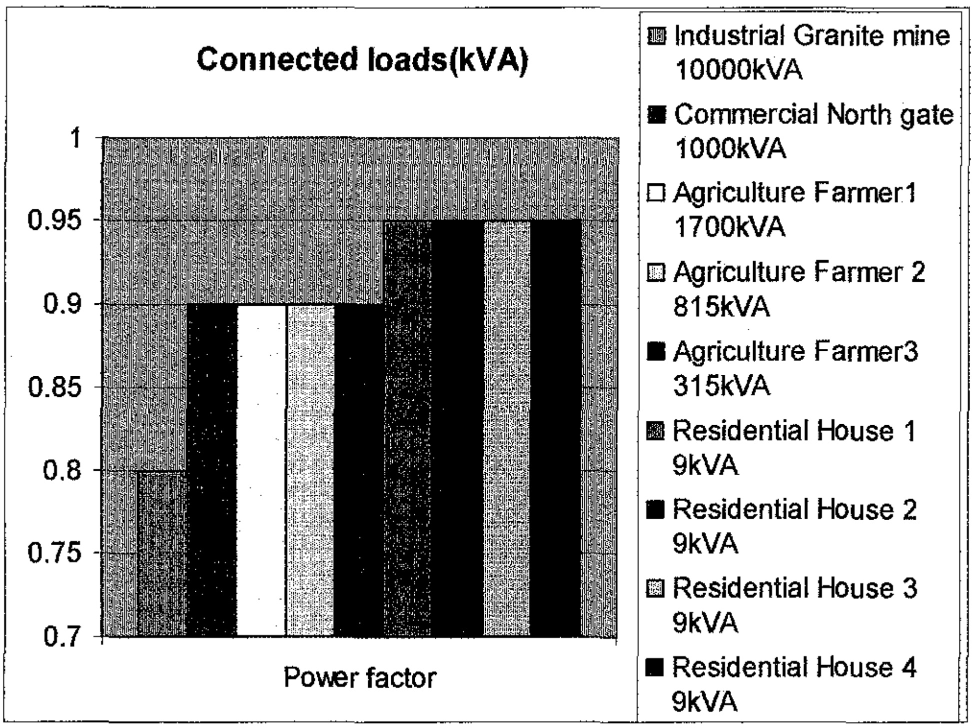


Figure 3.1: Graph of loads connected with their power factor

3.1.2 Power System Lay Out

A one line diagram of the proposed system will be designed and it will show the layout of the power system transmission and distribution, its main objective is to show the location of the different loads, distribution system and transmission system. These load will be used to compute the total power consumed, in turn will be able to choose the voltage level of the lines feeding the loads. Having obtained the value of power and voltage, the current can be calculated which will help with the selection of the type transmission conductor size and material, transformer and other related devices. Different materials handle different current ratings, thus the material choice will be based on the current that will be carried to the loads. Care is taken in choosing conductors that will also be able to maintain supply even under maximum demand and not only under average demand.

3.1.3 Transmission Line Conductor

The transmission line formulas are collected, there will be a need to choose voltage levels and type of conductor size and material that will be used so as to able to compute the actual R, L and C value of the line. Once we know the amount of current flow which allows for the selection of conductor material will be able to select transmission line voltage levels and protection schemes that can be applied. The type of conductor used is selected from the library available in the RecticMaster software. The conductor is selected using the current that flow between the two substations.

3.1.4 Substation Components and Layout

Brief write up on the Substation construction and consideration. This refers to all apparatus, equipment, and protection schemes. This list include components like circuit breakers, busbars, isolators and different protection devices that can be applied such as over current relays, distance relays, earth fault relay, buszone relay ect.

3.1.5 Schematic Drawing and Diagrams

The system will be represented as a single line diagram but our calculation is based on three phase system which is summed up on the single line diagram. The various elements are shown symbolically using standard IEC symbols, superimposed upon the single line diagram thus producing a schematic drawing of the power transmission model.

3.1.6 System Study

The problem of stability in a network concerns energy balance and the ability to generate sufficient restoring forces to counter system disturbance, will be addressed by doing a study of analytical aspects, load flow study, steady state stability, transient stability and short-circuit behaviors. A load study of the current and future system will be done to see how the addition of the new line will affect the rest of the system. A voltage study will be conducted on the distribution system to check that the loads are supplied within standard tolerance ±5%.

3.2 Tools

3.2.1 Power System Simulation for Engineers (PSSE)

This software is used for the transmission network; a load study of the interconnected network is conducted, this inclusive of the following;

- Load study before the new transmission line is added
- Load study after the line is connected
- Analyse the impact of the new line on the existing system by comparing the losses on the system and fault current.

The load study is conducted with objective of finding how the network extension impacts on the rest of the network. It if the extension compromises the existing system extensively, the design will be re-engineered until we get expected losses.

3.2.2 RecticMaster

This software is used to model the distribution system, this inclusive of the following

- Connected loads
- Distribution lines used and their rating
- The distribution substation
- All the mini substation supplying loads directly

A voltage profile of the network is done so be able to see if the network operates within specified bandwidth which is ± 5% of the rated voltage.

3.2.3 Microstaion V8.1

This software is used to draw the station electric diagram of the transmission substation. The diagram is inclusive of all substation apparatus and shows the different apparatus are interconnect. This diagram shows the location and interrelation of substation equipment.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Transmission Design simulation

The growth ramp in Ledig and Bosok due to electrification, commercialization and industrialization raises a need for transmission strengthening; using existing lines will cause an overload condition on the existing network. The proposed solution requires that a new transmission line is constructed by tapping into one of the main lines on the transmission grid. Different designs where considered, based on their finance and feasibility one was selected.

The designed involved creating a new, dedicated transmission substation Tswane, which will supply the Thabang distribution station. Thabang will in turn supply the Ledig and Bosok area. Tswane is a 400/33kV substation that is supplied from a Tee-off from the Leseding 400kV busbar. A 33kv distribution line is constructed, feeding the 33/22kV Thabang substation.

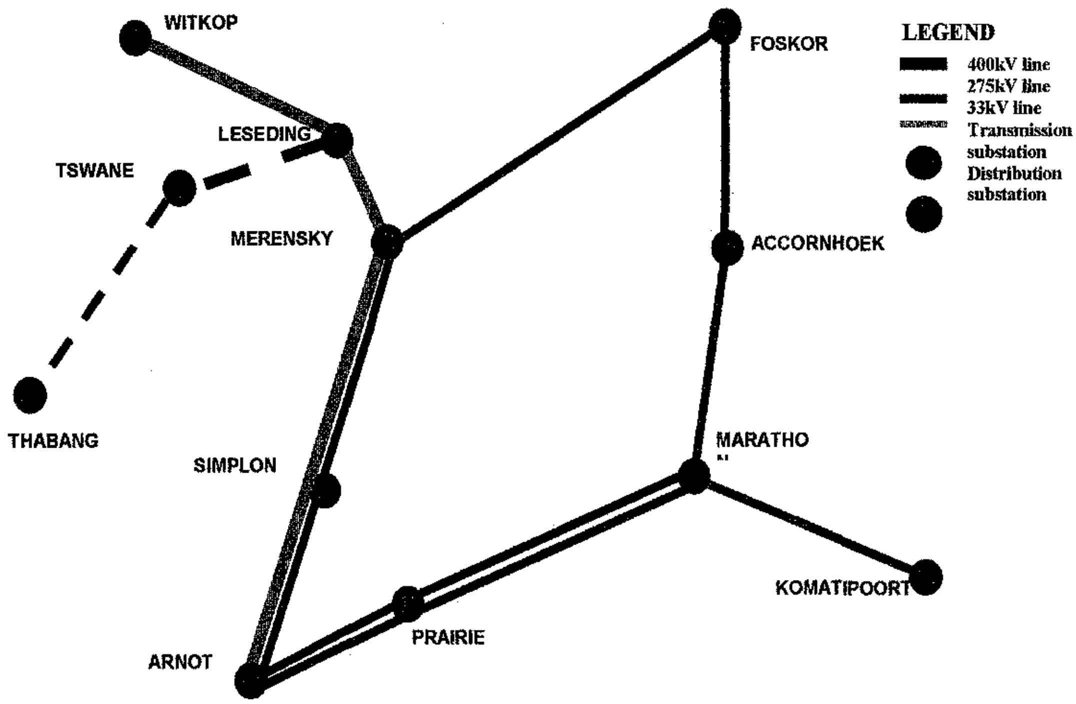


Figure 4.1: Geographical location of Tswane and Thabang substations.

Figure 4.1 is the geographical layout of the portion of the North West Transmission network showing the location of the site where Tswane operations will take place. The location is about 18km from Leseding and Thabang which is 25km from Tswane.

4.1.1 Load Study of the Transmission System

A load study of the present system is conducted so it can be compared to the load study of the system after the Leseding- Tswane transmission is added. This help use to evaluate the system condition to see how the proposed line will impact the whole grid, in a case where the addition of the line causes too many problem another design would have to be formulated.

From the load study one can see, that the proposed transmission substation Tswane is feed from the 400kV busbar called Janus4, which is the high voltage side of the Leseding substation. Witkop, Merensky and Duhva are stations also connected to Leseding 400kV/132kV substation.

