**A strategy for the management of energy
losses in a local electricity distribution network**

by

Johannes Wilhelmus Fourie

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SUMMARY

This dissertation contains a strategy to minimize the non-technical electrical energy losses in an electrical distribution network. In order to develop the strategy, a model was constructed that simulates an electrical distribution network and includes different parameters that calculate the estimated technical losses in the electricity distribution network. The model was then used as the base to develop the strategy to minimize the electrical energy losses in an electrical distribution network.

Increasing energy costs and environmentalists actions to protect the natural resources, force energy supply companies to conserve and reduce energy usage. Therefore the research focused on the reduction of electrical energy losses in distribution networks. The loss occurrences are divided into two categories: technical and non-technical losses. Reducing these losses ensure that the cost of electricity to customers will be reduced and in turn improve the efficiency of the distribution network.

The model developed to calculate the non-technical losses in an electrical distribution network was tested at two different networks. Firstly at the University of Pretoria, where the network segment consisted of different network busses delivering electrical energy. Secondly results were obtained in a residential network of the Tshwane Metropolitan Council. In this network there was only one bus but various different time intervals were used to determine the time interval most suitable for determining the electrical energy losses in the electrical distribution network.

The model was used primarily to quantify the technical losses as a base point towards determining the non-technical losses. Using the model one is able to forecast the technical energy losses of a section in the electricity distribution network and this enabled one to develop a strategy to minimize the energy losses in the distribution network. The model will enable municipalities or electricity distribution companies to estimate electrical energy losses in their electrical supply networks and facilitate the development of strategies to reduce electrical energy losses.

KEYWORDS

Technical losses, non-technical losses, electrical distribution network.

OPSOMMING

Die verhandeling ontwikkel 'n strategie om die nie-tegniese elektriese verliese in 'n elektriese verspreidings netwerk te minimiseer. Om die strategie te ontwikkel was 'n model ontwikkel wat die elektriese verspreidings netwerk simuleer. Die model sluit ook veranderlikes in wat die tegniese verliese van die elektriese verspreidings netwerk bereken. Die model word verder gebruik as die basis waarop die strategie vir die minimiseering van die elektriese verliese gebaseer word.

Die toename in energie koste en omgewingsbewustes se aksies om die natuurlike hulpbronne te beskerm, forseer energie verskaffende maatskappy om die energie verbruik te spaar en te verminder. Daarom word navorsing toegespits op die vermindering van elektriese energie verliese in elektriese verspreidings netwerke. Die energie verliese kan in twee kategorieë verdeel word nl.: tegniese verliese en nie-tegniese verliese. Die vermindering van die verliese verseker dat die koste van elektrisiteit na verbruikers verminder word en verseker ook dat die effektiwiteit van die verspreidings netwerk verbeter.

Die model om die nie-tegniese verliese in 'n elektriese verspreidings netwerk te bereken was getoets in twee verskillende netwerke. Eerstens by die Universiteit van Pretoria, waar die netwerk segment bestaan het uit verskillende netwerk busse, wat elektrisiteit lewe. Tweedens was resulate verkry van residensiële netwerk van die Tshwane Metropolitaanse Raad wat slegs uit een bus bestaan het. Verskillende tyds intervalle was gemeet en daarvolgens was die mees geskikte tyds interval gekies om die elektriese energie verliese in 'n elektriese verspreidings netwerk te bepaal.

Die model was hoofsaaklik gebruik om die tegniese verliese te kwantifiseer en is as basis gebruik vir die bepaling van die nie-tegniese verliese. Deur die model te gebruik is dit moontlik om die tegniese verliese van 'n gedeelte van die elektriese verspreidings netwerk te voorspel en hiervolgens kan 'n stategie ontwikkel word om die energie verliese in die network te minimeer. Die model sal stadsrade of elektriese verspredings maatskappye in staat stel om energie verliese in betrokke elektriese verskaffings netwerke te kan voorspel en sal dit moontlik maak om 'n strategie te ontwikkel om energie verliese te verminder.

SLEUTELWOORDE

Tegniese verliese, nie-tegniese verliese, elektriese verspreidings network.

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CHAPTER 1: INTRODUCTION

1.1.   Problem statement

Increasing energy costs and environmentalists actions to protect the natural resources, force energy supply companies to conserve and reduce energy usage [1]. Many companies are also forced to research methods to reduce energy consumption during peak demand periods as a result of higher tariff that are applicable to energy consumed during peak demand periods. These tariffs differ by as much as five times standard tariff charge outside peak periods. Thus, an area that has therefore been receiving particular attention is the question of how to reduce energy losses that occur in electricity supply networks.

According to Davidson *et al.*[2], the electrical energy losses can be divided into two main groups:

Technical losses

- losses due to physical aspect, and

Non-technical losses

- unauthorized line tapping or metering bypassing, and
- inadequate or faulty meters and equipment.

Reducing the technical and non-technical losses will ensure that the cost of electricity to the supplier will be reduced, as less electricity will be used from the power generating company. The cost of the electricity to the customer will therefore also be less, as they will not have to pay for the losses in the electricity supply network. Both these reductions will have a positive influence on the cost of electricity.

According to Krishnaswamy [3] the following can be investigated to determine the technical losses in a network:

- the effect of circulating current because of the interconnection of electricity supply networks, the voltage regulation,
- the phase balance, and
- the power factor.

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Municipalities use Krishnaswamy's methods to determine the losses in the different sections of a distribution network. The approach is an unpractical method as it uses average losses over the entire distribution network to determine the technical losses.

The approach used in this dissertation identifies the different types of technical losses in a distribution network and associate the losses with a percentage of the different segments. Each section in the distribution network is then statistically evaluated to determine if the energy balance holds for that section of the network. This approach can identify a problem area should it exist within the network segment of the electrical distribution network. By identifying problem areas and resolving the problems electrical distribution companies can improve the energy distribution and save the electrical consumer revenue.

The focus of this dissertation is to develop a strategy that will minimize the non-technical electrical energy losses of an electricity distribution network. To be able to develop a strategy, a model that simulates the electricity supply network is constructed and includes different parameters to calculate the estimated technical losses of the electricity distribution network. This model is used as the base to develop a strategy to minimize the energy losses of the electricity distribution network. The strategy was evaluated in a section of the Main Campus of the University of Pretoria's electricity distribution network. The strategy was also verified in a section of the Tshwane Metropolitan Council. Figure 1.1 shows an electricity distribution network and each box in the setup is a point of measurement.
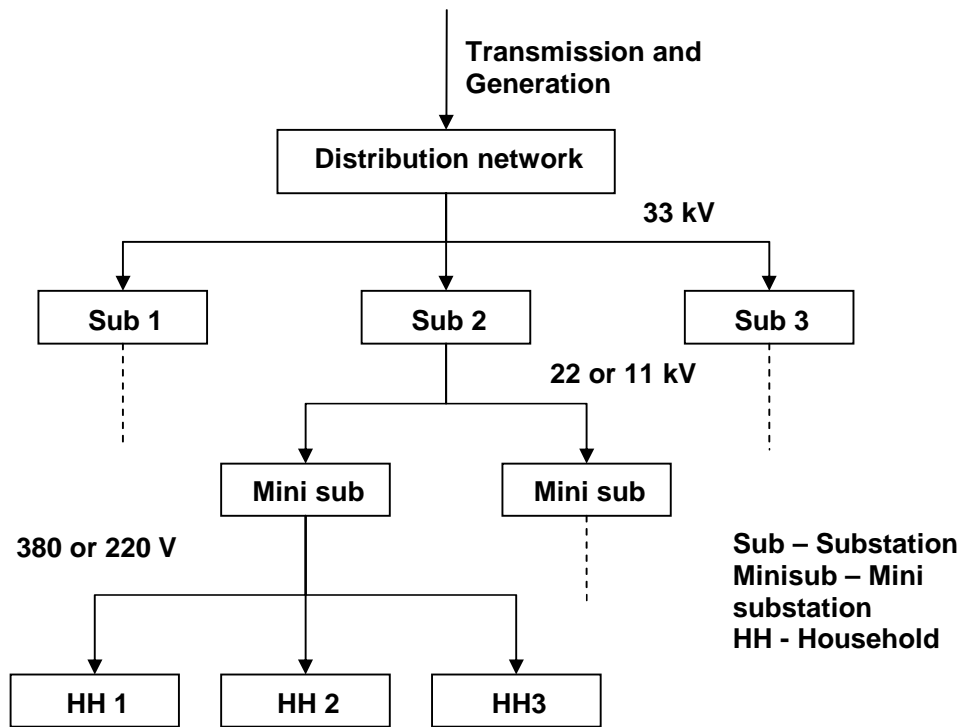
Figure 1.1: An electricity distribution network

1.2.   Main and Specific Objectives

This dissertation formulates a strategy to minimize energy losses in an electrical distribution network. The strategy focuses primarily on quantifying technical losses as a base point towards determining the non-technical losses. To determine the technical losses a model was constructed to quantify these losses and to calculate the non-technical losses in an electricity distribution network.

The model used enables one to forecast the electrical losses of a section in the electricity supply network. With the use of this model one is able to develop a strategy to minimize the electrical losses in an electricity distribution network.

The main objective of this dissertation is to develop a strategy to minimize energy losses in an electrical distribution network. To achieve the main objective the following specific objectives were determined:

- construction of a model to determine the technical losses,

- determine a method to calculate the non-technical losses,

- determine a procedure to identify the problem areas, and

- construct a matrix to prioritize the problem areas.

1.3.   Contributions of this study

This dissertation contributes in developing a strategy to minimize electricity losses in an electricity distribution network. Quantifying the magnitude of technical and non-technical losses determines the total electrical energy lost in the electricity distribution network. According to Chen *et. al.*[4] the technical losses are specific and can therefore be calculated. He also points out that minimization of technical losses are minimal in comparison to the non-technical losses. This dissertation will therefore endeavor to minimize the non-technical losses and the benefits obtained are:

- a reduction in electrical energy generation and system capacity, and

- a reduction in the cost of electrical energy to the consumer.

1.4.   Overview of dissertation

This dissertation constructs a model to forecast the electrical energy losses in an electricity distribution network. The model incorporates the factors and parameters that contribute to the electricity losses in a section of the electricity distribution network. It is able to quantify the technical and non-technical losses in the electricity distribution network and the model was used to develop a strategy to minimize energy losses in the network. This enables electricity distribution companies in South Africa to estimate electricity losses in their electricity distribution networks.

In chapter 2 an overview is giving to show the different mathematical equations that can be used to determine the electrical energy losses in the distribution network. This chapter also explains the relative work already done in the determination of the electrical energy losses in an electrical distribution network. In chapter 3 the development of the model was explained in detail with the derivation of the strategy of the minimization of the electrical energy losses in the distribution network. Chapter 4 discusses the case studies and the

results of the case studies that have been done. The first part of the chapter discusses the results obtain using different busses in the distribution network and the second part discusses the results of different time interval and the effect that the periods have on the results. In Chapter 5 a conclusion of the work was drawn as well as recommendations for future work.

CHAPTER 2: OVERVIEW OF LITERATURE

2.1   Efficient electricity use

Efficient use of electrical energy includes all the technical and economical (non-technical) measures aimed at reducing the electrical energy demand of an electricity distribution network. Although implementation of an electrical energy management strategy may require an initial investment, short-term financial returns can be achieved through lower cost due to the reduced electrical energy demand. In this dissertation the focus is to develop a strategy to reduce electrical losses in an electricity distribution network, which have a high electrical energy demand and thus a high potential for energy savings.

Electrical energy usage is vital to economic development in developing countries and poverty will not be reduced without greater use of electricity [5]. Assuming that the energy demand grows by 2.6 % per year, the total energy consumption by the year 2050 would double that of the level of consumption in 1998 [5]. The challenge is to break the link between economic growth and electric energy consumption by pursuing efficient production processes and reducing waste. At the same time, the link between electric energy consumption and pollution will be broken and the economy will rely more on renewables and therefore using fossil fuels more efficiently.

Electricity power industries in developing countries according to World Bank lose more than 20% of their generated electricity to theft or inefficiencies. One way to stop these losses is to encourage private-sector participation in trying to stop the theft. However, many projects aimed at stopping theft and cutting electricity losses have not achieved their goal. Therefore a huge scope exists to reduce electrical energy losses in developing countries that use district distribution systems. The World Bank has assisted in reducing the electrical energy losses and has reduced losses remarkably: 15-20 % of the input electrical energy has been saved by implementing private-sector participation. In South Africa the government uses demand side management initiatives to reduce electrical energy. The private-sector company is been rewarded for their participation in an electrical savings bonus or a penalty if no energy is been saved over a period of time.

The electrical usage in the residential sector is inefficient according to the World Bank and electrical energy savings can be increased either by using energy-saving lighting or more importantly the electrical consumption for residential users could be investigated and the demand side management strategic planning done to reduce electrical energy losses in this sector. In the next section the electricity demands for the distribution networks in South Africa is discussed as well as the impact that electricity generation has on the environment.

2.1.1.   Household sector electricity use

According to Lane *et al.* [6], residential households electricity demand contribute to 20% of the national peak electricity demand and is the largest customer base sector in an electrical energy distribution network. The contribution in electrical energy consumptions in South Africa is therefore expected to rise to 37% by the year 2015 if customer growth and electricity demand increases steadily. Thus, the increase in electrical energy demand forces electrical supply companies to either cut down on electrical energy losses or to generate more energy that will have a negative impact on the environment.