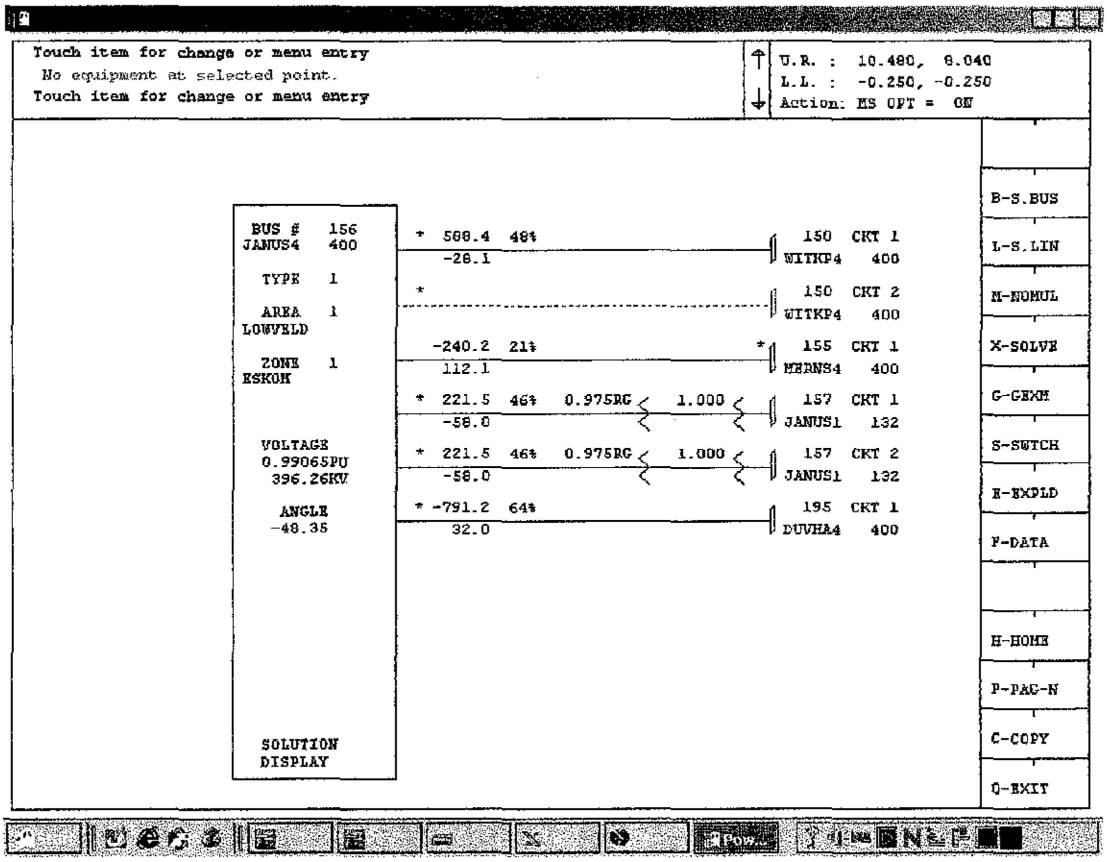


Figure 4.2: Load study of the transmission system before 400kV line.

The objective of a load study is to evaluate the performance of a network and to examine the effectiveness of the proposed system. Thus it is essential that a load flow is conducted in the planning stage.

The load flow study is carried out with the following main objectives, which is to determine:

- The flow of active and reactive power in the network branches
- Voltage levels at each busbar to ensure satisfactory voltage profile in the whole system
- No circuits are overloaded, and the busbar voltages are within acceptable limits.
- Optimum system loading conditions
- Optimum system losses

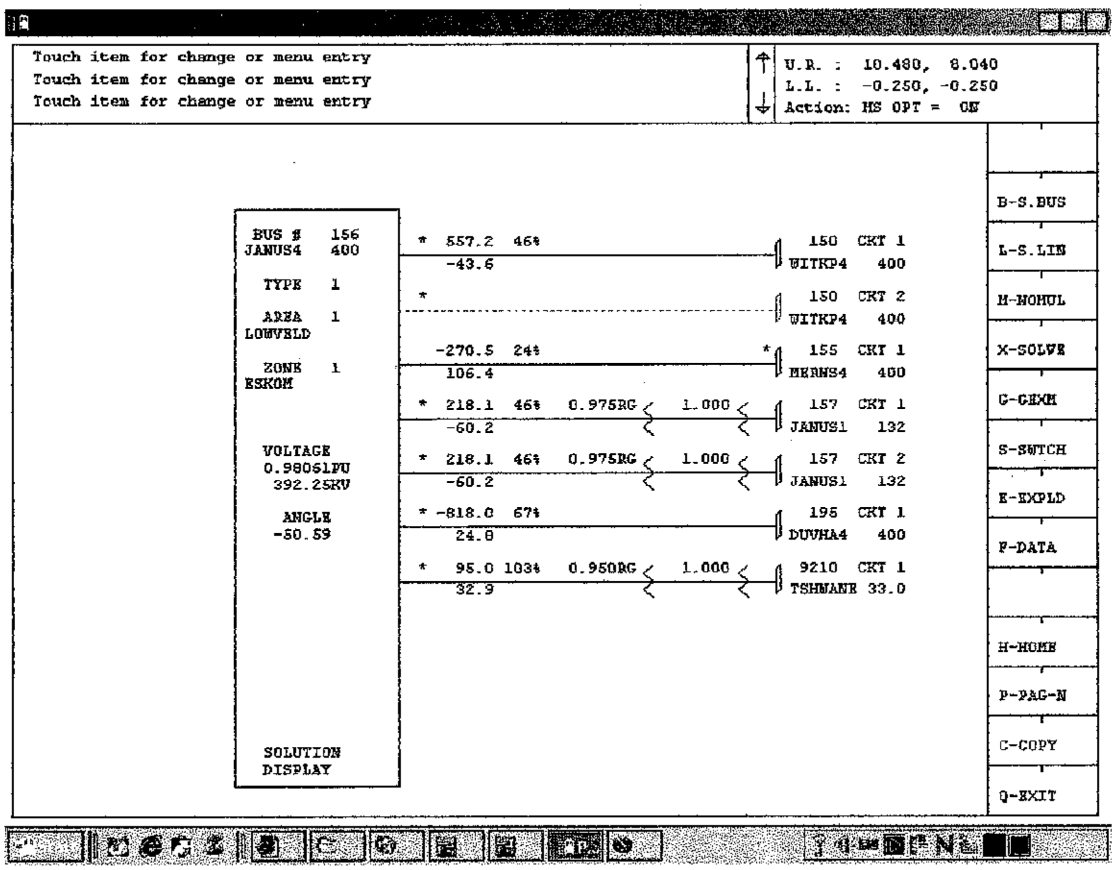


Figure 4.3: Load study of the transmission system after 400kV line

The load study is conducted again on the system after the 400kV line to Tswane is added. The aim is to be able to compare the status of the system before and after the proposed design and see if it has any disadvantageous impact on the system as a whole.

Table 4.1 shows the state of the system at present compared to the system after the 400kV line, for the full report see Appendix 1 and figure 4.2, 4.4. The sate of the system is evaluated from its fault level, voltage level and power losses. The values obtained from the load study, after the 400kv Leseding – Tswane line have been added to the system, will be used as input to the distribution system.

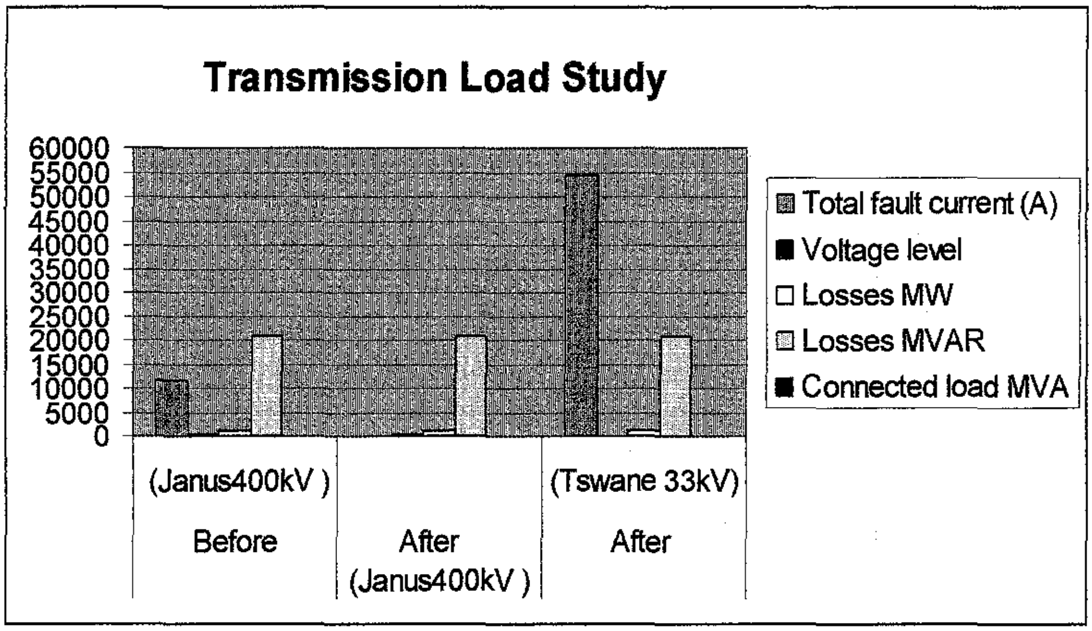


Figure4.4: Graph of transmission load study before compared to after 400kV line

System load study	**Before (Janus400kV)**	**After (Janus400kV)**	**After (Tswane 33kV)**
Total fault current (A)	11569.1	11 569	54559.3
Voltage level	396.26	395.56	33.895
Losses MW	1209	1220.97	1220.97
Losses MVAR	20631.48	20911.79	20911.79
Connected load MVA	99.9	99.9	99.9

Table 4.1: Transmission load study before compared to after 400kV line is added.

Figure 4.4 show the busbar that has been added to the system to strength the network, so as to be able to supply the Ledig and Bosok area. The load connected to the Thabang distribution will be shown in detail on the distribution network.