2.2.2.   Impact of electricity usage on the environment

Electricity generation accounts for a huge portion of unwanted emissions into the atmosphere [6]. The greenhouse gases that are typically produced by power stations are carbon monoxide (CO), methane (CH_4), nitrogen oxides (NO_X), nitrous oxide (N_2O) and carbon dioxide (CO_2). Making use of effective energy management is a cost effective alternative to decreasing pollution in the electrical energy industry [6]. Studies show that power stations in South Africa produce 92,73 kg of greenhouse gasses per GJ (Giga Joule) of electric energy [8]. According to Davidson *et al.* [2], Eskom have 10 800 GWh (Gigawatt hour) of electrical energy losses in a typical month. The impact of the energy losses on the environment is indicated in Table 2-1. From Table 2-1 it is evident that losses in an electricity distribution network have an enormous impact on the environment. To reduce electrical distribution network losses will therefore amount to significant financial and natural resource savings.

Table 2-1.: Environmental impact of electrical energy losses [2]

Environmental measure	Typical impact	Impact due to losses
Water use	1.25 kL/MWh	13500 ML
Ash emission	0.37 kg/MWh	4 ktonne
Coal use	480 kg/MWh	5.18 Mtonne
CO2 output	900 kg/MWh	9.72 Mtonne
SOX output	7.4 kg/MWh	80 ktonne
NOX output	3.7 kg/MWh	40 ktone

To reduce the effect that electrical energy generation has on the environment, the energy must be efficiently managed. Two major factors that contribute to the loss in electrical energy are non-technical losses and technical losses.

2.2. Non-technical losses

An ideal electrical energy distribution network will generate electrical power X and distribute the electrical power to the network equal to X. Due to losses in the transmission and distribution sections of the electrical energy network less than X electrical energy is distributed to the network. This loss in electrical energy is the system losses of the electrical distribution network. It is given by:

$$\sum P_{Generated} = \sum P_{Distributed} + \sum P_{System\,losses} \qquad (2\text{-}1)$$

The system losses of an electrical distribution network can be divided into two main groups the technical losses and the non-technical losses. Non-technical losses are dominant in the lower sections of the electricity distribution network and are losses due to:

- unauthorized line tappings
- meter tampering
- damage to cables and other electrical equipment, and
- inaccurate estimations of non metered or measured supplies (public lighting, municipal facilities, park facilities, incorrect CT or VT ratios, faulty meters).

A reduction in non-technical losses will have a direct economic benefit in reducing electricity prices paid by the customer and it will increase the revenue of electrical

distribution supply companies as the electrical energy losses decrease and more electrical energy could be sold to the customer. The non-technical losses are almost impossible to calculate from first principles as these losses are depended on human intervention on the electrical energy distribution network. Therefore to calculate the non-technical losses an indirect approach is needed. The indirect approach to calculate the non-technical losses of an electrical distribution network is given by Davidson *et. al.* [2]

$$P_{Non-technical} = \sum P_{Generated} - \left(\sum P_{Distributed} + \sum P_{Technical\ losses} \right) \quad (2\text{-}2)$$

The non-technical and technical losses of the distribution network is interconnected and calculated as the total losses of the electrical distribution network. Therefore it is necessary to derive calculated estimated values for either the technical or non-technical losses in the network. As mentioned the non-technical losses are impossible to calculate, thus the technical losses must be derived and quantified for an electrical distribution network [2]. The next section will discuss the different types of technical losses and methods used to calculate technical losses in an electrical energy distribution network.

2.3. Technical losses

Technical losses according to Davidson *et al.* [2] are due to the current flowing in a conductor generating heat and affecting resistance, causing electricity loss. In all conductors at least one of the following losses occurs:

- copper losses
- dielectric losses, and
- induction/radiation losses.

These conductor losses are also called technical losses, thus it includes line losses in the distribution network and the conduction losses of transformers. The main factors impacting technical losses according to Neetling *et al.* [8] are:

- substations,
- circuits,

- voltage levels,

- type of circuits (air, underground, mixed, ie. location of cattle),

- type of load (residential, commercial, industrial, mixed),

- transformation points,

- installed capacity,

- predicted demand, and

- length of the circuits.

Technical losses represent 6-8 % of the cost of generated electricity and 25% of the cost to deliver the electricity to the customer [2]. A reduction in technical losses will originate two important savings:

- a decrease in energy required to be generated, and

- a decrease in the maximum demand.

The next section will focus on the three types of conductor losses mentioned above namely copper losses, dielectric losses and induction/radiation losses.

2.3.1. Types of technical (conductor) losses

Atmospheric temperature is the most important parameter influencing the fluctuation in conductor losses. Therefore, a heat balance equation is considered to calculate conductor losses of an electrical distribution network. The heat balancing equation states that the heat absorbed by the conductor is equal to the heat emitted by the conductor. Heat absorbed by the conductor is due to the resistance of current flowing in the conductor at a specific temperature and the heating of the sun on the conductor. The heat emitted by the conductor is due to induction and radiation. An equation of the heat balancing equation is given as: [10]

$$Heat\ absorbed = Heat\ emitted$$
$$I^2R + P_{Sun} = P_{Radiation} + P_{Induction}$$

(2-3)

2.3.1.1 Copper losses

Copper conductor windings are used in electricity distribution networks due to its high conductivity. The high ductility of the copper makes it effortless to bend the conductors into tight bends around the magnetic core and thus minimize the amount of copper volume needed for the windings. At high current densities losses are significant and equal to I^2R. I^2R losses are influenced by temperature as follows: [11]

$$I^2 R_t = I^2 R_{20}\left(1 + a\left(t - 20°C\right)\right) \quad W/m \qquad (2\text{-}4)$$

Where α is the temperature coefficient (typically 0.004 /m˚C), R_{20} is the resistance (Ω) of the conductor at 20°C, I in amps (A) and t is the temperature in ˚C of the conductor. These losses are inherent in all conductors because of the finite resistance of the conductors.

Transformer losses in the electricity distribution network are also considered as copper losses due to the internal impedance of the transformer coils and the core losses. Transformers connected in the energy distribution network are connected permanently to the power supply system; therefore the no-load losses of the transformers must be taken into consideration.

No-load losses according to Sen [12] depend on the maximum value of flux in the core. The flux or eddy current loss of a transformer is

$$P_e = K_e B^2_{\text{max}} f^2 \qquad (2\text{-}5)$$

where P_e is the eddy current loss in the transformer, K_e is a constant value depending on the type of material and the lamination thickness in mm, B is the flux density (T) and f is the frequency (Hz) of the transformer.

2.3.1.2. Dielectric losses

Dielectric absorption is remnant polarization trapped on dielectric interfaces [13]. Dielectric absorption cause significant losses in an electricity distribution network due to

the heating of the conductors. This heating is primarily due to the sun heating the earth and is calculated as follow:

$$P_{Sun} = K_S \cdot S_i \cdot d \quad \text{W} \quad (2\text{-}6)$$

Where P_{sun} is the heating of the conductor due to the sun in Watt, K_S is the solar absorption coefficient (m), S_i is the solar radiation intensity (typically 1300 W/m^2), and d is the diameter of the conductor (m).

2.3.1.3. Induction and radiation losses

Induction and radiation losses are produced by the electromagnetic fields surrounding conductors. Induction losses occur when magnetic fields around a conductor link to another magnetic object and current is inducted to the object, thus the power is lost to the object [2]. In an electrical distribution network induction losses occur due to wind and are given as:

$$
\begin{aligned}
P_{Induction} &= 10.2 \cdot (V \cdot d)^{0.52} \cdot (T_c - T_a) \quad W/m \quad for\ windspeed > 0.14\,m/s \\
P_{Induction} &= 9 \cdot (d)^{0.75} \cdot (T_c - T_a)^{1.25} \quad W/m \quad for\ windspeed < 0.14\,m/s \qquad (2\text{-}7) \\
and\ V &= u \cdot d
\end{aligned}
$$

Where V is the effective wind velocity (m/s), d is the diameter of the conductor (m), Tc is the temperature of the conductor (typically 53.994 K), Ta is the ambient temperature (typically 330 K), u is the actual wind velocity (m/s), and d is the relative air pressure.

Radiation losses are the result of magnetic lines of force about a conductor that do not return when the cycle alternates. The lines of force project into space and are being absorbed by another object. Radiation losses are calculated using:

$$P_{Radiation} = K_R \cdot S \cdot p \cdot d \cdot \left(T_C{}^4 - T_a{}^4\right) \quad W/m \quad (2\text{-}8)$$

Where K_R is the radiation coefficient, S is the Stephan constant (5.71×10^{-9} W/m^2), d is the diameter of the conductor (m), T_c is the temperature of the conductor (typically 53.994 K), and T_a is the ambient temperature (typically 330 K).

2.3.2. Secondary factors influencing technical losses

Although copper losses, dielectric losses and induction and radiation losses are the major types of losses that occur in an electrical distribution network, secondary types of electrical energy losses also occur in the network. According to Davidson *et al* [2] these secondary losses occur due to circulating currents in the network, voltage regulation equipment, techniques and equipment used to balances the voltage phases of the network and equipment to correct the power factor of the network.

2.3.2.1. Circulating current

With highly interconnected electrical distribution networks striving to avoid failures of the network, circulating currents occur in the electrical distribution network and therefore increases the losses of the network. Maintaining constant voltage levels in the distribution network minimize circulating current losses.

2.3.2.2. Voltage regulation

Line losses in an electricity distribution network increases with the square of the load current when the resistance is constant. Thus by maintaining or decreasing the voltage across the load would reduce the line losses of the electrical distribution network [2].

2.3.2.3. Phase balancing

Phase balancing is of significance when the electrical distribution network becomes heavily overloaded. According to Krishnaswamy [3] in order to minimize the electrical power losses in an overloaded network, the phase load maximum deviation must be below 10 %.

2.3.2.4. Power factor

At unity power factor the current is minimum and any reactive component will cause an increase in current with a resultant increase in the real power loss of the electricity distribution network. For electricity distribution networks with large inductive loads, losses due to inductive energy (VArs) become significant.

The secondary factors influencing technical losses are relatively small compared to the losses in the conductors. Therefore the secondary losses are negligible and omitted in this dissertation. In the next section approaches to calculate technical losses will be discussed.

2.3.3. Approaches for loss calculation

The calculation of technical losses can be done using various approaches with different degrees of accuracy. For the management of technical losses a balance between absolute calculation accuracy and the effort must prevail. According to Nortje [14], acceptable approaches to calculate technical losses of an electricity distribution network can be divided into two groups. These are the full accuracy methods and methods of representative load profiles as discussed below.

2.3.3.1. Full accuracy method

According to Nortje [14], a full accuracy method can only be achieved with an electrical distribution network model and statistical metering instrumentation installed at each household receiving electricity. A comprehensive electrical distribution network model

includes the flow layout diagram of the electricity through the network, the different conductor lengths and the resistivity of each conductor. This method is therefore an impractical method to use for large electrical distribution networks as changes to the network would alter the parameters of the model and updating of the parameters could be neglected resulting in an error calculating the technical losses of the electrical distribution network. A further contributing factor to the impracticality of the method is the enormous number of measurements, data capturing and manipulation of costs that must be done. The full accuracy method although impractical for large networks, works well for smaller electricity distribution networks or in conjunction with other loss calculation methods.

2.3.3.2. Representative load profile method

As with the full accuracy method the representative load profile method also requires a representative electrical distribution network model for technical loss calculation. The technical loss calculation methodology also requires the monthly measurement of electrical household energy (kWh). From the representative electrical model and the electrical household energy measurement it is possible to use sampled electrical household energy data averages over a specific time interval to establish an average representative monthly electrical household load profile as illustrated in Figure 2.1.
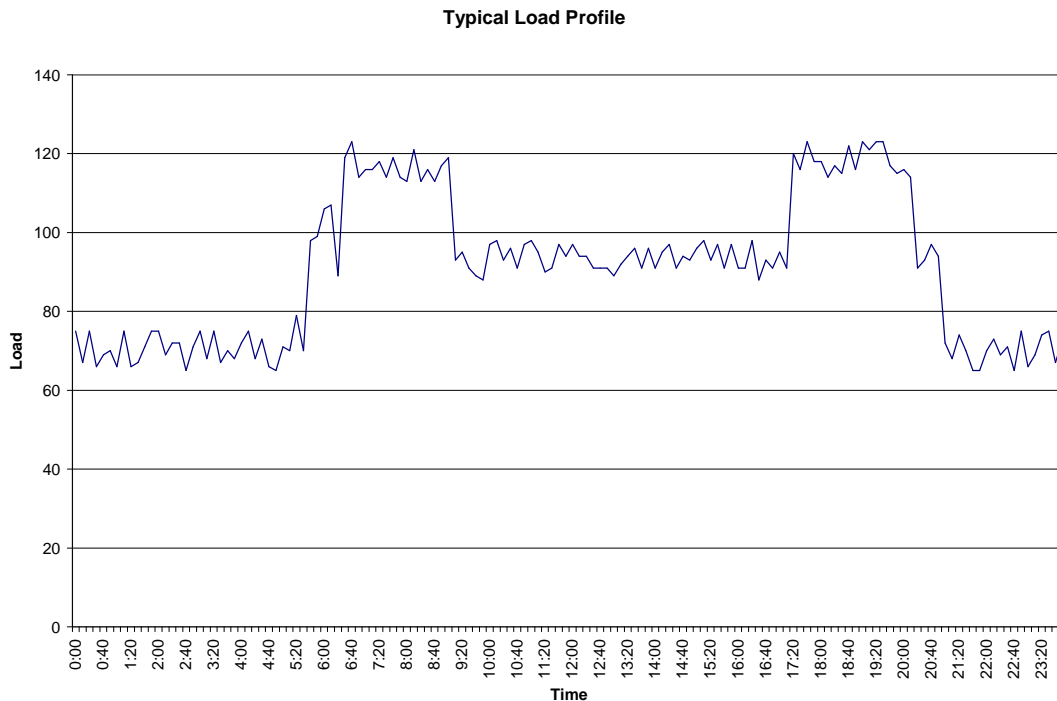
Figure 2.1: Typical residential load curve

Thus with the representative profile method an estimated diversity behavior could be determined empirically for any number of consumers, assuming that the diversity affects the load factor ie. constant loads and the diversity factor and the load factor relationship is linear to the diversity factor. The representative load profile method assumes the following: [15]

$$\sum \text{Energy Losses} = \sum \text{Incoming Energy} - \sum \text{Energy Sold} \qquad (2\text{-}9)$$

Equation 2-9 is commonly used in municipalities and load supply authorities in South Africa to estimate the electrical energy used by customers. This assumption calculates the electrical power losses by adding and subtracting power at specific times in the electricity distribution network. The advantages using this assumption in conjunction with the representative load profile method is that it is relatively easy to calculate the power differences and there are only two input parameters used (incoming power and power sold) to calculate the power differences. The disadvantage of this approach is that it depends on the correctness of the estimated load profiles at each segment in the electricity distribution network. An electricity distribution network consists of different segments that distribute

electricity to the customers. The different segments of the network will be discussed in the next section.

2.3.4.   Calculation of technical loss segments

The sectors of an electricity distribution network consist of two main groups, the primary feeders and the distribution feeders. The combination of the primary feeders and the distribution feeders of an electrical distribution network account for two thirds of the electrical energy losses in the network [16]. These results are based on physical measurements and a practical guideline for electricity distribution companies to determine technical losses in an electricity distribution network. The hierarchy of an electrical distribution network consists of a substation, primary lines, service transformers, secondary stations and electrical services. (Refer to Figure 1.1)

According to Oliveira *et al* [17] the electrical distribution hierarchy of an electrical distribution network could be subdivided into eight different segments, namely: energy meters, customer connections to the network, low voltage networks, distribution transformers, medium voltage networks, distribution substations, sub transmission systems and other technical losses as shown in Figure 2.2. Other technical losses include equipment losses in capacitors, voltage regulators, connectors and insulators. A theoretical method of evaluation of these different distribution segment losses is discussed below in terms of the load currents used by the different electricity distribution segments. In determining the load currents, representative load profiles were obtained that represents the daily usage of the electricity.

2.3.4.1. Energy meter losses

Technical losses in energy meters are due to iron losses in the voltage coils of the energy meters and may be assumed as constant in the electricity distribution network, since the energy meters do not depend on the current flowing in the electricity distribution network. According to Oliveira *et al* [17] losses in energy meters (e_m) in kWh can be obtain by:

$$e_m = \frac{p_m \cdot N_m \cdot (i_1 + 2i_2 + 3i_3) \cdot T}{1000} \text{(kWh/day)} \quad (2\text{-}10)$$

where p_m is the average demand losses of each voltage coil of the meter (W), N_m is the total number of energy meters, i_1 is the percentage of single-phase meters, i_2 is the percentage of double-phase meters, i_3 is the percentage of three-phase meters, and T is the time interval considered (hours).

2.3.4.2. Customer connection losses

The computation of losses in customer connections is based on the assumption that the length and electrical resistance of the conductor was previously defined [14]. The daily energy losses (e_r) are given by:

$$e_r = \frac{k \cdot R \cdot L \cdot \Delta t \cdot \sum_{i=1}^{N_t} I_i^2}{1000} \text{(kWh/day)} \quad (2\text{-}11)$$

where k is the number of conductors connected to the customers and current flow is under normal conditions (k = 2 for single and double phase and k = 3 for three phase), R is the conductor electrical resistance (Ω/km), L is the average lateral length (km), I_i is the electric current on the lateral for time interval t (A), Δt is the time interval duration (hour), and N_t is the number of daily intervals. Equation 2-11 is divided by a thousand to express the value in kilowatt instead of watt. In calculating the customer connections a constant current is assumed meaning that the current level does not vary with the supplied voltage. Thus the current can be evaluated as a function of the interval demand and the rated voltage.

2.3.4.3. Low voltage network losses

The representative load profile method, the corresponding currents for each measured interval t and the representative low voltage distribution network configuration could be used to evaluate the low voltage network technical losses in all the branches of the

network. The network branches as shown in Figure 2-2 represent a three-phase conductor and a ground conductor.
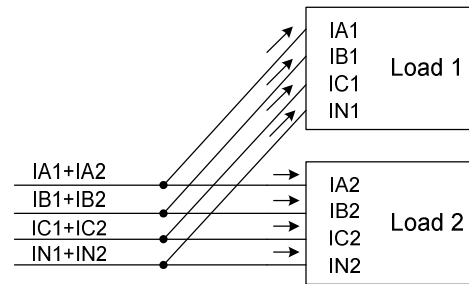
Figure 2.2: Network branches in a low voltage distribution network [17]

The branch currents results from Kirchhoff's current law applied to each network node to give the resultant sum of the currents are equal to zero. The daily energy losses for a given network branch (e_s) can be evaluated by:

$$e_s = \frac{1}{1000} \sum_{t=1}^{96} \left(\sum_{i=1}^{N_{cond}} \left(R_i \cdot I_{i,t}^2 \right) \right) \cdot \Delta t \ \text{kW/day} \quad (2\text{-}12)$$

Where R_i is the conductor electrical resistance (Ω/km), $I_{i,t}$ is the electric current i on the conductor time interval t (A), Δt is the time interval duration, and N_{cond} is the number of conductors (phases and ground) for each branch. Equation 2-12 is divided by a thousand to express the value in kilowatt [14]. The summation value of 96 is representative of 15 minute intervals for a day.

2.3.4.4. Distribution transformer losses

Electrical distribution network currents are determined for all branches of the network up to the transformer node. Therefore the currents for phase and ground conductors, for every interval t, at the distribution transformer result from the representative load profile applied to the low voltage network. Given the transformer rated data, daily electrical energy losses for a distribution transformer (e_t) are given by:

$$e_t = p_{fe} \cdot S_N \cdot 24 + p_{Cu} \cdot S_N \cdot \sum_{t=1}^{96} \left(\frac{S_t}{S_N} \right)^2 \cdot \Delta t \ \ \text{kVAh} \qquad (2\text{-}13)$$

Where S_N is the transformer rating (kVA), S_t is the transformer loading for time interval t (kVA), p_{fe} is the rated iron losses (per unit (pu)), p_{cu} is the copper losses (pu), and Δt is the interval duration (hours). The summation value of 96 is representative of 15 minute intervals for a day [14].

2.3.4.5. Medium voltage network losses

Computation of losses for a medium voltage electrical distribution network is analogous to the method used for the low voltage electrical distribution networks but the medium voltage network use different parameters. The medium voltage distribution network parameters used are the demand loads of the distribution transformers, the medium voltage customers demand and public lighting transformers [17].

2.3.4.6. Distribution substation losses

Representative feeder load curves are obtained as a result from the application of the representative load profile method applied to the medium voltage distribution networks. The aggregation of a load curve of a substation's outgoing feeders leads to the substation load curve. Given the rated data of the substation transformers, the corresponding daily losses of the distribution substation (e_t) can be determined by: [14]

$$e_t = p_{fe} \cdot S_N \cdot 24 + p_{Cu} \cdot S_N \cdot \sum_{t=1}^{96} \left(\frac{S_t}{S_N} \right)^2 \cdot \Delta t \ \ \text{kVAh/day} \qquad (2\text{-}14)$$

Where S_N is the transformer rating (kVA), S_t is the transformer loading for interval t (kVA), p_{fe} is the rated iron losses (pu), p_{cu} is the copper losses (pu), and Δt is the interval duration (hours). The summation value of 96 is representative of 15 minute intervals for a day [17].

2.3.4.7. Sub transmission network losses

Losses in the sub transmission network is estimated by the use of a percentage index, obtained by the application of the representative load profile method to a given segment of the electrical distribution network. These indexes are regularly recomputed as possible changes in the distribution network configurations may occur [17].

2.3.4.8. Energy balance for a distribution network

Applying the above loss calculation methods for each section of the electrical distribution network makes it possible to estimate the technical losses for each of the segments considered in the network [17]. These segment losses are used to determine a segment loss index (e_p) in kWh for a given electrical distribution network or segment of the distribution network and is defined as:

$$e_p(\%) = \frac{E_p}{E_{supplied}} \cdot 100 = \frac{E_p}{E_{following} + E_p} \cdot 100 \quad (2\text{-}15)$$

Where $E_{supplied}$ is the energy supplied to the distribution network segment (kWh), and $E_{following}$ is the energy supplied to the subsequent distribution network segment (kWh).

According to Grainger *et. al.* [16] an estimation for the overall energy flow in the electrical distribution network can be obtained from the computed loss indices per segment, the energy supplied (measured on the distribution nodes) and the billed energy. This is known as an energy balance equation and given as:

$$E_{total} = E_{con} + E_{p,tec} + E_{p,com} \quad (2\text{-}16)$$

Where E_{total} is the total energy supplied by the electrical distribution network, E_{con} is the total billed energy of the distribution network considering the low and medium voltage distribution network segments as well as the sub transmission customers, $E_{p,tec}$ is the technical losses for the distribution network obtain by adding the energy losses in all

segment of the network considered, and $E_{p,com}$ is the commercial or non-technical losses for the electricity distribution network.

A estimation for the non-technical losses $E_{p,com}$ and the corresponding percentage index is given by:

$$e_{p,com}(\%) = \frac{E_{p,com}}{E_{total}} \cdot 100 \qquad (2\text{-}17)$$

In the next section a strategic plan layout will be discussed in an effort to minimize the electrical losses of an electrical energy distribution network.

2.4. Strategic planning

Strategic planning is an organization form of project management that is designed to handle all types of projects ranging from small feasible studies to massive projects [18], [19]. The most important person involved in the strategic planning process is the project manager. The project manager's involvement in the project and the communication to executives and lower level personnel often make the difference between a well implemented strategy and one of catastrophe. This section will discuss important considerations to implement a strategy.

2.4.1. Planning the strategy

Planning a strategy is a function that should be performed by project managers. Project managers normally use a matrix structure in an effort to obtain the most effective and efficient utilization of resources while they attempt to achieve the objectives of the project within the constraints of time, performance and cost. For a project to be within constraints the goals and objectives of the strategic plan must be clearly identified, together with any limiting factors haltering the time, cost and performance of the project. Project managers prefer to work in concrete rather than abstract notation and therefore they must implement

the strategic plan they developed themselves. Project managers that plan a strategy should take the following into consideration:

- Environmental analysis
- Setting objectives
- List alternative strategies
- List possible threats and opportunities
- Prepare forecasts
- Select a strategy portfolio
- Prepare action programs
- Monitor and control the project

2.4.2.   Project manager reporting

Strategic planning managers should report high in the organization hierarchy and must have sufficient authority to obtain qualified resources. Often functional groups are nearsighted and assign their best resources to those projects that can be expected to yield immediate profits. This nearsightedness must at all time be avoided as the success of project management is based on the motivational behavior of the project manager seeing the project from birth to death. Seeing the result of such a project is probably the strongest motivational force in any form of project or management of a project.

Strategic management reporting is designed to force conflicts to be resolved at the lower levels of the project implementation thus freeing the project managers for more vital concerns. Although this philosophy is acceptable conflicts that arise during the strategic planning process should be made known to executives rather than trying to solve them at the lower levels of the project implementation. This should avoid catastrophe to the implementation and control of the project.

In strategic planning, project managers must realize that, more often than not, articulating the project strategy to lower level personnel may prove detrimental as this would take away the projects competitiveness from other companies regarding the same projects.

2.5. Summary of literature

The efficient use of electrical energy will slow the destruction of the environments natural resources and will also reduce the cost of electricity for the consumers. As discussed in the literature study the technical losses in an electricity distribution network can be calculated. Thus reduction in electricity generation will be due to non-technical losses and a strategy to limit the non-technical losses will be derived in the next chapter.

CHAPTER 3: DEVELOPMENT OF THE MODEL AND THE FORMULATION OF THE STRATEGY

3.1. Need for efficient use of electrical energy

The inefficiency of electrical energy usage is mainly due to losses in the low voltage segments of an electrical distribution network and is subdivided into technical and non-technical losses. Technical losses as explain can be calculated and used to estimate the total losses on the distribution network. Using the estimated technical loss value of a segment of the network and the value of the total electrical energy delivered to the segment of the distribution network, the non technical losses can be identified in the distribution network. The identification of the problems that cause the non technical losses creates opportunities for improving the efficiency of electrical energy used in an electrical distribution network. In this chapter the model constructed to calculate the technical losses and the process to identify the problems causing the non technical losses in the electrical energy distribution network will be discussed.

3.2. General description of the functions of the model

To determine the technical losses a model was constructed to quantify the technical losses in an electricity distribution network. The model forecasts the technical losses of a section in the electricity distribution network and it is used to calculate an estimated value of the electrical energy used by a section in the distribution network. The method used to calculate the technical losses of an electrical distribution network provides estimated energy loss values for each segment in the distribution network.

3.3. Value system

In the dissertation a model is constructed to forecast the electrical energy losses in an electricity distribution network. This model incorporates the factors and parameters that

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contribute to electrical energy losses in a section of the electricity distribution network. Using the factors and parameters it enables the model to quantify the technical losses in the electricity distribution network. This is used to calculate the non-technical losses in a section of the distribution network that enables distribution companies to estimate electricity losses and identify problem areas in their electricity distribution networks.