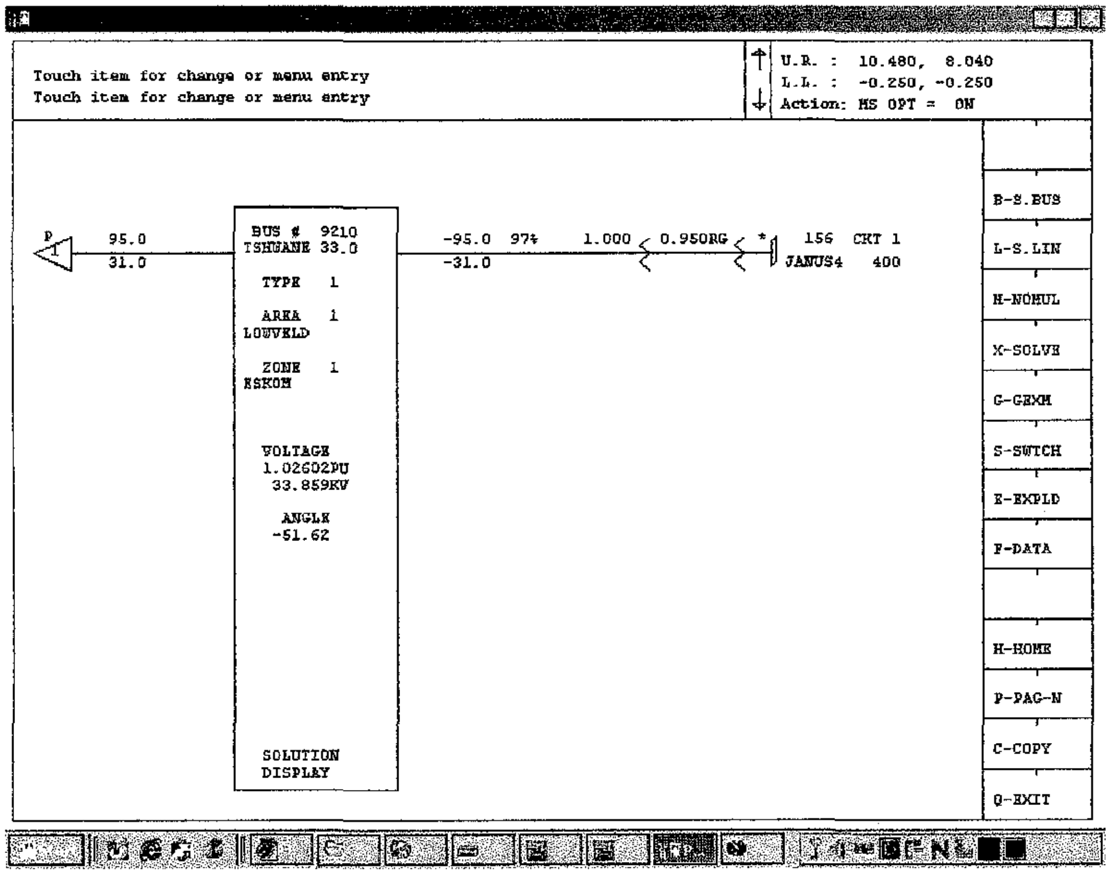


Figure 4.5: Tswane busbar with the distribution load connected.

4.2 Distribution Design Simulation

The distribution system for the Ledig and Bosok is a radial system. It is connected to one source, thus it is exposed to many interruptions possibilities- the most important are those due to overhead line and transformer failure. Both these components have finite failure rates and such interruptions are expected and statistically predictable. A study will be conducted on different protection schemes that can be applied to reduce the likelihood of the failure occurring.

The distribution system consists of the following:

Substation	Actual supply	Transformer	MVA Rating	Actual supply
Thabang	13MVA	33/22kV	45	12.9MVA
Leratong	1.7MVA	22/11kV	4	1.7MVA
Mini 1	61.9kVA	22kV/400V	0.050	18.2kVA
Mini 2	44.3kVA	22kV/400V	0.050	18.2kVA
Mini 3	26.6kVA	22kV/400V	0.050	9.1kVA
Mini 4	18kVA	22kV/400V	0.050	18.2kVA

Table 4.2: Distribution substations and mini – substations

The distribution system consists of a high voltage primary distribution of 33/22kV, a secondary distribution of 22/11kV and four pole transformers that are supplying the residential loads. All large costumers, which in this system refer to the inductive loads, are connected to the high voltage primary and secondary distribution substation and all the non-motor loads are connected to the feeders of the pole transformers. The system only deals with the loads from the feeder point of view.

Load type	Name	Rating	Power factor
Industrial	Granite mine	10MVA	0.8
Commercial	North gate	1MVA	0.9
Agriculture	Farmer1	1.7MVA	0.9
Agriculture	Farmer 2	815kVA	0.9
Agriculture	Farmer3	315kVA	0.9
Residential	House 1	9kVA	0.95
Residential	House 2	9kVA	0.95
Residential	House 3	9kVA	0.95
Residential	House 4	9kVA	0.95

Table 4.3: Loads connected to the distribution system

4.2.1 Distribution Network

The networks provide maximum reliability and operating flexibility. The network has the most economical and effective method in serving the high density loads. A transformer loading factor of 75% and below has been chosen to insure that system can handle the load ever under peak demand (maximum demand)

The loads are connected to the distribution system, all inductive motors are connected to the primary distribution substation feeders and all non-motor loads are connected to the mini-substation distribution feeders

.

The schematic diagram, figure 4.5 shows the distribution and reticulation system with its connected loads.

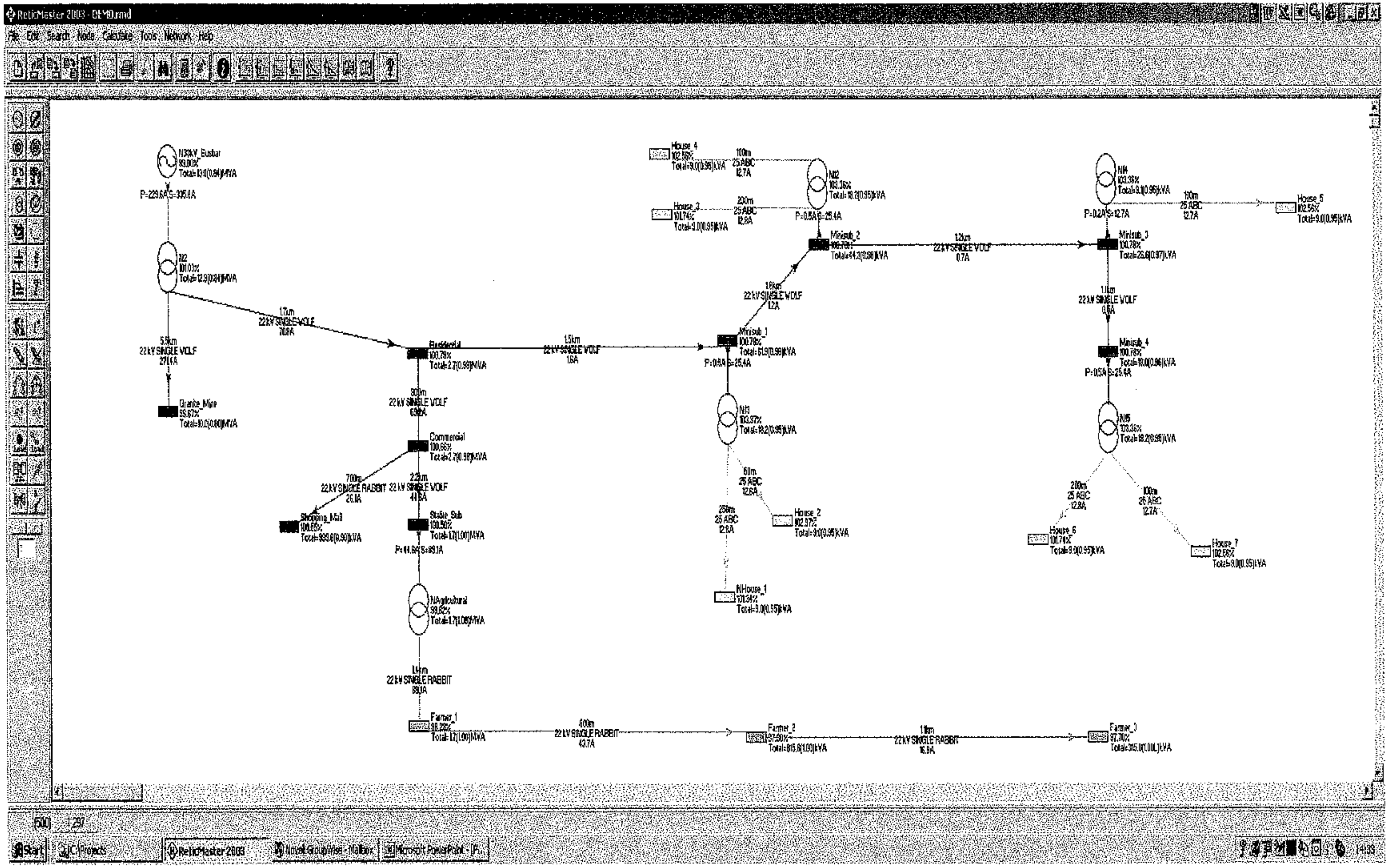


Figure 4.5: Distribution and reticulation network

4.2.2 Distribution and Reticulation Lines

The conductors used in the network are selected using the current that will flow in that conductor. The area under study is subject to an increase in the load capacity thus the conductor chosen have some extra capacity to accommodate future increase in the load consumption. The following diagram, figure 4.6 shows the conductors used in the network. The current flowing in all the other conductors can be viewed in figure 4.5.

Distribution Line	Conductor Name	Distance (km)	Rated voltage (kV)	Current (A)
Thabang – Granite mine	Single Wolf	5.5	22	271.1
Thabang – Residential	Single Wolf	1.7	22	70.8
Residential–Commercial	Single Wolf	0.9	22	69.2
Commercial–North Gate	Single Wolf	0.7	22	26.1
Commercial – Leratong	Single Wolf	2.2	22	44.6
Leratong – Farmer 1	Single Rabbit	1.4	22	89.1
Farmer 1 – Farmer 2	Single Rabbit	0.8	22	43.7
Farmer 2 – Farmer 3	Single Rabbit	1.1	22	16.9
Residential – Mini 1	Single Wolf	1.5	22	1.6
Mini 1 – Mini 2	Single Wolf	1.8	22	1.2
Mimi 1 – House 1	25 ABC	0.25	0.4	12.8
Mini 1 – House 2	25 ABC	0.05	0.4	12.6
Mini 2 – House 3	25 ABC	0.2	0.4	12.8
Mini 2 – House 4	25 ABC	0.1	0.4	12.7
Mini 2 – Mini 3	Single wolf	1.2	0.4	0.7
Mini 3 – House 5	25 ABC	0.1	0.4	12.7
Mini 3 – Mini 4	25 ABC	1.1	0.4	12.7
Mini 4 – House 6	25 ABC	0.2	0.4	12.8
Mini 4 – House 7	25 ABC	0.1	0.4	12.7