3.4. Functional analysis

```
                        ┌─────────────────┐
                        │ FU 1            │
                        │    Determine    │
                        │ technical losses│
                        └─────────────────┘

            ┌─────────────────┐
            │ FU 2            │
            │ Measured usage  │
            └─────────────────┘

┌───────────────┐   ┌───────────────┐   ┌───────────────┐
│ FU 5          │   │ FU 4          │   │ FU 3          │
│  Solve problem│ ← │    Identify   │ ← │   Difference  │
│    areas      │   │ problem areas │   │  equals non-  │
│               │   │               │   │ technical     │
│               │   │               │   │ losses        │
└───────────────┘   └───────────────┘   └───────────────┘
```
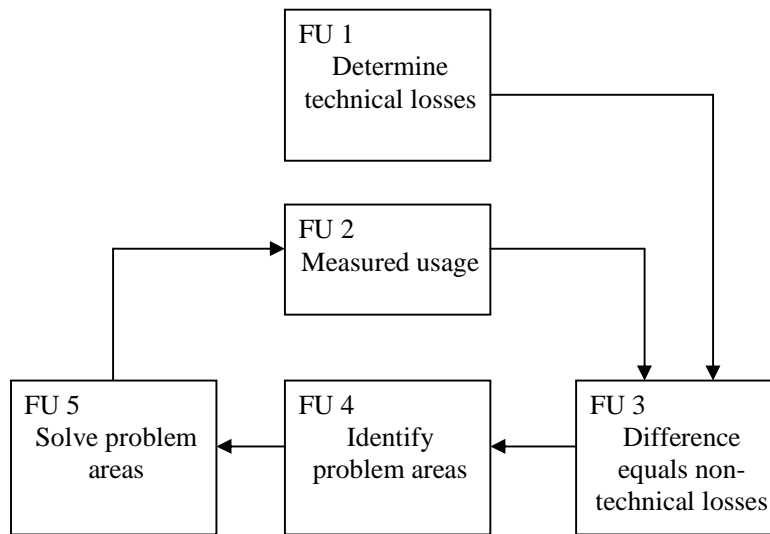
Figure 3-1: Functional diagram of the model

Figure 3-1 displays the functional diagram of the model. The functional units (FU) are explained as follows:

FU 1   -   Method that calculates the technical losses of a section in the electricity distribution network.

FU 2   -   Measuring data received from the meters implemented in a section of the electricity distribution network.

FU 3   -   Determine the total losses and the non-technical losses of the network.

FU 4   -   Identify the areas with the highest non-technical losses also referred to as problem areas.

FU 5   -   Solve the problem areas identified in FU 4.

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3.5. Development of the model

The model that will be used to develop a strategy to minimize the electrical energy losses in an electrical distribution network has five distinct steps. Firstly, the integral part of the model is the calculation of the technical losses in the distribution network. This is done using Microsoft Excel calculations and Visual Basic programming language to calculate each segments technical loss for the entire distribution network. Secondly, the technical losses in each segment are compared with the measured outgoing electrical energy of the distribution network segment. This correlation of the technical losses is used to draw conclusions on the correctness of the distribution of electrical energy in the distribution network. A flow diagram of the development of the different processes implemented to develop the model is shown in Figure 3-2.
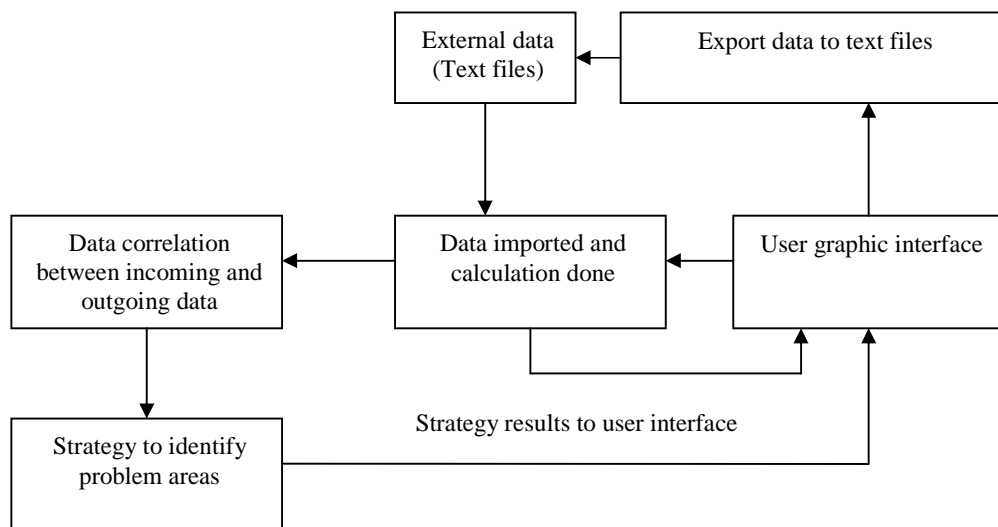
Figure 3.2: Flow diagram of calculation of technical losses connecting to the model to determine electrical energy losses.

The model uses electrical measured data from different segments of the distribution network as input to evaluate losses in the electrical distribution network. All the electrical data measured at different segments in the distribution network over a period of time (ie. daily, weekly, monthly) is exported to a tab delimited text file. This is done to standardize the format of the electrical data. These different exported text files are imported into a Microsoft Excel spreadsheet to calculate the total electrical energy used in the different segments of the distribution network and the segment losses of the distribution network is calculated. From the results obtained in the calculation of the technical losses a correlation

to identifying the problem areas in the distribution network could be determined between the incoming electrical power of a network segment and the outgoing electrical power of the segment. The next sections will discuss the methodology used to evaluate the different results for the model in determining a strategy for the minimization of non-technical losses in an electrical distribution network.

3.5.1.   Importing the text files

The electrical data imported needs to be specified by four parameters in order to identify the different network segments in the distribution network. The parameters are the name of the meter, the bus name the electrical energy is sent from, the bus name the electrical energy is sent to, and the type of network segment the electrical energy is sent from. It is not necessary to define a parameter for the type of network segment the electrical energy is sent to because the model assumes that all electrical energy is transported from an energy bus to another electrical energy bus. With this assumption the model could determine where the bus is sending the electrical energy. The model further assumes that if no electrical transformation occurs on the bus in the distribution network the connection of the network segment to another segment in the distribution network is equal to the customer connection percentage losses.

The meter names of the electrical distribution network are taken as a base point for importing the meter reading values into the spreadsheet. This meter reading values logged could be in any time interval as long as the various logged values of the meter readings are for the same specified time duration (eg. a month). Thus meter A could be half hourly measured for a month and meter B could be daily measured for a month. The model will use these electrical energy measurements and add each meters measured values for the specific time interval (a month) to evaluate the electrical distribution network segments. An example of the imported electrical data is shown in Table3-1.

Table 3-1 : Importation of electrical energy data (8 November 2003)

Time	pta1incomer	pta2incomer	pta3incomer	gwtrf1	gwtrf2	erika
01:00	354.0	378.0	348.0	32.0	32.0	28.0
02:00	360.0	384.0	348.0	32.0	32.0	32.0
03:00	360.0	384.0	342.0	32.0	32.0	28.0
04:00	360.0	378.0	348.0	32.0	31.2	32.0
05:00	354.0	378.0	342.0	32.0	32.8	28.0
06:00	360.0	384.0	348.0	32.8	32.8	36.0
07:00	354.0	378.0	342.0	31.2	31.2	32.0
08:00	354.0	378.0	342.0	32.8	32.8	32.0
09:00	354.0	378.0	342.0	32.0	32.0	32.0
10:00	360.0	384.0	348.0	36.8	36.8	36.0
11:00	360.0	378.0	342.0	43.2	44.0	40.0
12:00	348.0	378.0	336.0	40.0	40.8	32.0

The importation of the different network segments measurements are done automatically and the user of the software must be aware that the meter names, bus name from the network, the bus name to the network, and the network segment from the network will influence the electrical distribution network evaluation. Thus if these parameters are incorrectly defined or misspelled the evaluation of the distribution network will be incorrect.

3.5.2.   Technical loss calculation algorithms

Calculating the technical losses of an electrical distribution network is subdivided into eight different areas where problems could occur and they are:

- energy meters,
- customer connections to the network,
- low voltage networks,
- distribution transformers,
- medium voltage networks,
- distribution substations,
- sub transmission systems, and
- other technical losses.

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The identification of these different problem areas were discussed theoretically in the literature study and showed that it is almost impossible to determine all the different parameters of a distribution network. In this model a different approach than the theoretical calculation was used to be able to use a minimum of parameters but still be able to identify the problem areas in the electrical distribution network. The model uses a percentage estimation of the loss parameters defined for the different segments in the distribution network. This approach although not as accurate as the theoretical calculation, gives an indication of the electrical energy lost in the network segment and are used to determine the total technical losses of the electrical distribution network. The approach also makes the implementation of the model practically feasible.

The percentage calculations in the model define a minimum and maximum percentage parameter for the different network segments in the distribution network. These parameters are used to calculate the losses of each segment in the electrical distribution network as a percentage of the input electrical energy to the network segment. Small errors in the measurements of the meter readings are eliminated in the model as a typical value for the electrical energy lost in each segment is calculated. This typical energy loss value is the average value of the minimum and maximum electrical energy loss in each segment of the electrical distribution network.

There are eight different network problem areas in which electrical energy losses could occur in the distribution network and the model assumes that electrical energy flow from a bus onto a cable to another bus in the electrical distribution network. A bus is a point in the electrical distribution network where one or more electrical connections are connected together. These assumptions conclude that the electrical losses in the distribution network could be divided into two main groups. They are the losses on the cables and the losses on the bus of the distribution network. The losses occurring in the cables of the distribution network are:

- the sub transmission losses,
- the medium voltage network losses,
- the low voltage network losses,
- customer connection losses,
- energy meter losses,

- and other components.

The losses occurring on the bus of a distribution network are:

- the distribution substation losses,

- the distribution transformer losses,

- the customer connection,

- and other components losses.

Take note that customer connection losses and other components losses could occur in both the cables and the bus of the distribution network.

With the four input parameters obtained from importing the meter measurements as text files. An algorithm was used to determine the different busses of the distribution network. The algorithm is used for both the bus from which the electrical energy is flowing and for the bus to which the electrical energy is flowing. The algorithm's pseudo-code is given as:


```
valueadd = false
i = 0
Busname(i) is the names of the bus defined
Busvalue(i) is the electrical energy value of the bus defined

For x = 0 To Number of meters
    testname = Get the test bus name
    testvalue = Get the value of the electrical energy

For j = 0 To i
   If testname = BusNames(j) Then
BusValue(j) = BusValue(j) + testvalue
   valueadd = True
   End If
 Next j


If valueadd = False Then
```

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```
   i = i + 1
  BusNames(i) = testvalue      ;Add a new busname
   BusValue(i, 1) = test      ;Add a new busvalue
Else
     valueadd = False          ;Reset the valueadd value
 End If
Next x
```

With this algorithm the different busses from and to a network segment are defined and the difference of each network segment is determined. This is used to estimate the technical losses of each network segment and to calculate the total technical losses of the distribution network.

The algorithm for the determination of the electrical distribution network losses uses the following steps to determine the losses:

- the loss calculation of the different network segments on the network,
- the calculation of the other losses on the network,
- the calculation of the energy meters on the distribution network,
- the calculation of the customer connection losses on the network segment, and
- the calculation of the transformer/bus losses of the distribution network.

A schematic diagram of the determination of the losses is shown in Figure 3-3.
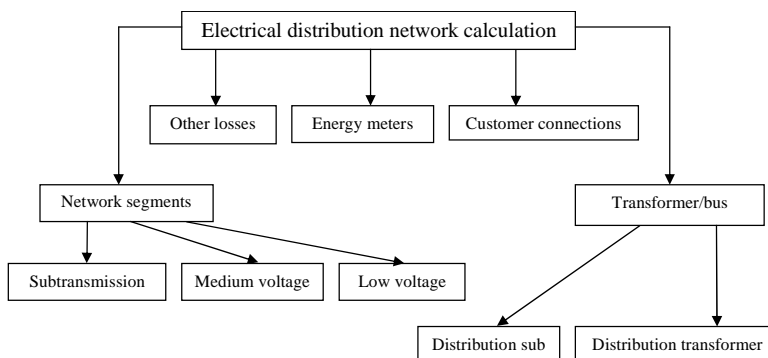
Figure 3-3 : Steps in determining network segment losses in a electrical distribution network

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3.5.2.1. Network segment loss calculation

As shown in figure 3-3 the calculation of the different network segments is divided into:

- sub transmission losses,
- medium voltage network losses, and
- low voltage network losses.

These different network losses are identified from the "type of network segment from" input parameter and the associated network segment loss is calculated as a percentage of the input electrical energy to the particular network segment.

3.5.2.2. Other network loss calculation

The other technical losses are calculated if the type of the network segment states other losses. This difference could be either due to capacitor banks installed in the network segment or due to voltage regulators with feedback systems implemented on the network. The parameter "other technical losses" enables the user to define any unfamiliar or unknown network design layouts.

3.5.2.3. Energy meter calculation

The calculation of losses occurring in energy meters is done assuming that all the energy losses of electrical energy meters are approximately the same percentage of electrical energy used by the network segment. This assumption can be used since the electrical energy meter losses in an electrical distribution network are small compared to all other losses influencing the electrical distribution network. The modeling of energy meter losses defines a meter name for each meter measuring in the distribution network and the energy meter loss calculation uses the sum of the specific defined meter measurements from the network to calculate a percentage energy meter loss for each meter.

3.5.2.4. Customer connection calculation

There are three possibilities in determining if a segment of the network is connected to the customer. The first is if the input parameter for the type of network segment is omitted the model assumes that the network segment is connected to a customer and the loss calculation is associated with the percentage of the "customer connections" parameter of the electrical energy in the segment. The second is if the parameter defining the network segment is omitted the model assumes that the network segment is connected to a customer and calculates the loss as a percentage of the input energy of the network segment. The third is if the bus defined by the model is omitted, the model assumes a customer connection and the loss in the network segment is calculated as a percentage of the input energy to the bus.

3.5.2.5. Transformer/bus loss calculation

Losses that occur on the bus of an electrical distribution network could be one of the following: [20]

- distribution transformer losses,
- distribution substation transformer losses, or
- customer connection losses.

The different losses on the bus are determined using the "input" parameter of the bus to which the electrical energy is flowing. If these electrical energy parameters for the "bus to" and the "bus from" differ there is a electrical transformation in electrical energy on the network bus. However, if the "bus name to" and the "bus name from" stays the same there is no transformation on the network bus and the model assumes the losses on the bus of the distribution network is the same as the assumption used for a customer connection loss on the network. There are two different possibilities if the network parameters differ. Firstly the energy could flow from the transmission network systems to the medium voltage network of the distribution network and these losses are the distribution sub station losses and calculated as a percentage of the electrical energy input at the bus. The second possibility is the medium voltage network that distributes the energy to a low voltage

network in the distribution network. These losses in the conversion of the network is known as the "distribution transformer losses" [20] parameter and calculated as a percentage of the input energy of the network on the bus.

3.5.3. Correlation of segments

The correlation of values according to the oxford dictionary means the interdependence of value quantities. In the model the actual measured electrical energy of the different network segments is related to the estimated electrical energy of the different network segments. As discussed previously the estimated electrical energy losses could be determined and from these different calculated electrical energy loss values, typical values are derived for each of the different segments in the distribution network. As mentioned previously these typical values are derived due to the fact that the measurements of the electrical energy in the network may be inaccurate in the model. The model therefore uses a maximum and minimum tolerance value for this typical network estimation values in an effort to minimize the effect of small variances in the meter measurements. These minimum and maximum values are also used to calculate the minimum and maximum values for the measured values of the different segments of the network. These maximum and minimum values will not influence the calculation of the determination of the non-technical losses because the same minimum and maximum percentages are used to calculate both the estimated and measured values of the network and the values are a relationship that will increase and decreases as the percentage values increase or decrease.

All the different losses in the network are calculated in the model and for each value a minimum and maximum values is calculated as a percentage of the specific network loss. From these calculations the total estimated electrical energy usage for the different busses are projected. The percentage difference of the projected electrical energy usage of the different busses and the total measured electrical usage for the busses are calculated with the projected electrical usage for the busses used as the reference point for each bus.

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3.5.4.   Statistical calculation of the segments

The model uses the following statistical calculations to identify potential problems in the electrical distribution network:

- the determination of a p value using a two-tailed paired-t test for each bus on the distribution network,
- calculate the f test value of each of the distribution network busses,
- the standard deviation of each of the busses on the distribution network, and
- calculating the confidence intervals electrical power of the distribution network bus.

3.5.4.1. P values

To understand P values, one needs to understand fixed level testing [21]. With fixed level testing, a null hypothesis is proposed along with a level for the test, usually 0.05. All possible outcomes of the experiment are listed in order to identify extreme outcomes that would occur less than 5% of the time in aggregate if the null hypothesis were true. This set of values is known as the critical region because if any of the values are observed, something extreme has occurred. Data is collected and if any one of those extreme outcomes occurs the results are said to be significant at the 0.05 level. The null hypothesis is rejected at the 0.05 level of significance. This procedure is known as fixed level testing because the level of the test is fixed prior to data collection. The procedure begins by specifying the hypothesis to be tested and the test statistic to be used along with a set of outcomes that will cause the hypothesis to be rejected. Only then is data collected to see whether they lead to rejection of the null hypothesis.

Many researchers realized the limitations of reporting on research results when the results achieve the 0.05 level of significance. The question of whether a result was just barely significant or wildly so remains unanswered? Would data that was significant at the 0.05 level be significant at the 0.01 level? Even if the results are wildly statistically significant, is the effect large enough to be of any practical importance?

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It therefore became common practice to report the observed significance level (or P value), the smallest fixed level at which the null hypothesis can be rejected. If your personal fixed level is greater than or equal to the P value, you would reject the null hypothesis. If your personal fixed level is less than the P value, you would fail to reject the null hypothesis. For example, if a P value is 0.027, the results are significant for all fixed levels greater than 0.027 (such as 0.05) and not significant for all fixed levels less than 0.027 (such as 0.01). A person who uses the 0.05 level would reject the null hypothesis while a person who uses the 0.01 level would fail to reject it.

A P value is often described as the probability of seeing results as more extreme as those actually observed if the null hypothesis were true. The P value is just another way to describe the results of fixed level tests. Every so often, a call is made for a ban on significance tests. The main reason behind these movements is that P values tell us nothing about the magnitudes of the effects that might lead to the rejection or failure to reject the null hypothesis. Significance tests blur the distinction between statistical significance and practical importance. It is possible for a difference of little practical importance to achieve a high degree of statistical significance. It is also possible for clinically important differences to be missed because an experiment lacks the power to detect them. However, significance tests provide a useful summary of the data and these concerns are easily remedied by supplementing significance tests with the appropriate confidence intervals for the effects of interest.

When hypotheses of equal population means are tested, determining whether P is less than 0.05 is just another way of examining a confidence interval for the mean difference to see whether it excludes 0. The hypothesis of equality will be rejected at level α if and only if a $100 (1 - \alpha)$ % confidence interval for the mean difference fails to contain 0. For example, the hypothesis of equality of population means will be rejected at the 0.05 level if and only if a 95% confidence interval for the mean difference does not contain 0. The hypothesis will be rejected at the 0.01 level if and only if a 99% confidence interval does not contain zero.

As useful as confidence intervals are, they are not a cure-all. They offer estimates of the effects they measure, but only in the context in which the data was collected. It would not