Table 4.4: Distribution and Reticulation lines

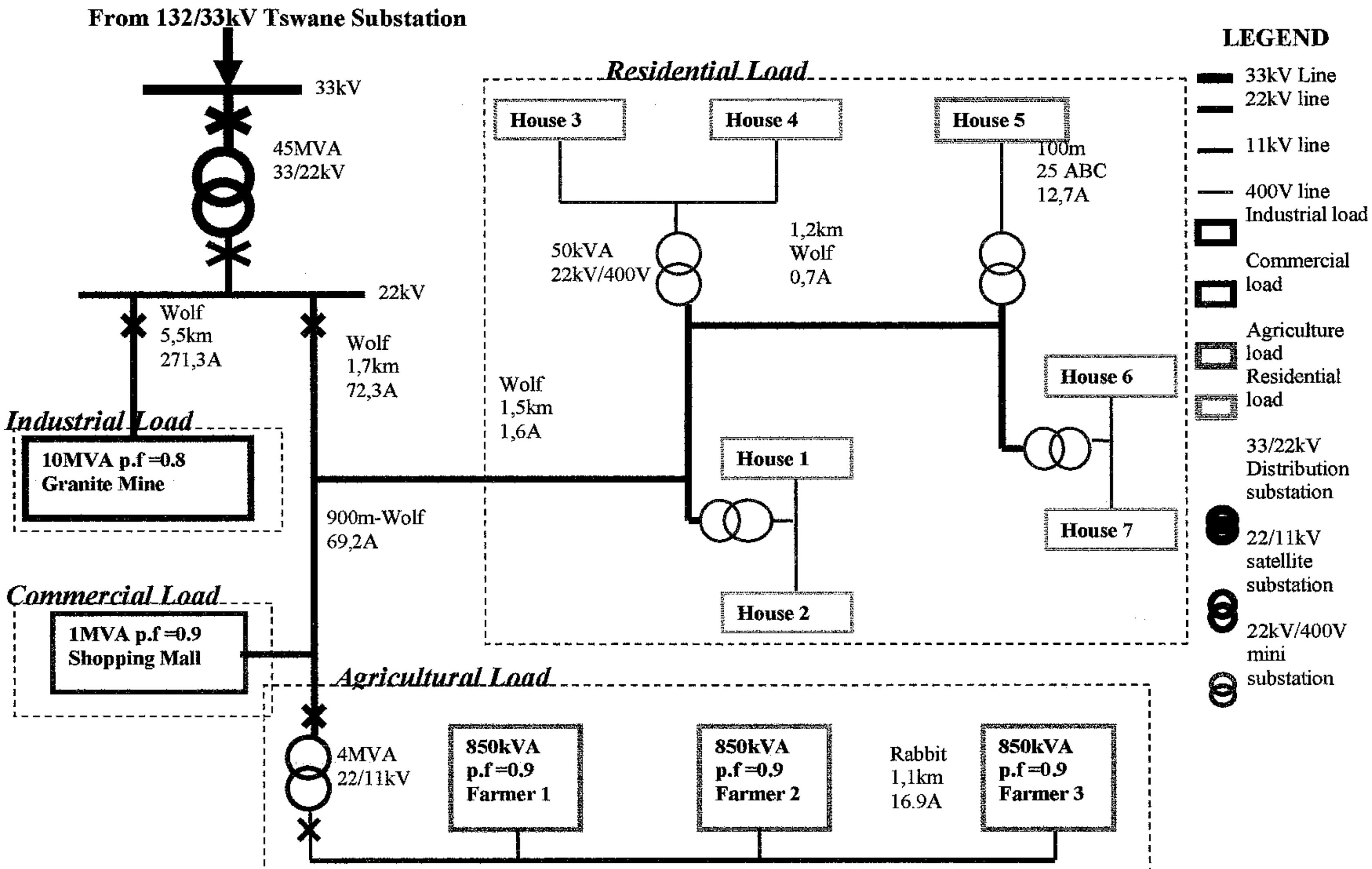


Figure 4.6: Distribution and Reticulation lines

4.2.3 Voltage Profile

The voltage control within a power system is done in such a manner that the voltage profile throughout the entire system is kept within acceptable limits at all points at all times.

The reason why voltage control is necessary are as followings:

- It is the basic quality criteria in the delivery of power.
- System power transfer ability (steady sate / thermal) is determined by voltage level.
- System stability is affected by voltage level.
- Magnetic saturation on over voltage.
- Harmonic generation due to saturation.

The Electricity Act calls for a general limit of ± 5% for a duration not exceeding 10 consecutive minutes. Other limits may however, be agreed upon in individual supply contract.

Voltage changes can be affected by the following means;

- Transformer tap changing
- Reactive power generation or absorption
- Load reduction or increase
- Changes in transmission line / system series impedance

Utilities determine their own standards for low voltage but typically voltage of 95% of nominal are the normal transmission system low limit. Voltage limits within the low voltage distribution system figure 4.5 are often more strict as customer equipment has little tolerance for voltage deviations. Sustained low voltages on power system can lead to excessive losses due to high current values and thermal damage to customer equipment. An extreme example of the harm caused by voltage is the possibility of voltage collapse.

Voltage fluctuations are deviations in the voltage away from the nominal value. These may be high speed, micro-seconds (spikes, notches) short term, milli-seconds (dips, brownout, surges) or long term, seconds (protracted under or over voltages).

Fault type	Magnitude	Duration
Notches	5% to 25%	100 – 3000 μs
Spikes	50% to 300%	10 – 3000 μs
Dips	10% to 80%	20 – 200 ms
Surge	10% to 40%	20 – 200ms
Under voltage	5% to 20%	1 – 600s
Over voltage	5% to 20%	1 – 600s

Table 4.5: Faults caused by voltage level deviations.

Low voltage in the power system occurs for many reasons, including:

- Higher than expected power system loading
- Faults and other abnormal events (short circuit)
- Sudden loss of key transmission lines
- Loss of normal MVAr source
- Sudden addition of large loads
- Disconnected switched or lighting strike

These faults are detected by protection relays which subsequently disconnect the faulted section of the system by opening circuit breakers. Depending on the speed of the detection and operation of the circuit breakers, the faults can last from 50 to 500ms.

From the above discussion one can conclude that the voltage profile of a system is of vital importance from a healthy system. The voltage profile of the distribution system is done to be able to see that:

- voltage levels are with the acceptable bandwidth of ± 5%
- there is no over voltages or under voltages

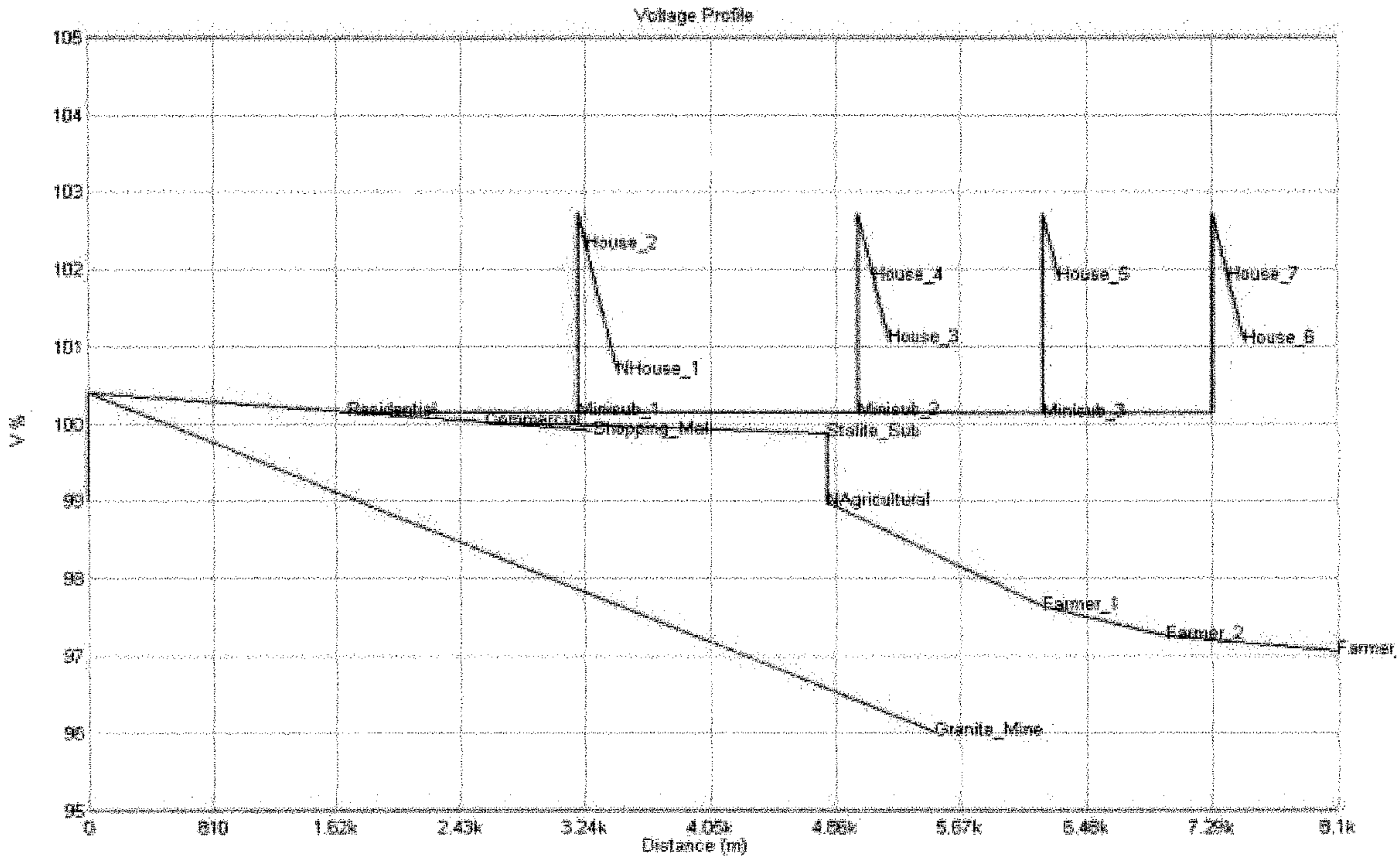


Figure 4.7: Distribution system voltage profile.

As can be seem from figure 4.7 the voltage levels of the distribution network is within the acceptable bandwidth. All power system grids are subject to system faults like the one listed above, but power utilities have come up with way to remedy voltage fluctuations. Conventional methods for voltage control are as follows:

- At the power station by means generator MVAr adjustment.
- At the main transmission system level by means of reactive power generation and absorption. This is generally achieved through static VAr compensators which are fast acting and has the ability to generate and absorb MVAr's. Transformer tap changing is used as a slower and 'back-up' mechanism. Individual fixed capacitor banks are used at centers points' of large load. Shunt rectors are used in conjunction with very long lines.
- At distribution level use transformers tap changer and fixed capacitor bank.
- At reticulation level is mainly by means of transformer tap changing and to a lesser degree by shunt capacitor bank switching.

Generator excitation control and tap changing has a direct effect on voltage control. MVAr control, affect voltage through the control of load power factor (and hence the reactive load voltage drop). The voltage change obtained from any given addition or subtraction will hence depend on the power factor improvement (towards unity).

4.3 Substations

Electrical power is generated at the source of the primary energy e.g. coal fired or dam. Generation hence takes place at a relatively small number of locations and power needs to be transmitted from these points to he loads on a country, wide integrated network.