be surprising to see confidence intervals vary between studies much more than any one interval would suggest. This can be the result of the technician, measurement technique.

3.5.4.2. T-test

The two-sample paired t test is used to test the null hypothesis of the population mean [22]. Given two paired sets X_i and Y_i of n measured values, the paired t-test determines whether they differ from each other in a significant way under the assumptions that the paired differences are independent and identically normally distributed.

The criteria used to determine if a paired t-test can be used is that the number of points in each data set must be the same, and they must be organized in pairs, in which there is a definite relationship between each pair of data points .

The calculation of the p value returns the two-tailed p value of a paired-t test. The t test generates a standard score value for each bus value with respect to the minimum, typical and maximum value of each of the different busses on the network. It returns a p value for each bus on the distribution using the two-tailed probability for the normal distribution. This function is used to assess the likelihood that the actual measured electrical energy output for a specific bus and the estimated electrical energy for the same bus are derived from the same electrical energy input bus on the distribution network.

3.5.4.3. F test

An F-test is used to test if the standard deviations of two populations are equal [23]. This test can be a two-tailed test or a one-tailed test. The two-tailed version tests against the alternative that the standard deviations are not equal. The one-tailed version only tests in one direction, that is the standard deviation from the first population is either greater than or less than the second population standard deviation. The choice in this dissertation is the two-tailed test therefore it tests if the standard deviations are not equal.

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The f-test use two independent samples of size N_1 and N_2 to measure for the probability that they have the same variance. The estimators of the variance are s_1^2 and s_2^2 and the test statistic ratio $T = s_1^2 / s_2^2$, which follows an F Distribution.

More specifically, the p-value of a statistical significance test (f-test) represents the probability of obtaining values of the test statistic that are equal to or greater in magnitude than the observed test statistic. To calculate a p-value, sample data are collected from the different network segments and calculates the appropriate test statistic for the sample [24].

The f test statistical function used in the model returns the two-tailed probability that the variances in the actual measure electrical energy and the estimated electrical energy are not significantly different. This function is used to determine whether the measured and estimated electrical energy have significantly different variances.

The confidence interval in the model calculates the mean of the bus of both the measured and estimated electrical energy. It is used in the model to determine, with a particular level of confidence that could be altered in the model, the lowest and highest electrical energy level of use for a particular bus in the electrical distribution network. This level of confidence it compared to the actual measured value of the electrical energy used by the bus and the confidence interval should be an order or more lower than the actual measured electrical energy to be assumed operating correctly. If the value for the confidence interval and that of the actual measured values are in the same order the difference between the measured electrical energy and that of the estimated electrical energy are large, indicating a problem on the specific network bus. Statistical calculation of segments is used to determine if non-technical losses occur in a segment.

3.5.5.   Problem area identification

Determining the problem areas in the electrical distribution network is done using the different electrical losses of the electrical distribution network as explained in the previous sections, and comparing the projected and measured electrical power over a period of time. Each period of time losses are imported into a worksheet of a Microsoft Excel spreadsheet.

This information is needed to determine if there are problems in the network. The information needed to identify the problem areas are:

- the statistical calculated values of each of the busses in the distribution network as discussed in the previous section, and
- the bus name and the minimum, typical and maximum values of the:
  - network losses,
  - meter losses,
  - customer connections,
  - transformer losses,
  - the measured electrical energy delivered to the bus,
  - the sum of the total projected electrical energy losses,
  - the total projected electrical energy absorbed, and
  - the total measured electrical energy absorbed by the bus.

Using these parameters for the projected and measured electrical energy, two different worksheets were created. The one is for the projected electrical energy used by the different busses of the distribution network and the second is the measured electrical energy used by the network for a predetermined time (typically 12 months). These two worksheets are used to compare the monthly electrical energy usage of each bus with each other and to identify calculated electrical energy values not following the norm of electrical energy usage for the specific network segment.

A general mean for the different busses on the electrical distribution network is calculated for the predetermined time. These calculated values are used as reference electrical energy values for the different network segments in the distribution network. These values should be nearly the same as the values obtained for each time iteration (a month) in the distribution network busses since minor fluctuations in the meter measurements would be eliminated by previous calculations. If the values are not closely matched the model assumes that there are potential problems on the specific bus of the distribution network and visa versa. The model also calculates the p value of the paired t test, does an f test, and calculates the confidence interval and standard deviation of the distribution network based on the newly calculated mean values of the network.

3.6. Approach in developing the strategy to minimize electrical energy losses

Due to the rapid increase in the electrical energy demand, most of the development in electrical distribution networks has taken place over the last decade and aimed at producing larger electrical energy demand distribution networks. This has given rise to distribution network structures in which electricity is mainly transported to customers from large power stations by transmission systems and distributed to the customer by distribution networks. At the distribution level, development has produced combined cycle power stations which feed the electrical energy to the distribution network. This electrical feeding was always been strongly hierarchical in the configuration but in recent times the need to reduce electricity costs in a more economical competitive market play a decisive role in developing strategies to minimize the losses in the electrical distribution networks.

These trends in the development of electrical distribution networks are leading to scenarios that can be described as follows: [25]

- a slow rise in the electrical energy demand for electrical power in industry,
- larger exchange of electrical energy within interconnected systems,
- importing large blocks of electrical energy by private companies,
- demand for increased electrical energy quality, and
- electrical energy savings by the customer.

Electrical distribution networks are mostly influenced by trends towards the use of distributed electrical energy networks, stricter demands on the quality of electrical energy supply and the desire to use less electrical energy. The decentralization of the electricity market contributes to the changes in the electrical distribution network system and is proceeding at different rates in different countries around the world. The models developed around the world regarding the effective use of electrical energy and the strategies to minimize electrical energy losses have one common structure for the electrical power supply industry as shown in figure 3-4.
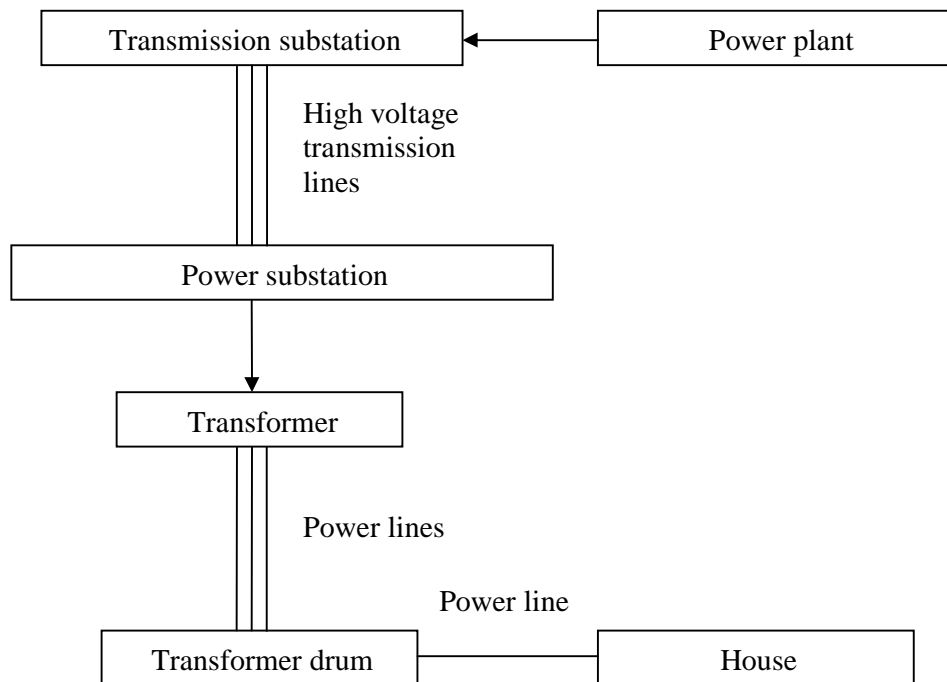
Figure 3-4 : Structure of an electrical energy supply network [25]

The structure used in Figure 3-4 to distribute electrical energy in an electrical energy supply network was used to develop a function diagram as shown in Figure 3-1 and to determine a strategy to minimize the electrical energy losses occurring in the distribution network. The strategy developed uses five main components and a feedback loop to the distribution network to implement the strategy. The strategy is depended on different network parameters to quantify the technical losses, identify the problem areas and solving the problems areas to re-evaluate the electrical distribution network. The implementation of the strategy needs at least the layout structure of the distribution network and the measured values of the meters in different segments of the distribution network. The main components needed to implement the strategy to minimize the losses in an electrical distribution network used will be discussed below. The Microsoft Visual Basic code of the implemented strategy and the calculation of the electrical energy losses in a distribution network is given in Appendix A.

Chapter 3 Development of the model and the derivation of the strategy

3.6.1. Calculation of technical losses

As shown in Figure 3-5 the calculation of the technical losses is a part of the development of the strategy in this dissertation and this calculation is needed for the determination of the non-technical losses in the developed model.
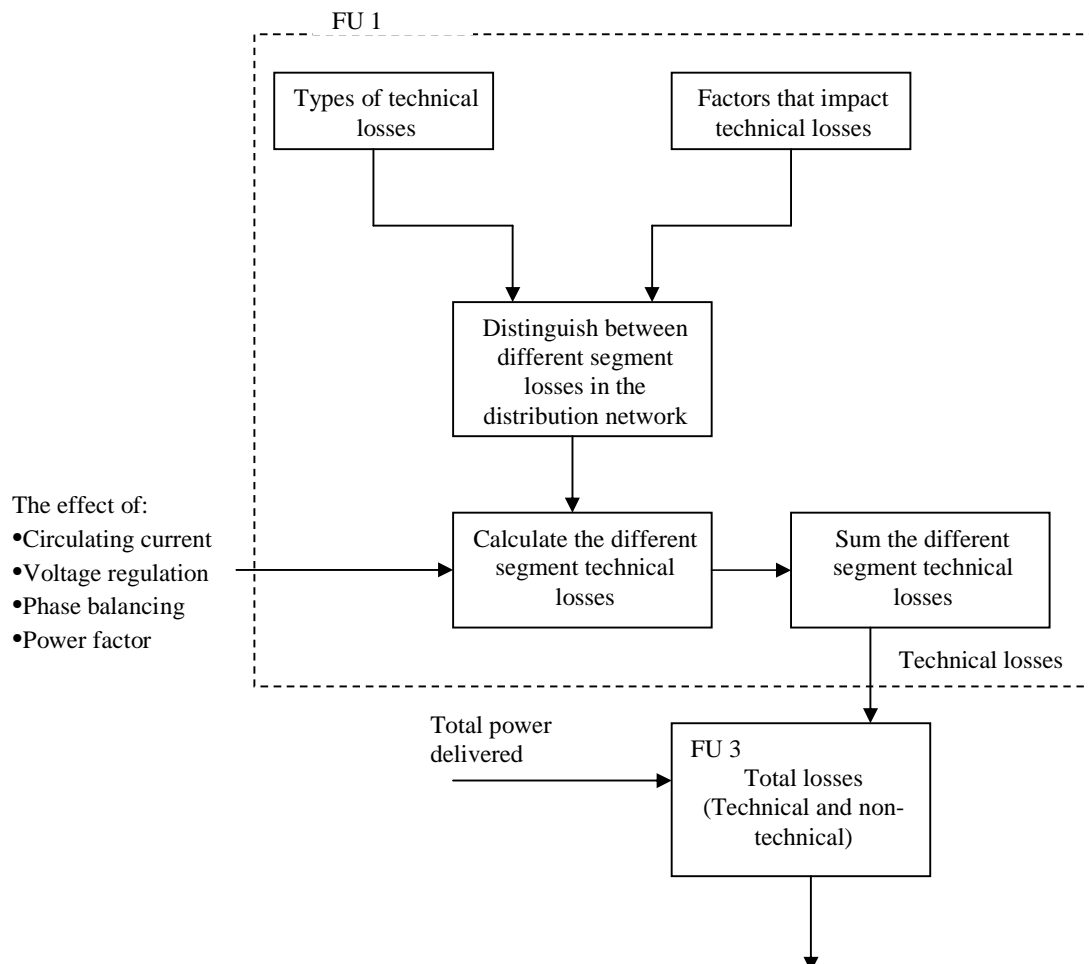
Figure 3-5: Technical loss calculation

To determine the technical losses of a distribution network the type of electrical loss occurring in the network segment needs to be identified. There are three types of technical losses in an electrical distribution network as discussed previously; they are copper losses, dielectric losses and induction or radiation losses. A further element influencing the calculation of technical losses in a distribution network is the factors that influence the distribution network.

Secondary effects that influence technical losses in an electrical distribution network are due to circulating currents in the distribution network, voltage regulation equipment, techniques and equipment used to balance the voltage phases of the network and equipment to correct the power factor of the network. These secondary factors as well as the different losses occurring in the different segments of the distribution network were used to calculate the technical losses in the distribution network. Although the secondary factors may influence the technical losses it is small compared to the different network segment losses and omitted in this dissertation.

With the secondary effects that influence technical losses omitted and using the different types of electrical losses occurring in an electrical distribution network, the model derived eight distinct segments that classify all the different segments in an electricity distribution network to calculate the technical losses. The eight different segments are mentioned earlier.

Models used to calculate the technical losses in an electrical distribution network almost always calculate the theoretical values of these losses. This model suggests a method using the supply electrical energy of the network segment and calculates the technical losses as a percentage of the supply electrical energy to the distribution network segment. This method is used in an attempt to minimize the calculation time but to still get an accurate model. This method was adopted as the layout of the initial distribution network is seldom updated when equipment changes are made to the distribution reticulation network.

If all the different segments of the electrical distribution network are determined the summation of the segments gives the total technical losses of the electrical distribution network under investigation. The total technical losses of the distribution network are the estimated calculated value of total electrical energy loss in the electrical distribution network.

3.6.2.   Measured usage

The measured usage is part of the identifying process of the model. These include the determination of the different meters used by the electrical distribution network to measure at different segments in the distribution network. To identify this segments a schematic

diagram of the flow of electrical energy in the distribution network is needed. Figure 3-6 shows an example of a schematic that includes all segments identified for an electrical distribution network.

ST: Sub transmission
DS: Distribution substation
DT: Distribution transformer
MV: Medium voltage network
LV: Low voltage network
CC: Customer connection
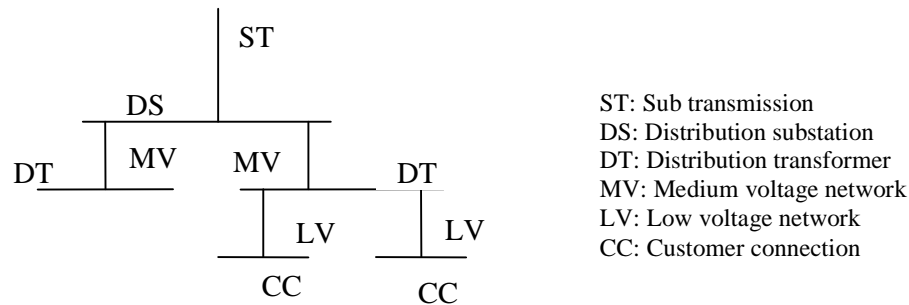
Figure 3-6 : Example at a simple segment schematic layout of an electrical distribution network

3.6.3. Calculation of non-technical losses

In measuring the electrical energy usage of the electrical distribution network the technical and non-technical losses are measured simultaneously. Due to this simultaneous measuring it is necessary to derive estimated technical energy usage values for the technical losses in the network. Thus in quantifying the technical losses the non-technical losses could be calculated using an indirect approach as given by equation 2-2.

3.6.4. Identify problem areas

In identifying problem areas in an electrical distribution network, the technical and the non-technical losses of the network segment must be known. These known values are used to determine if the network segment is valid. Validation of the different network segments is done using a paired t-test and an analysis of variance.

3.6.4.1. Paired-t test

A two sample t paired test is used to compare the estimated total losses of the network and the measured network losses for the distribution network [21]. A paired t test is used because it analyses only the differences in the two output electrical energies from the input

electrical energy of the network segment. This therefore eliminates the variation in other factors that can influence the network segment in the distribution network. The variation in the network can be due to the different terrain the cables are laid in, the length of the cables and the weather conditions. Thus using the paired t test the different measurements in the network are taken under homogenous conditions but the conditions of the different readings may change for each network segment in the network.

The following explanation will illustrate the homogenous conditions under which the measurements are taken. Let X_1 be a set of measurements representing the estimated values of the network segment and X_2 be a set of the measured values for the same network segment. Assume that the mean and the variance for the populations represented by X_1 are μ_1 and s_1^2, and the mean and variance of the population presented by X_2 are μ_2 and s_2^2. The difference of each pair of observations are defined as $D_j = X_{1j} - X_{2j}$, where $j = 1, 2, 3$. The difference of each pair is assumed to be normally distributed with mean

$$m_D = E(X_1 - X_2) = E(X_1) - E(X_2) = m_1 - m_2 \qquad (3\text{-}2)$$

and variance σ_D^2. Thus the testing of the hypotheses about the difference between μ_1 and μ_2 can be accomplished by performing the paired t test. Specifically testing H_0: $\mu_1 - \mu_2 = \Delta_0$ against H_1: $\mu_1 - \mu_2 \neq \Delta_0$ is equivalent of testing

$$H_0 : m_D = \Delta_0$$
$$H_1 : m_D \neq \Delta_0 \qquad (3\text{-}3)$$

The test statistic used in the model is given as follows:

$$T_0 = \frac{\overline{D} - \Delta_0}{S_D / \sqrt{n}} \qquad (3\text{-}4)$$

Where D is the sample average of the observations, D_0 is a constant, S_D is the sample standard deviation and n is the number of samples in the observation of the network segment (typically $n = 3$).

Chapter 3   Development of the model and the derivation of the strategy

The paired t test yields a t value that needs to be compared to a predetermined t value. It is used to determine a level of confidence to conclude that the two sample means are significantly different from each other or vice versa. If the value is not significantly different it is assumed that the network segment is functioning correctly without any significant loss in non-technical losses. But if there is a significant difference in the value it is assumed that the network segment has a significant amount of non-technical losses and thus the distribution network segment is identified as a problem area.

3.6.4.2. Analysis of variance

Analysis of variance is used to test for the significance of regression. This regression is tested between the different means of the distribution network segments. The procedure uses the means of the measured and estimated values to partition the total variability of the distribution network in into meaningful components as basis for the test. The analysis of variance identity is as follows:

$$SS_T = SS_R + SS_E \quad (3\text{-}5)$$

Where SS_T is the total corrected sum of squares, SS_E is the residual sum of squares and SS_R is the regression sum of squares. The total corrected sum of squares has n – 1 degrees of freedom. The test statistic for the analysis of variance (F_0) is as follows:

$$F_0 = \frac{MS_R}{MS_E} \quad (3\text{-}6)$$

Where the quantity of MS_R is called the regression mean square, and MS_E is the mean square of the residual. To assess the validity of the null hypothesis the following procedure is used:

- the original measured and estimated electrical energy is used in the test statistic to obtain a calculated test statistic,

- the resulting test statistic value is compared to the critical value of the measured and estimated results, and

- the null hypotheses is rejected if the calculated value is larger than the tabled critical value, or the hypotheses are accepted if the calculated test value is less that the critical value.

This critical value of the hypotheses is used to determine if the different segments of the distribution network are related. A predetermined confidence level is used to validate the hypotheses and if the hypothesis is rejected there is reason to believe that the different segments in the network are not interconnected. Or if the hypothesis is accepted the different network segments are interconnected and a reliable distribution network is operational.

3.6.5.   Solve problem areas

Problem areas can be identified using the statistical methods as discussed. These problem areas are prioritized according to the quantity of the non-technical losses and used as reference to the investigation of problem areas. The investigation of the problem areas and the problem solving of the areas are done using inspection teams that conduct a survey in the problem area, finding the causes of the losses in electrical distribution network. As problems are identified a predetermined procedure could be followed to correct the problem.

Audit teams are responsible to identify the source of a problem in the problem areas and to notify the responsible authority to correct the identified problem. This should lead to a reduction in the total electrical energy usage in the distribution network segment and a reduction in the non-technical losses of the segment. Solving the problems areas in order of priority is the feedback procedure implemented in the electrical distribution network and an important part of the implementation of the strategy to minimize the electrical losses in an electrical distribution network. This acts as the measure of control in the distribution network and will determine the effectiveness of the strategy implemented.

3.7. Limitations of model

Some minor limitations of the model in determining the electrical energy losses were encountered. This limitation was the current method of measuring electrical energy. The measuring is done once every three months and for the other two months the electrical energy usage is estimated as an average of the particular network segment. This is due to human resource shortages experience at municipalities in South Africa. This type of practice is commonly used because the tariff structure allows it to measure only once every three months. It is done because the tariff structure allows for an average paying bill. These estimated values are not problematic for the first iteration of measurement but if the measurement is omitted in the next iteration of meter readings then it could lead to the model interpreting the estimated values of the network segment as a problem area in the distribution network because the estimated measurements could become significantly large for the network segment. The model therefore does not take into consideration the estimated measurements made for several months.

Another problem in the estimation of meter readings is the fact that metering at substations is done electronically and measurement of analogue meters implemented in the lower voltage network segments is done by hand. This leads to a time delay in measuring the meter readings and could lead to the identification of problem areas in the distribution network if the measurements are taken over a long time period for example over two or more days.

The second factor that could limit the implementation of the model is the misunderstanding of the status of an electrical distribution network. This includes defining the layout and different measuring points in the distribution network. A method in defining the layout and the state of the electrical distribution network could be done using the following steps:

- collect and analyze the information and data
- talk to people familiar with the distribution network layout (system planners, engineer, technicians)
- view the network first hand
- confirm the different network segment measurements, and
- determine if the particular network segment has errors.

3.8. Verification of the model

In an environment where more emphasis is placed on the efficient utilization of electrical energy, it becomes necessary not only to distribute the electrical energy but to pay attention to verifying the management techniques of electrical energy. This verification should help reduce the electrical energy losses and the principle behind the reduction of these losses is a structured strategy to manage the electrical energy losses. The strategy used to verify if losses in an electrical distribution network are identified is divided into five steps as shown in Figure 3-7.
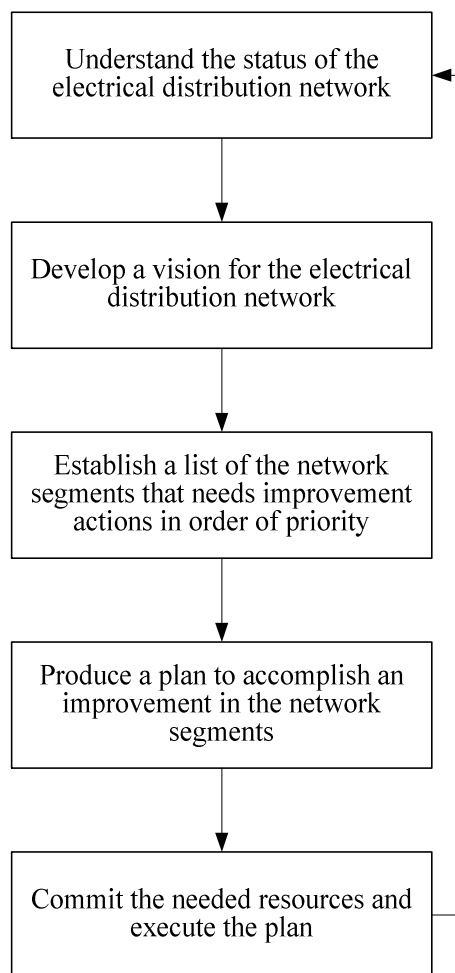
Figure 3-7: Identifying problem areas

These five steps are used to identify problem areas and improve on them. In the next iteration of the model these identified problem areas should be of a lower priority than the

previous iteration. If a problem area is higher then the assumption of the model parameters is assumed to be inaccurate for the specific network segment and needs to be reviewed. The distribution network model is assumed to be correct if the identified problem areas are of a lower priority than on the previous iteration of the model.

CHAPTER 4: CASE STUDIES OF THE MODEL

The model developed was evaluated using electrical measured data obtained from the main campus of the University of Pretoria and tested using data from Tshwane Metropolitan Council.