This is very much like a road, in order to make a road network workable and safe; it has organizing and regulating systems at all junctions in form of stop streets, yield signs, circles, traffic light etc. when a portion of road is unsafe or unstable, bye-pass arrangements are made to ensure continuity of in the flow of traffic.

A power system similarly requires regulating and controlling devices at all junctions to make the system workable, safe and reliable. The arrangements can be very simple to very complex depending on the voltage level, importance of the network, criticality of the loads, the amount of power being transferred and reliability requirement. A substation is an arrangement of multiple junction points, generally of more than one voltage level. All voltage levels change points are placed at substation with two or more in-and outgoing circuits at each voltage level.

4.3.1 Size and Configuration

The size and configuration is determined by the number of junctions required and number of voltage levels created at that point. This again depends on the density of the load points and the density of the primary network being tapped into.

The proposed transmission substation Tswane is feed from a transmission line tapped as tee-off from the 400k V busbar in the Leseding substation. This however has a disadvantage that any problem, fault or outage (temporary or permanent) also affects the main line rapidly. The Tswane substation is a 400/33/22kV which in turn feeds the distribution system.

To ensure continuity of supply the substation has the following arrangement:

- Double bus and one zone arrangement (HV and LV).
- Busbar links are coupled by means of bus couplers.
- Busbar links on all the feeders and the transformer (HV and LV) to allow for flexible coupling of any circuit to any one of the four busbar sections as well as optimum grouping of feeders and transformer for a maximum security of supply figure 4.4.
- Auxiliary 22kV/380V transformer to supply the control room.

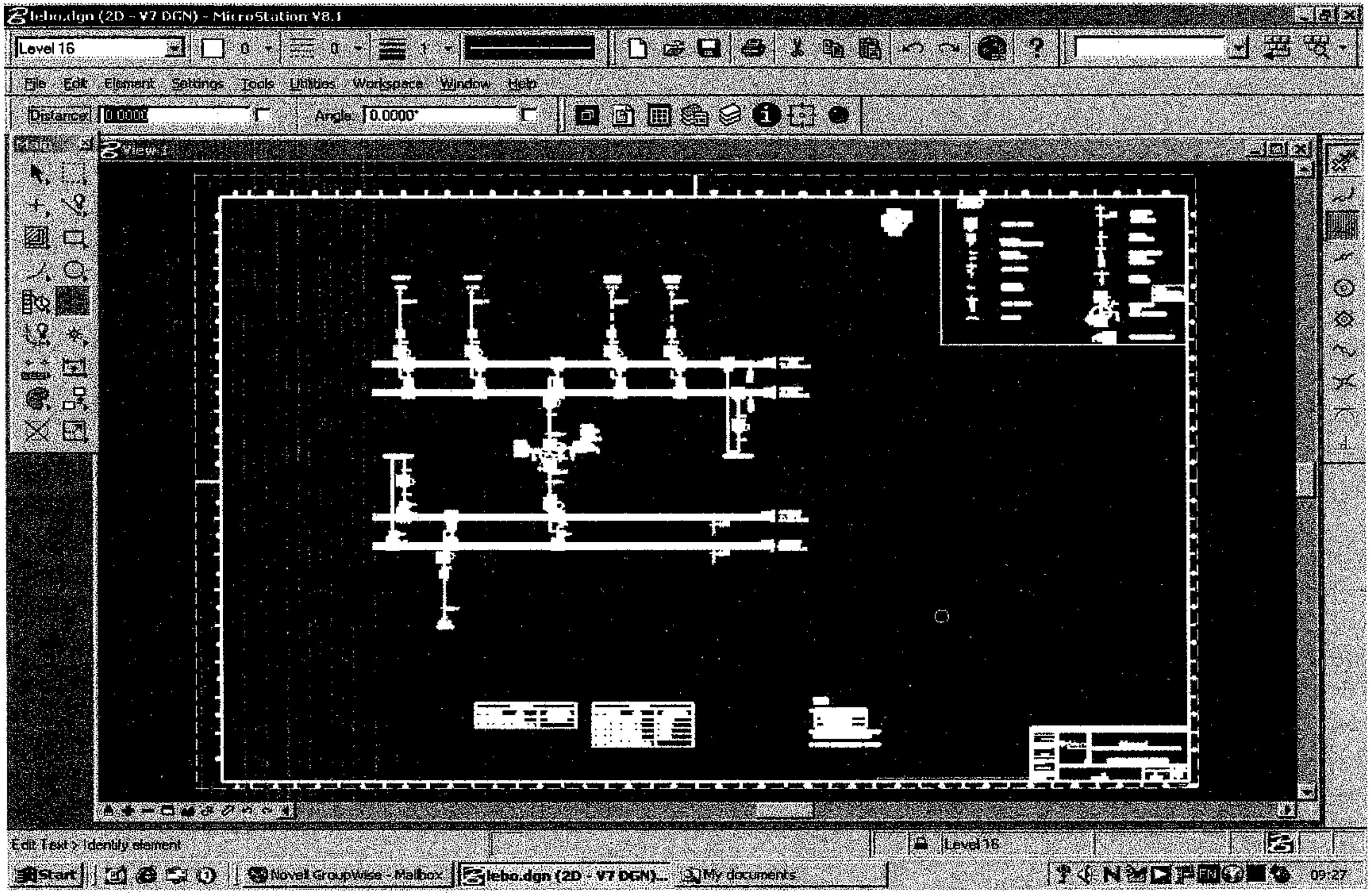
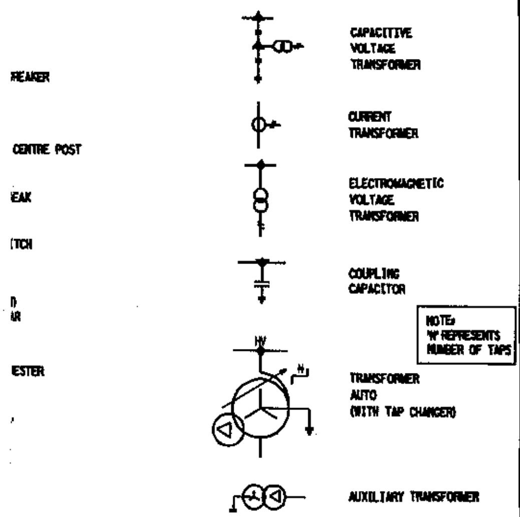


Figure 4.8: Transmission substation Tswane 400/33kV

2	3	4	19	20	21	22



A B C D E F G H J K L M N P Q R

Eskom Transmission

TSHWANE

STATION ELECTRIC DIAGRAM

4.3.2 Power Transfer Requirement

The power transferred through a substation is the net result for all incoming or outgoing power flows. Tswane substation has a power transfer rating of a 100MVA, thus the double busbar station gives it flexibility in linking to optimize power flow balance for any system condition and peak power flow period. Minimum current will hence flow through the bus-couplers minimizing the disruption, should these switches be tripped or busbar faults occur. It also optimizes the requirement to keep fault current levels on the busbars within the capabilities of the switch gear and other critical plant items.

4.3.3 Operational Flexibility

Operation flexibility is always required but not to an ever increasing extent as stations become larger the power volume transfer increases and the extent of the networks and customers / loads being impacted by its failure, increases.

Operation flexibility is required to provide for an optimal arrangement of incoming and outgoing circuits which allow for:

- The transfer of maximum power without overloading any circuit or busbar.
- Minimal disruption incase any of the incoming or outgoing circuits is lost.
- Maximum stability of the system for any loss or disruption.
- Optimized security for any contingencies under abnormal external conditions i.e. it should be possible to re-arrange the linking should the network conditions (externally) change from the normal situation.
- It should allow for rapid and safe access and safe working conditions for the purpose of maintenance (outages) and replacement of plant items.

The Tswane substation double busbar arrangement ensures that this level of flexibility is achieved. But it however adds complexity of protection and control system as well as operating procedure which is acceptable since its inherently reliable and totally flexible for maintaining and restoring power during maintenance and plant failure outages.

4.3.4 Substation Equipment

Dependability and reliability is a measure of the probability that the system would fail in one way or another and cause a disruption in supply within a network or to a customer, or whole area of customers. The probability of failure of a system is dependent on the probability of failure of any one or more critical elements of the system.

In order to manage the reliability of a system, one must manage the following:

- Sound selection of individual elements
- Sound engineering in the integration of all elements together
- Minimizing complexity
- Maximizing flexibility process
- Provision for redundancy

One has to strike a good balance between all these issues as some are conflicting. Redundancy and flexibility increase size and complicity, which increases maintenance and operating, reducing the margin for error and increases the probability of failure. These critical factors were kept in mind when station equipment was selected.

Equipment	Rating	Quantity	Cost (Rands)
Feeder bay			
Isolator (rotating center)	400kV	3	810 000
Circuit breaker	400kV	1	1 200 000
Current transformer	400kV	3	450 000
Surge arrester	400kV	3	138 000
	Total		**2 598 000**
Bus coupler			
Motorized switch gear	400kV	2	180 000
Isolator (center break)	400kV	2	540 000
Earth switch	400kV	12	294 000
Circuit breaker	400kV	1	1 200 000
Current transformer	400kV	6	900 000
	Total		**3 114 000**

Bus bar			
Conductor (triple bull)	400kV	1	285 000
Capacitive voltage transformer	400kV	3	279 000
	Total		**564 000**
Transformer bay			
Motorized switch gear	400kV	2	180 000
Isolator (center break)	400kV	2	540 000
Circuit breaker	400kV	1	1 200 000
Current transformer	400kV	3	450 000
Earth switch	400kV	3	294 000
Surge arrester	400kV	3	138 000
		Total	**2 802 000**
Transformers			
Transformer (YNa0d1)	400/33/22kV	1	5 000 000
Auxiliary transformer (Dyn11)	22kV/380V	1	75 000
		Total	**5 075 000**
Feeder bay			
Isolator (rotating center)	33kV	3	72 000
Circuit breaker	33kV	1	140 000
Current transformer	33kV	3	36 000
Surge arrester	33kV	3	12 000
			260 000
Buscoupler			
Isolator (center break)	33kV	2	48 000
Circuit breaker	33kV	1	140 000
Current transformer	33kV	6	72 000
		Total	**260 000**
Busbar			
Conductor (double bull)	33kV	1	98 000
Voltage transformer	33kV	3	**15 000**
		Total	**113 000**
Transformer bay			
Isolator (center break)	33kV	2	48 000
Circuit breaker	33kV	1	140 000
Current transformer	33kV	3	36 000
Surge arrester	33kV	3	12 000
Surge arrester	22kV	3	9 000
		Total	**245 000**

Tswane Substation			
Feeder bay	400kV	1	2 598 000
(2 future- 33kV)	33kV	2	520 000
Bus bar	400kv	2	1 128 000
	33kV	2	226 000
Transformer bay	400kV	1	2 802 000
	33kV	1	245 000
Transformer	400/33/22kV	1	5 000 000
	22kV/380V	1	75 000
Bus coupler	400kV	1	3 114 000
	33kV	1	260 000
		Total	**15 968 000**

Table 4.6: Cost estimation of all equipment required in the station excluding labour

4.3.4.1 Equipments Function

Figure 4.5 displays the layout of the Tswane 400/33kV transmission substation, it consist of a double busbar arrangement with bus coupler joining them, one transformer bay and 5 (2 future) feeder bays. The design follows a typical substation layout used by Eskom, shows the plant items and their positions.

For clarity a brief functionality discussion is given for each of the items:

4.3.4.2 Power Transformers

The purpose of a transformer is to step up and step down the voltage, 400kV is received from the incoming feeder and is stepped down to 33kV which is transmitted to different places. A 400/33/22kV power transformer and 22kV/380V auxiliary transformer is utilized in the project.

4.3.4.3 Circuit Breaker

Circuit breaker are required to control electrical power networks by switching circuits on, by carrying loads and by switching off (electrical isolation) under manual or automatic supervision. In short it's used to make and break a circuit under both normal and fault conditions thus they are used as protection against any electrical faults that may accidentally happen. Most very high voltage breaker operation is LOR (Local Off Remote), which means its can be operated locally from high voltage yard or remotely from a control room and national control. In the project air blast breakers are used on the HV side while oil breakers are used on the LV side.

4.3.4.4 Isolator

Is a device used for making and breaking a circuit when no load current or limited current flow, it can be motorized or operate manually. Their main purpose is to connect circuit breaker to a busbar or transmission line. No load condition means the breaker controlling that isolator must first be open. Double break pantographs and manual center break isolators are used in the project.

4.3.4.5 Earth Switch

An earth switch connects apparatus electrically to earth in such a manner to ensure immediate discharge of electrical energy to ground at all times. When equipment is isolated and tested dead (off) the earth switch is closed to safeguard the equipment. They can be fitted individual or form part of he isolator construction, they are found on equipment with a rated voltage of 132kV and higher.

4.3.4.6 Voltage and Capacitor Voltage Transformer

They step down voltage so we can measure the lower voltage by using measuring instruments, which serve as input data for protection schemes. Each cores of the transformers is dedicated to a particular protection scheme.

4.3.4.7 Busbar

The purpose of a busbar is to act as the main point of supply for the circuit breakers in the substation. The connection onto the busbar is done by means of isolators which accompany a circuit breaker.

4.3.4.8 Bus Coupler

These switches perform the basic function as switches fitted to lines, transformers etc. It allows for rapid, safe and selective disconnected and re-connection of sections of busbar within a multi-busbar station. Bus coupler switches form an integral part of bus protection schemes. The protection zones generally overlap across these switches and a fault will trip both zones. It is a contentious issue whether to provide additional detection system to determine which zone has faulted in order to trip only one zone.

4.4 Safety

Safety is paramount to all issues relating to the value of human life and well being, on the one hand, and the dependability and reliability of a station on the other hand. Any unsafe act is a threat to human, network and system performance and availability.

The following issues are relevant:

- Plant and system must inherently have the capability and capacity to be operated safely under normal and expected abnormal operation conditions and environment.
- Plant must have reliable and clear indications of whether it is energized, open, closed earthed, loaded, overloaded ect.
- Protection devices, where required, must be fitted and be operational.
- Unsafe access or contact must be avoided through controlled systems and procedure.
- Sufficient space, access routes, clearances etc. must be maintainable under all expected working conditions.
- Clear identification, sign and labels on all equipment.

Of all the facts mentioned above, we always remember that the safety of people is the main priority and then comes the conditions of our equipment.

4.5 Protection

Protection of a system or network usually ensures automatic disconnection (i.e. the opening of circuit breakers) for short circuits occurring in one or more of items of primary equipment, e.g. overhead lines or cables, transformers, generators, busbars and circuit breakers themselves

The object is to leave as many electricity consumers unaffected by power cuts as possible, i.e. maximum continuity of supply is maintained.

The three main tenets of the protection philosophy are:

a) To minimize risk/danger to life.

b) To maintain continuity of supply.

c) To minimize damage and repair costs

4.5.1 Protection Relay Attributes

Power systems are susceptible to a large of undesired events like lighting, animal encroachment, ice and wind storms, switching errors, and power surges. If any of these events occur, the power system can be damaged and customer service disrupted. It is the job of power system protective equipment to detect the onset of undesired events and take appropriate action. Appropriate action often includes the tripping of the circuit breakers, which isolates the trouble from the rest of the power system and minimizes damage. The purpose of protective relays is to minimize damage and isolate problems. An important point to remember is that protective relays do not prevent trouble, but instead they respond to trouble and minimize further damage, since they operate quickly, usually in a few milliseconds

In judging a relay performance we use the following attributes:

- Selectivity – It is the ability of the protective scheme to select that part of the system that is in trouble and disconnect the faulty part without disturbing the rest of the system. The best way to provide for selectivity is to divide the entire system in to several protective zones, when a fault occur in a specific zone only the circuit breaker in that zone with open leaving the rest of the system in tact.

- Availability - This is defined as the proportion of the total time that protection equipment installed will be able to perform its function dependably.

- Security - The security of a relay is its ability not to operate during faults outside its intended zone of protection and not to trip during normal power system conditions.

- Sensitivity - This is the ability of a relay to operate for low fault currents within its zone of protection. Sensitivity has the tendency to increase dependability, but to reduce security.

- Dependability - The dependability of a relay is its ability to operate for all fault conditions within its defined zone of protection. These relays although inactive for 99 % of the time must always be available and react correctly under fault conditions.

- Speed - This is the measure of the time taken for the correct identification of a fault condition and the tripping of the CB to clear the fault current as fast as possible without current chopping. For transmission, a fault clearance time of 100 ms or less is acceptable.

- Simplicity of the primary system enables simple protection to be used. Operation of simple primary and secondary equipment is more reliable and is more easily understood by operating staff.

4.5.2 Feeder Protection

Feeders are used to provide the interconnection between various substations. By means of the resultant transmission and distribution networks, the consumers are linked to the sources of generation. Feeder protection is required to swiftly isolate the feeder at both (all) ends in the event of an electrical fault such as a short circuit. This is required to reduce damage to primary plant and also to minimize the duration of the voltage depressions on the remaining healthy system.

Relays possess the ability to be set. Settings are the means by which a relay is 'set-up' to perform correctly for the specific system parameters and/or fault conditions relevant to the location within the network in which the relay is applied. The amount and type of settings to be applied depends on the kind of relay and its measuring principle.

There are a number of different types of feeder protection relays each based on a different measurement principle, these being:

- Distance (impedance)
- Directional comparison
- Circulating current
- Balanced voltage
- Phase comparison
- Current differential

Of these, the impedance measuring type is by far the most common type used by on the EHV (≥275kV) network. However, a relay employing the impedance measuring principle is not best suited for all applications, particularly for very short lines. In the future these applications will be realized using modern current differential relays together with impedance relays.

4.4.2 EHV Protection

On the EHV system (≥ 275kV) it is present standard practice to apply dual main protection schemes, i.e. protection schemes containing two totally independent protection systems of equal capability, but not necessarily of the same manufacture or measuring principle, operating in a one-out-of-two arrangement. It is also present practice to not only have dual primary protection relays (distance/impedance and current differential), but also to duplicate all other protection relaying functions, e.g. back-up protection (earth fault, over current, over voltage protection, breaker fail protection). These EHV schemes are designed to perform single and three pole tripping (for a fault on one phase only, only that phase is tripped; for a multi phase fault, all three phases are tripped).

4.5.3 HV Protection

On the HV system (≤132kV, ≥ 66kV) the common practice is to have only one main protection (primary relay) with the required back-up protection (Overcurrent and earth fault). A single breaker fail protection function may be included, but then only if busbar protection is installed at the substation. The main protection relays are mostly less sophisticated than those applied at EHV. The most common application requirement is for three pole tripping schemes only, so cheaper schemes are designed to provide this

4.5.4 Low HV Protection

On the lower voltage HV (≤66kV, ≥33kV) networks where the lines in general are very much shorter than on the EHV network, protection schemes based current differential relays. On the longer lines, distance relays are applied.

4.5.5 Busbar Protection.

Busbar protection is unit protection. Unit protection is defined as a protection system, which responds to fault conditions lying within a clearly defined zone. Busbar protection is required when the system doesn't cover the busbar or when high-speed fault clearance is necessary for system stability. The main requirement of busbar protection is stability, which implies that the protection should not operate for external faults or outside interference. It is necessary to divide the busbar into sections, by grouping the incoming and outgoing feeders together, by doing this we achieve a certain degree of discrimination, which means a fault on one busbar section will not result in a total loss of supply.

Busbar fault at many major power and distribution stations will have very serious repercussions for the system if busbar protection fails or is switched off, therefore it's essential to take precaution. The main requirement of busbar protection is stability, which implies that the protection should not operate for external faults; to achieve this the following requirement must be achieved:

- It must be completely reliable, since the protection may be called upon to operate once or twice in the life of the primary plant so failure to operate under fault condition would be unacceptable
- It must be absolutely stable under through fault condition since the failure to stabilize would cause unnecessary widespread interruption of supply.
- It must be capable of complete discrimination between sections of the busbar to ensure that minimum numbers of circuit breakers are tripped to isolate the fault.
- It must posses' high speed of operation to minimize damage and maintain system stability.

Busbar protection is not duplicated as is common for other types of protection and so when busbar protection is switched out backup protection must clear a busbar fault. The main protection for busbar protection is, busbar differential, Overcurrent, earth fault and breaker fail protection

4.5.6 Distance Protection

This form of protection is used for transmission lines and in its usual form is not actually unit protection per se. It should not be used for lines shorter than about 4 km. The relay measures the ratio of the faulted line voltage and the feeder fault current. It therefore measures the impedance of the line from the busbars to the point of fault. As such it is also known as "distance/impedance" protection.

The relay usually has three elements, whose impedance pick-up points are adjusted to be equal to about 80 % of the line (to the next station in this radial line), known as ZONE 1, to about 120 % (i.e. past the next station in this line), ZONE 2, and to about 150 % (also past the next station in this line), ZONE 3. These distances are known as the REACH of the relay. Since the impedance of a transmission line is proportional to its length, a distance protection relay is designed to measure line impedance.

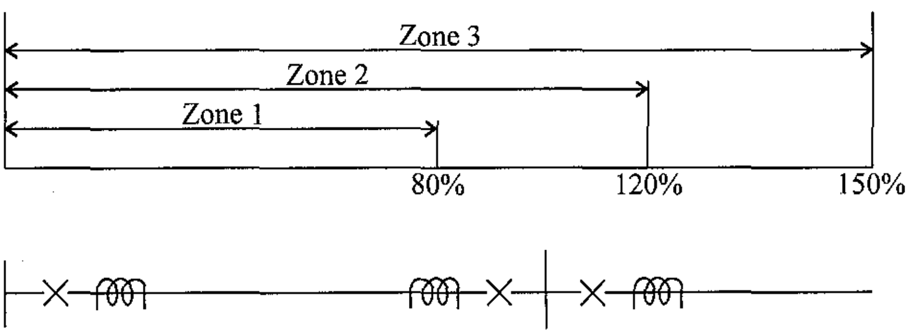


Figure4.9: How a line is divided in to zones.

Zone 1 is instantaneous and time delays are added to the other two zones, Zone 2—1 second and Zone 3 – 1,5 seconds.

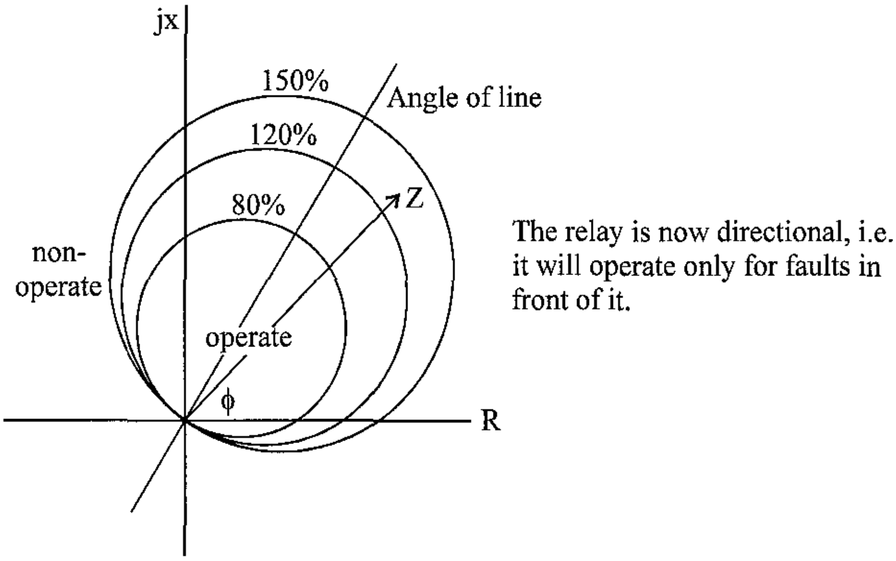


Figure4.10: Impedance/distance relay operation.

Since the line impedance in ohms / km is a constant (function of conductor type and size, and conductor spacing (configuration), the impedance measured to the point of fault is directly proportional to the distance along the line route.

Distance protection is essentially a non-unit system of protection providing both primary and back-up facilities within a single relay. It can easily be modified into a 'unit' system of protection by combining it with a signalling channel. In this form it is eminently suitable for the protection of important EHV transmission lines. At HV levels, distance protection schemes are often applied without the signalling channel.

4.4.7 Back-Up Protection

Back-up protection is essentially a non-unit protection able to detect and operate for faults well beyond the protected line. Such protection must therefore operate slower than the main protection affording only time delayed cover. The main purpose for providing back-up protection is to ensure that nothing prevents the clearance of a fault from the system. Back-up protection may be obtained automatically as an inherent feature of the main protection, or separately by means of additional equipment. Two categories of back-up protection exists termed local back-up and remote back-up.

The purpose of local back-up protection is to supplement the main protection in case the latter should fail to operate, or to deal with faults that fall outside the operating characteristic of the main protection, e.g. very high resistance earth faults. This protection therefore provides local time delayed cover for faults occurring on the protected line.

The purpose of remote back-up is to supplement the protection on adjacent circuit(s) by disconnecting the uncleared fault one section further back. The local protection scheme therefore provides time delayed cover for uncleared remote faults on the adjacent circuit(s).

4.5.8 Breaker Fail

Breaker fail protection is incorporated into the protection schemes to cater for the possibility that, although the protection has operated and closed the trip output contacts, the breaker fails to trip. This can be as a result of a mechanical problem with the breaker or an electrical problem such as an open circuit in the trip circuit, burnt out trip coil, etc.

The breaker fail relay is initiated by the protection relay at the same time as it issues the trip order to the breaker. The breaker fail relay determines whether the breaker has opened successfully either by monitoring the status of breaker auxiliary contacts or by measuring that the current has stopped flowing. The current detectors are specially designed to be fast resetting and are generally preferred to the auxiliary contacts as the performance of the latter can be unreliable. The resetting of the initiating signal is not used to monitor successful opening of the breaker as the reset times of protection relays can be inconsistent and may be relatively slow.

When initiated, the breaker fail relay starts an internal timer. This timer keeps running until the breaker is detected to have opened successfully. If this does not occur before the timer times out, the breaker is deemed to have failed. The breaker fail relay then issues a signal to the buszone protection to trip all breakers one breaker away, i.e. the breakers of all the equipment on the same zone as the faulty breaker, in order to remove the fault from the system. Breaker fail protection therefore provides the required back-up protection with the minimum of time delay, and confines the tripping operation to the one station, as compared with the alternative of tripping the remote ends of all the connected circuits if there were no breaker fail.

4.6 Reclosing

As the majority of faults (80-90%) on overhead lines are of a transient nature, automatic reclosing is employed. Such transient faults are cleared when the relevant circuit breakers are tripped and do not recur when the line is re-energized.

Automatic reclosing provides benefits for both the customer and the supply utility. When a faulted line is tripped, there is increased source impedance to the customer which can result in him experiencing a prolonged voltage dip at the terminals of his equipment. Auto reclosing therefore improves the customer's quality of supply by reducing the duration and magnitude of such voltage dips. Auto reclosing also improves the security of supply for customers with multiple infeeds, and increases the availability of supply for those with a single infeed by minimizing the duration of the disruptions. As far as the supply utility is concerned, auto reclosing enhances stability on the interconnected system by reducing without a significant delay the connecting impedance between the two sources back to the pre-fault value (the connecting impedance was increased when the line tripped).

As approximately 85-95% of all overhead line faults are single phase, significant benefits can be gained by employing single pole tripping and auto reclosing. The quality of the customer's voltage supply is further improved as the remaining two phases lessen the increase in his source impedance. The voltage supply to the customer is also maintained on all three phases due to the inevitable star-delta connected transformer between the source and the load. Single phase auto reclosing also further enhances system stability.

Synchronism is maintained as some synchronizing power can be transmitted across the two healthy phases

CHAPTER 5

CONCLUSION

5.1 Conclusion

The distribution system, one line diagram is modeled, it consist of one 33/22kV Thabang substation, 22/11kV Leratong substation and four mini-substations. From figure 4.5 and table 4.3 one can see how the loads are interconnected on the distribution system The system utilizes star to delta distribution transformers. A voltage profile is carried out using demand factor, load factor, diversity factor, utilization factor and power factor, so to be able to confirm that the system is operation with allowable limits.

The data gathered from the distribution system is used to design a transmission system that will deliver the required power. Tswane substation, see figure 4.1 is modeled as a station electric diagram with all the interconnected apparatus. A load study is conducted on the transmission network before and after inclusion of the designed network see figure 4.2,4.3 and table 4.1, this allows for a detailed analysis of how the transmission network impacts on the present system. The data gathered is the used as an input to the distribution system and it is simulated again to check for power flow and voltage profile see figure 4.7.

The load study identifies the real, imaginary and complex power flow in the system. All these qualities are check to see check that none of the apparatus are overloaded. The transmission load study was done with the intension of finding the losses of the system as a whole.

After a number of designs were simulated, one was selected, whereby when all analysis were conducted it operated within specified limits and its impact on the network was reasonable and as expected from the theoretical study see table 4.1.

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APPENDI X I

TRANSMISSION LOAD FLOW REPORT *(BEFORE)*

AT BUS 156 [JANUS4 400] AREA 1 (KV L-G) V+: / 0.000/ 0.00

THEV. R, X, X/R: POSITIVE 0.00335 0.01189 3.544

THREE PHASE FAULT

------- FROM -------	AREA	CKT	I/Z	/I+/	AN(I+)	/Z+/	AN(Z+)	APP X/R
150 [WITKP4 400]	5	1	AMP/OHM	3718.1	-132.34	22.55	85.32	12.204
155 [MERNS4 400]	1	1	AMP/OHM	4024.4	-121.65	18.43	85.32	12.216
157 [JANUS1 132]	1	1	AMP/OHM	232.6	-123.30	4.95	90.00	9999.999
157 [JANUS1 132]	1	2	AMP/OHM	232.6	-123.30	4.95	90.00	9999.999
195 [DUVHA4 400]	2	1	AMP/OHM	3468.7	-113.14	63.80	85.22	11.961
TOTAL FAULT CURRENT (AMPS)				11574.9	-122.59			

PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E THU, JAN 08 2004 14:40
TUTUKA ALPHA NETWORK EXPANSION RATING
YEAR 2003 BASE NETWORK SET A

BUS 156 JANUS4 400	AREA	CKT	MW	MVAR	MVA	%I	0.9907PU -48.35 156
1							396.26KV
TO 150 WITKP4 400	5	1	588.4	-28.1	589.0	48	
TO 155 MERNS4 400	1	1	-240.2	112.1	265.1	21	
TO 157 JANUS1 132	1	1	221.5	-58.0	229.0	46	0.9750RG
TO 157 JANUS1 132	1	2	221.5	-58.0	229.0	46	0.9750RG
TO 195 DUVHA4 400	2	1	-791.2	32.0	791.9	64	

PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E THU, JAN 08 2004 14:40
TUTUKA ALPHA NETWORK EXPANSION
YEAR 2003 BASE NETWORK

*********************** SUMMARY FOR COMPLETE SYSTEM ***********************

SYSTEM SWING BUS SUMMARY

BUS	X---NAME---X	X--- AREA ---X	X--- ZONE ---X	MW	MVAR	MVABASE
9705	MATLA_1 20.0	3 [HVLD_STH]	1 [ESKOM]	2961.3	885.9	666.0

NON-TRANSFORMER BRANCHES BETWEEN TWO VOLTAGE LEVELS:

1010 [VDKLF_G1]	TO	1196 [RDEKL2 220]	CKT 1
1163 [PERSS2 275]	TO	1373 [PERSS_D2]	CKT 1
1163 [PERSS2 275]	TO	1489 [PERSS_D1]	CKT 1
1163 [PERSS2 275]	TO	1544 [PERSS_D3]	CKT 1
1282 [POSDN2 220]	TO	1320 [POSDN_D1]	CKT 1
1282 [POSDN2 220]	TO	1321 [POSDN_D2]	CKT 1
1322 [AGGNS_D1]	TO	1760 [AGGNS2 220]	CKT 1
1323 [AGGNS_D2]	TO	1760 [AGGNS2 220]	CKT 1
1368 [OLIEN_D2]	TO	2935 [OLIEN1 132]	CKT 1
1376 [OLIEN_D1]	TO	2935 [OLIEN1 132]	CKT 1
1386 [GARIP_G1]	TO	3095 [RGTVL1 132]	CKT 1
1760 [AGGNS2 220]	TO	5900 [HARIB2B220.0]	CKT 2

2900 [MULDR1 132] TO 6002 [MULDR_D2] CKT 1
2900 [MULDR1 132] TO 6003 [MULDR_D3] CKT 1

939 BUSES 106 PLANTS 98 MACHINES 451 LOADS
1469 BRANCHES 520 TRANSFORMERS 0 DC LINES 0 FACTS DEVICES

	X------ ACTUAL ------X		X----- NOMINAL ------X	
	MW	MVAR	MW	MVAR
FROM GENERATION	37432.0	8931.6	37432.0	8931.6
TO CONSTANT POWER LOAD	36222.9	11738.7	36222.9	11738.7
TO CONSTANT CURRENT	0.0	0.0	0.0	0.0
TO CONSTANT ADMITTANCE	0.0	0.0	0.0	0.0
TO BUS SHUNT	0.0	-9004.9	0.0	-8503.0
TO FACTS DEVICE SHUNT	0.0	0.0	0.0	0.0
TO LINE SHUNT	0.0	2532.1	0.0	2547.0
FROM LINE CHARGING	0.0	16965.7	0.0	16571.7

VOLTAGE		X----- LOSSES -----X		X-- LINE SHUNTS --X		CHARGING
LEVEL	BRANCHES	MW	MVAR	MW	MVAR	MVAR
765.0	3	48.53	1229.46	0.0	1535.4	2632.8
400.0	235	720.35	12438.47	0.0	949.9	10933.0
275.0	208	267.92	3542.33	0.0	0.0	2230.4
220.0	31	20.15	124.11	0.0	46.8	324.6
132.0	614	118.38	2259.29	0.0	0.0	778.8
110.0	1	0.00	0.95	0.0	0.0	0.0
88.0	300	31.51	878.05	0.0	0.0	41.5
66.0	27	2.30	27.33	0.0	0.0	2.6
44.0	14	0.00	6.09	0.0	0.0	0.0
33.0	10	0.00	15.45	0.0	0.0	0.0
22.0	2	0.00	0.21	0.0	0.0	0.0
20.0	1	0.04	0.09	0.0	0.0	22.1
11.0	3	0.00	2.41	0.0	0.0	0.0
0.0	20	0.00	107.24	0.0	0.0	0.0
TOTAL	1469	1209.17	20631.48	0.0	2532.1	16965.7

TRANSMISSION LOAD FLOW REPORT *(AFTER)*

AT BUS 156 [JANUS4 400] AREA 1 (KV L-G) V+: / 0.000/ 0.00

THEV. R, X, X/R: POSITIVE 0.00347 0.01173 3.385

THREE PHASE FAULT

------- FROM ---------	AREA	CKT	I/Z	/I+/	AN(I+)	/Z+/	AN(Z+)	APP X/R
150 [WITKP4 400]	5	1	AMP/OHM	3719.7	-134.07	22.55	85.32	12.204
155 [MERNS4 400]	1	1	AMP/OHM	4015.5	-123.15	18.43	85.32	12.216
157 [JANUS1 132]	1	1	AMP/OHM	234.5	-124.90	4.95	90.00	9999.999
157 [JANUS1 132]	1	2	AMP/OHM	234.5	-124.90	4.95	90.00	9999.999
195 [DUVHA4 400]	2	1	AMP/OHM	3470.1	-114.52	63.80	85.22	11.961
9210 [TSHWANE 33.0]	1	1	AMP/OHM	0.0	0.00	0.00	0.00	0.000
TOTAL FAULT CURRENT (AMPS)				11569.1	-124.14			

. PSS/E SHORT CIRCUIT OUTPUT THU, JAN 08 2004 14:43 . HOME BUS IS: .

```
. TUTUKA ALPHA NETWORK EXPANSION                    .  9210  .
. YEAR 2003 BASE NETWORK                      .[TSHWANE 33.0].
.    *** FAULTED BUS IS : 9210 [TSHWANE 33.0] ***     . 0 LEVELS AWAY.

AT BUS 9210 [TSHWANE 33.0] AREA  1  (KV L-G) V+: / 0.000/  0.00

THEV. R, X, X/R: POSITIVE 0.00461 0.03258  7.067

                         THREE PHASE FAULT
------- FROM -------AREA CKT I/Z   /I+/   AN(I+)  /Z+/  AN(Z+) APP X/R
 156 [JANUS4  400]  1 1  AMP/OHM 54559.3 -133.57  28.88  90.00 9999.999
          TO SHUNT  (AMPS)    0.0   0.00
TOTAL  FAULT  CURRENT  (AMPS) 54559.3  -133.57

 PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E     THU, JAN 08 2004  14:44
TUTUKA ALPHA NETWORK EXPANSION                             RATING
YEAR 2003 BASE NETWORK                                    SET A

BUS  9210 TSHWANE 33.0 AREA CKT   MW     MVAR    MVA  %I 1.0260PU -51.62 9210
            1                                              33.859KV
 TO LOAD-PQ                         95.0   31.0       99.9
 TO  156 JANUS4  400           1 1  -95.0  -31.0      99.9  97 0.9500UN

   PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E     THU, JAN 08 2004  14:44
TUTUKA ALPHA NETWORK EXPANSION
YEAR 2003 BASE NETWORK

*********************** SUMMARY FOR COMPLETE SYSTEM ***********************

              SYSTEM SWING BUS SUMMARY
 BUS X---NAME---X X--- AREA ---X X--- ZONE ---X    MW      MVAR  MVABASE
 9705 MATLA_1 20.0  3 [HVLD_STH]  1 [ESKOM  ]  3068.1   960.8   666.0

NON-TRANSFORMER BRANCHES BETWEEN TWO VOLTAGE LEVELS:
 1010 [VDKLF_G1   ]   TO  1196 [RDEKL2  220] CKT 1
 1163 [PERSS2  275]   TO  1373 [PERSS_D2   ]  CKT 1
 1163 [PERSS2  275]   TO  1489 [PERSS_D1   ]  CKT 1
 1163 [PERSS2  275]   TO  1544 [PERSS_D3   ]  CKT 1
 1282 [POSDN2  220]   TO  1320 [POSDN_D1   ]  CKT 1
 1282 [POSDN2  220]   TO  1321 [POSDN_D2   ]  CKT 1
 1322 [AGGNS_D1   ]   TO  1760 [AGGNS2  220]  CKT 1
 1323 [AGGNS_D2   ]   TO  1760 [AGGNS2  220]  CKT 1
 1368 [OLIEN_D2   ]   TO  2935 [OLIEN1  132]  CKT 1
 1376 [OLIEN_D1   ]   TO  2935 [OLIEN1  132]  CKT 1
 1386 [GARIP_G1   ]   TO  3095 [RGTVL1  132]  CKT 1
 1760 [AGGNS2  220]   TO  5900 [HARIB2B220.0] CKT 2
 2900 [MULDR1  132]   TO  6002 [MULDR_D2   ]  CKT 1
 2900 [MULDR1  132]   TO  6003 [MULDR_D3   ]  CKT 1

 940 BUSES      106 PLANTS        98 MACHINES    452 LOADS
 1470 BRANCHES    521 TRANSFORMERS      0 DC LINES      0 FACTS DEVICES
```

	X------ ACTUAL ------X		X----- NOMINAL ------X	
	MW	MVAR	MW	MVAR
FROM GENERATION	37538.8	9324.2	37538.8	9324.2
TO CONSTANT POWER LOAD	36317.9	11769.7	36317.9	11769.7
TO CONSTANT CURRENT	0.0	0.0	0.0	0.0
TO CONSTANT ADMITTANCE	0.0	0.0	0.0	0.0
TO BUS SHUNT	0.0	-8961.7	0.0	-8503.0
TO FACTS DEVICE SHUNT	0.0	0.0	0.0	0.0
TO LINE SHUNT	0.0	2529.7	0.0	2547.0
FROM LINE CHARGING	0.0	16925.3	0.0	16571.7

VOLTAGE		X----- LOSSES -----X		X-- LINE SHUNTS --X		CHARGING
LEVEL	BRANCHES	MW	MVAR	MW	MVAR	MVAR
765.0	3	48.58	1230.80	0.0	1534.3	2631.0
400.0	235	727.28	12658.29	0.0	948.6	10907.2
275.0	208	271.37	3581.76	0.0	0.0	2220.3
220.0	31	20.16	124.18	0.0	46.7	324.4
132.0	614	119.49	2271.40	0.0	0.0	776.4
110.0	1	0.00	0.96	0.0	0.0	0.0
88.0	300	31.74	883.40	0.0	0.0	41.2
66.0	27	2.30	27.37	0.0	0.0	2.6
44.0	14	0.00	6.09	0.0	0.0	0.0
33.0	11	0.00	17.40	0.0	0.0	0.0
22.0	2	0.00	0.21	0.0	0.0	0.0
20.0	1	0.04	0.09	0.0	0.0	22.1
11.0	3	0.00	2.41	0.0	0.0	0.0
0.0	20	0.00	107.43	0.0	0.0	0.0
TOTAL	1470	1220.97	20911.79	0.0	2529.7	16925.3