4.1   Verification of developed model at the University of Pretoria

The main campus of the University of Pretoria is supplied with energy from the electricity department of the Tshwane Metropolitan Council via 3 feeders of 11 kV each. Electrical measured data from different segments in the electrical distribution network were used to evaluate the model. The electrical distribution network at the University of Pretoria consists of six different network segments, namely:

- Women's hostel ring,
- West campus ring,
- North campus ring,
- East campus ring,
- Human Science (HB) ring, and
- Hilda ring.

Figure 4-1 shows the different network segments of the electrical distribution network at the University of Pretoria.
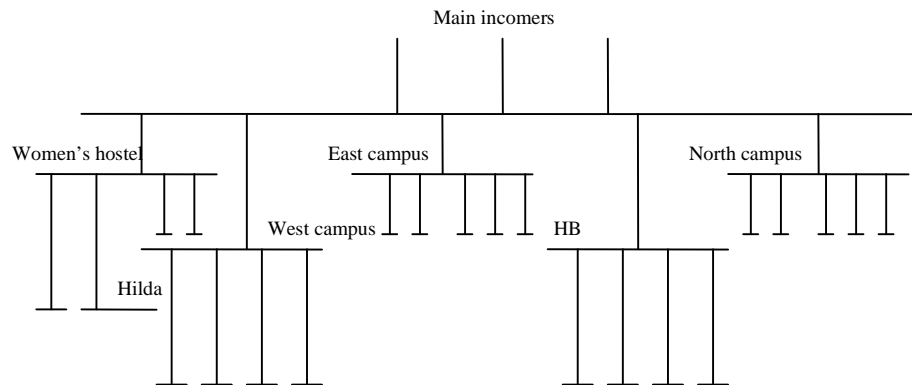
Figure 4-1: Test layout at University of Pretoria

Tshwane Incomer 1 | Tshwane Incomer 2 | Tshwane Incomer 3

GW bus

HB TRF 1 | HB TRF 2 | Jasmyn | Erika

Ladies Hostel Ring

Jasmyn TRF 1 | Jasmyn TRF 2 | Magrietjie TRF 1 | Magrietjie TRF 2 | Magrietjie TRF 3 | Magrietjie TRF 4 | Tuksdorp | Erika TRF 1 | Erika TRF 2 | Klaradyn Kitchen | Hilda

Hilda bus

Vergeet my nie | Jasmyn Kitchen | Asterhof

Business school | Economics

Merensky | Mineral science

Architecture | Eng 1

West Campus Ring

East Campus Ring

B.S. TRF 1 | B.S. TRF 2 | Agri TRF 1 | Agri TRF 2

North Campus Ring

Merensky TRF 1 | Merensky TRF 2 | Chancellar TRF 1 | NW 1 TRF 1

Build TRF 1 | Admin TRF 1 | Admin TRF 2 | Admin TRF 2 | MEG TRF 1 | MEG TRF 2

Edu TRF 1 | Edu TRF 2 | Econ TRF 1 | Econ TRF 2

Technical TRF 1 | Technical TRF 2 | Mineral Sc. TRF 1 | Mineral Sc. TRF 2

H. Mac TRF 1 | H. Mac TRF 2 | H. Mac TRF 3 | ING TRF 1 | ING TRF 2 | ING TRF 3

Figure 4-2: Single line network diagram layout.

Figure 4-2 shows the detailed single line layout of the different network segments in the electrical distribution network of the University of Pretoria.

The projected losses of each specific network segment in the network was calculated. The results and a network diagram of the specific network segments are given in Table 4-1 to Table 4-6 and from Figure 4-4 to Figure 4-10.

Figure 4-4 shows a network breakdown of the Main/HB bus.
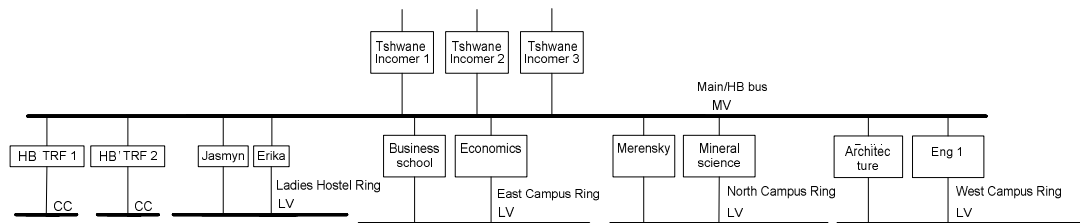
Figure 4-4: Main/HB bus layout.

The Main/HB bus has 3 incoming busses delivering energy to the network segment. There are 10 outgoing busses absorbing energy from the network segment. Two of these lines are customer connection termination connections and eight of the lines feed busses lower down in the network layout. The Main/HB bus is an 11kV connection bus and classified as a medium voltage (MV) network.

The energy balance equation for the Main/HB bus is given as:

$$\text{Total power loss} = \sum P_{in} - \sum P_{out}$$

$$\text{Total power loss} = \text{Tshwane Incomer 1} + \text{Tshwane Incomer 2} + \text{Tshwane Incomer 3} -$$
$$\left(\begin{array}{l} \text{GW TRF 1} + \text{GW TRF 2} + \text{Erika} + \text{Jasmyn} + \text{Build Environment} + \text{Eng. Tower} + \\ \text{Business School} + \text{Economics} + \text{Merensky} + \text{Mineral Science} \end{array} \right) \quad (4\text{-}1)$$

The projected electrical energy absorbed in the Main/HB bus is given in Table 4-1.

Table 4- 1: Projected total energy losses for the Main/HB bus.

Meter name	Bus name TO	Energy sum of meter	Network losses Bus name FROM			Type of loss	Meter losses			Customer connections Bus name TO		
			Min	Typical	Max		Min	Typical	Max	Min	Typical	Max
Tshwane Incomer 1	MAIN/HB Bus	1,011,687.0	505.8	1,011.7	1,517.5	CC	2,023.4	3,035.1	4,046.7			
Tshwane Incomer 2	MAIN/HB Bus	1,069,951.9	535.0	1,070.0	1,604.9	CC	2,139.9	3,209.9	4,279.8			
Tshwane Incomer 3	MAIN/HB Bus	967,961.4	484.0	968.0	1,451.9	CC	1,935.9	2,903.9	3,871.8			
Main/HB TRF 1	Customer Connection	132,717.7	663.6	1,990.8	3,317.9	MV	265.4	398.2	530.9	66.4	132.7	199.1
Main/HB TRF 2	Customer Connection	133,969.1	669.8	2,009.5	3,349.2	MV	267.9	401.9	535.9	67.0	134.0	201.0
Erika	Women's Hostel Ring	74,280.5	371.4	1,114.2	1,857.0	MV	148.6	222.8	297.1			
Jasmyn	Women's Hostel Ring	221,624.3	1,108.1	3,324.4	5,540.6	MV	443.2	664.9	886.5			
Build Environment	West Campus Ring	209,799.4	1,049.0	3,147.0	5,245.0	MV	419.6	629.4	839.2			
Eng.1	West Campus Ring	476,492.2	2,382.5	7,147.4	11,912.3	MV	953.0	1,429.5	1,906.0			
Business School	East Campus Ring	329,876.4	1,649.4	4,948.1	8,246.9	MV	659.8	989.6	1,319.5			
Economics	East Campus Ring	505,050.1	2,525.3	7,575.8	12,626.3	MV	1,010.1	1,515.2	2,020.2			
Merensky	North Campus Ring	390,720.1	1,953.6	5,860.8	9,768.0	MV	781.4	1,172.2	1,562.9			
Mineral Science	North Campus Ring	571,684.8	2,858.4	8,575.3	14,292.1	MV	1,143.4	1,715.1	2,286.7			

MV – Medium Voltage Network

CC – Customer Connection

Figure 4-5 shows a network breakdown of the North Campus ring bus.

Figure 4-5: North Campus ring bus layout.

The North Campus ring has 2 incoming busses delivering energy to the network segment. There are 9 outgoing busses absorbing energy from the network segment. Nine of these lines are customer connection termination connections in the network layout. The North Campus ring is a 1kV connection bus and classified as a low voltage (LV) network.

The energy balance equation for the MAIN/HB bus is given as:

$$\text{Total power loss} = \text{Merensky} + \text{Mineral Science} -$$
$$\begin{pmatrix} \text{Merensky TRF1} + \text{Merensky TRF2} + \text{Chancellors TRF1} + \text{NW1 TRF1} + \text{NW1 TRF2} + \\ \text{Technical TRF1} + \text{Technical TRF2} + \text{Mineral Science TRF1} + \text{Mineral Science TRF2} \end{pmatrix} (4-2)$$

The projected electrical energy absorbed in the North Campus ring is given in Table 4-2.

Table 4-2: Projected total losses for the North Campus ring.

Meter name	Bus name TO	Energy sum of meter	Network losses Bus name FROM			Type of loss	Meter losses			Customer connections Bus name TO		
			Min	Typical	Max		Min	Typical	Max	Min	Typical	Max
Merensky	North Campus Ring	390,720.1	1,953.6	5,860.8	9,768.0	MV	781.4	1,172.2	1,562.9			
Mineral Science	North Campus Ring	571,684.8	2,858.4	8,575.3	14,292.1	MV	1,143.4	1,715.1	2,286.7			
Merensky TRF1	Customer Connection	167,528.4	335.1	1,842.8	3,350.6	LV	335.1	502.6	670.1	83.8	167.5	251.3
Merensky TRF2	Customer Connection	161,741.0	323.5	1,779.2	3,234.8	LV	323.5	485.2	647.0	80.9	161.7	242.6
Chancellors TRF1	Customer Connection	57,204.2	114.4	629.2	1,144.1	LV	114.4	171.6	228.8	28.6	57.2	85.8
NW1 TRF1	Customer Connection	206,715.7	413.4	2,273.9	4,134.3	LV	413.4	620.1	826.9	103.4	206.7	310.1
NW1 TRF2	Customer Connection	150,194.8	300.4	1,652.1	3,003.9	LV	300.4	450.6	600.8	75.1	150.2	225.3
Technical TRF1	Customer Connection	6,681.8	13.4	73.5	133.6	LV	13.4	20.0	26.7	3.3	6.7	10.0
Technical TRF2	Customer Connection	12,997.9	26.0	143.0	260.0	LV	26.0	39.0	52.0	6.5	13.0	19.5
Mineral Science TRF1	Customer Connection	2,098.6	4.2	23.1	42.0	LV	4.2	6.3	8.4	1.0	2.1	3.1
Mineral Science TRF2	Customer Connection	61,363.9	122.7	675.0	1,227.3	LV	122.7	184.1	245.5	30.7	61.4	92.0

MV – Medium Voltage Network

LV – Low Voltage Network

Figure 4-6 shows a network breakdown of the West Campus ring bus.
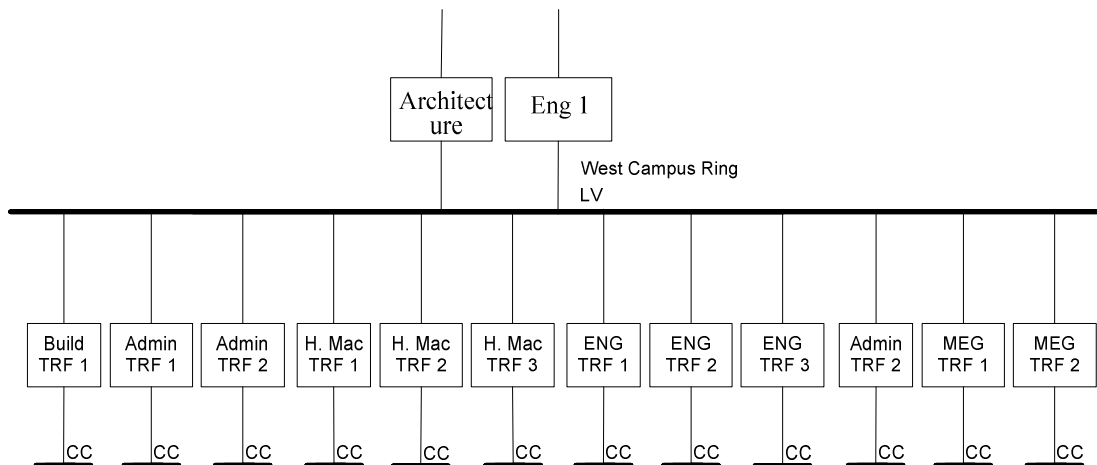
Figure 4-6: West Campus ring bus layout.
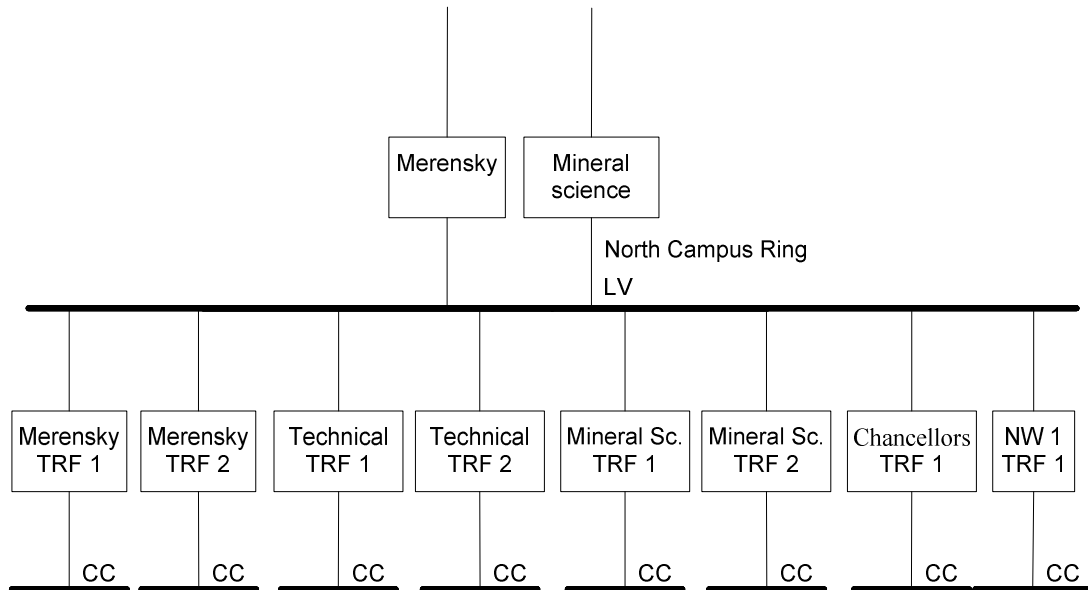
The West Campus ring has 2 incoming busses delivering energy to the network segment.

There are 11 outgoing busses absorbing energy from the network segment. Eleven of these

Chapter 4 Case studies of model

lines are customer connection termination connections. The West Campus ring is a 1kV connection bus and classified as a low voltage (LV) network.

The energy balance equation for the West Campus ring is given as:

$$\text{Total power loss} = \text{Eng. Tower} + \text{Architecture} -$$
$$\begin{pmatrix} \text{Architecture TRF1} + \text{Admin. TRF1} + \text{Admin. TRF 2} + \text{Meg TRF1} + \text{Meg TRF 2} \\ \text{H. Mac TRF1} + \text{H. Mac TRF 2} + \text{H. Mac TRF 3} + \text{ENG TRF1} + \text{ENG TRF 2} + \text{ENG TRF 3} \end{pmatrix} \quad (4\text{-}3)$$

The projected electrical energy absorbed in the West Campus ring is given in Table 4- 3.

Table 4-3: Projected total losses for the West Campus ring.

Meter name	Bus name TO	Energy sum of meter	Network losses Bus name FROM			Type of loss	Meter losses			Customer connections Bus name TO		
			Min	Typical	Max		Min	Typical	Max	Min	Typical	Max
Architecture	West Campus Ring	209,799.4	1,049.0	3,147.0	5245.0	MV	419.6	629.4	839.2			
Eng 1	West Campus Ring	476,492.1	2,382.5	7,147.4	1,912.3	MV	953.0	1,429.5	1,906.0			
Architecture TRF1	Customer Connection	69,390.6	138.8	763.3	1,387.8	LV	138.8	208.2	277.6	34.7	69.4	104.1
Admin TRF1	Customer Connection	68,363.6	136.7	752.0	1,367.3	LV	136.7	205.1	273.5	34.2	68.4	102.5
Admin TRF2	Customer Connection	73,064.5	146.1	803.7	1,461.3	LV	146.1	219.2	292.3	36.5	73.1	109.6
Meg TRF1	Customer Connection	2,396.7	4.8	26.4	47.9	LV	4.8	7.2	9.6	1.2	2.4	3.6
Meg TRF2	Customer Connection	2,700.2	5.4	29.7	54.0	LV	5.4	8.1	10.8	1.4	2.7	4.1
H. Mac TRF1	Customer Connection	96,991.7	194.0	1,066.9	1,939.8	LV	194.0	291.0	388.0	48.5	97.0	145.5
H. Mac TRF2	Customer Connection	1,449.6	2.9	15.9	29.0	LV	2.9	4.3	5.8	0.7	1.4	2.2
H. Mac TRF3	Customer Connection	62,737.3	125.5	690.1	1,254.7	LV	125.5	188.2	250.9	31.4	62.7	94.1
ENG TRF1	Customer Connection	20,943.6	41.9	230.4	418.9	LV	41.9	62.8	83.8	10.5	20.9	31.4
ENG TRF2	Customer Connection	64,086.6	128.2	705.0	1,281.7	LV	128.2	192.3	256.3	32.0	64.1	96.1
ENG TRF3	Customer Connection	71,503.6	143.0	786.5	1,430.1	LV	143.0	214.5	286.0	35.8	71.5	107.3

Figure 4-7 shows a network breakdown of the East Campus ring bus.
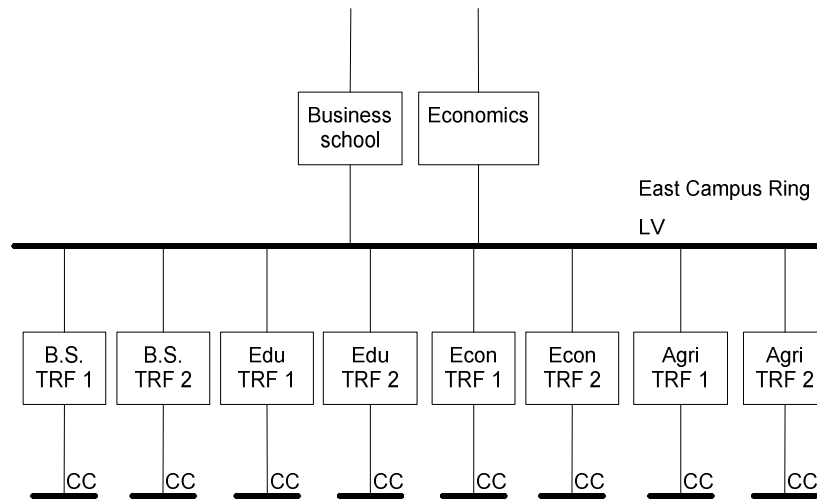
Figure 4-7: East Campus ring bus layout.

The East Campus ring has 2 incoming busses delivering energy to the network segment. There are 8 outgoing busses absorbing energy from the network segment. Eight of these lines are customer connection termination connections. The East Campus ring is a 1kV connection bus and classified as a low voltage (LV) network.

The energy balance equation for the West Campus ring is given as:

$$\text{Total power loss} = \text{Business school} + \text{Economics} - \begin{pmatrix} \text{B.S. TRF1} + \text{B.S. TRF2} + \text{Edu TRF1} + \text{Edu TRF2} \\ \text{Econ TRF1} + \text{Econ TRF2} + \text{Agri TRF1} + \text{Agri TRF2} \end{pmatrix} \quad (4\text{-}4)$$

The projected electrical energy absorbed in the East Campus ring is given in Table 4-4.

Chapter 4   Case studies of model

Table 4-4: Projected total losses for the East Campus ring.

Meter name	Bus name TO	Energy sum of meter	Network losses Bus name FROM			Type of loss	Meter losses			Customer connections Bus name TO		
			Min	Typical	Max		Min	Typical	Max	Min	Typical	Max
Business School	East Campus Ring	329,876.4	1,649.4	4,948.1	8,246.9	MV	659.8	989.6	1,319.5			
Economics	East Campus Ring	505,050.1	2,525.3	7,575.8	12,626.3	MV	1,010.1	1,515.2	2,020.2			
B.S. TRF1	Customer Connection	66,823.9	133.6	735.1	1,336.5	LV	133.6	200.5	267.3	33.4	66.8	100.2
B.S. TRF2	Customer Connection	52,674.5	105.3	579.4	1,053.5	LV	105.3	158.0	210.7	26.3	52.7	79.0
Agri TRF1	Customer Connection	78,575.8	157.2	864.3	1,571.5	LV	157.2	235.7	314.3	39.3	78.6	117.9
Agri TRF2	Customer Connection	124,368.9	248.7	1,368.1	2,487.4	LV	248.7	373.1	497.5	62.2	124.4	186.6
Edu TRF1	Customer Connection	118,119.4	236.2	1,299.3	2,362.4	LV	236.2	354.4	472.5	59.1	118.1	177.2
Edu TRF2	Customer Connection	210,700.3	421.4	2,317.7	4,214.0	LV	421.4	632.1	842.8	105.4	210.7	316.1
Econ TRF1	Customer Connection	71,366.3	142.7	785.0	1,427.3	LV	142.7	214.1	285.5	35.7	71.4	107.0
Econ TRF2	Customer Connection	72,607.1	145.2	798.7	1,452.1	LV	145.2	217.8	290.4	36.3	72.6	108.9

MV – Medium Voltage Network

LV – Low Voltage Network

Figure 4-8 shows a network breakdown of the Women's Hostel ring bus.
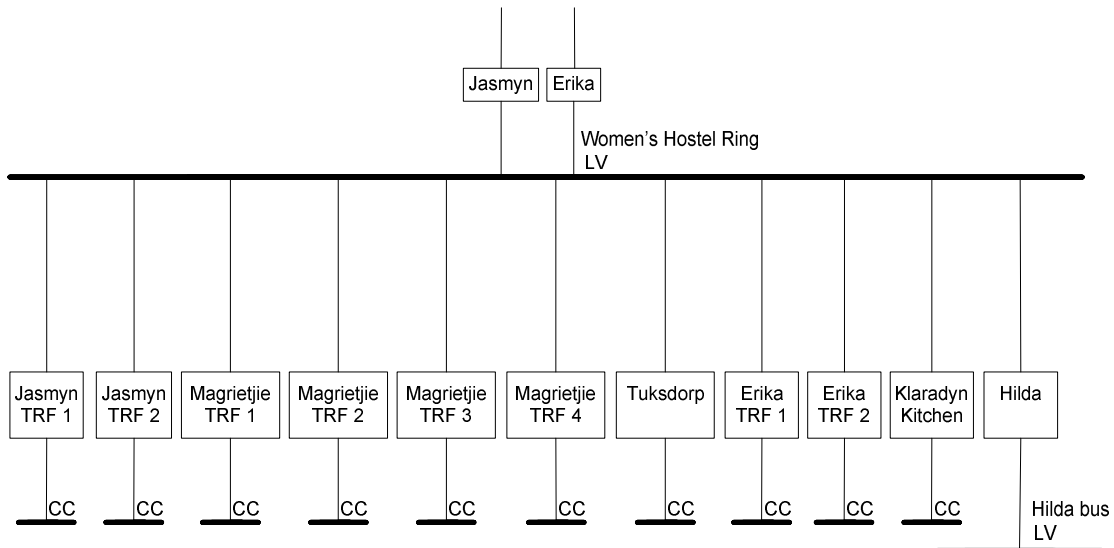
Figure 4-8: Women's Hostel ring bus layout.

The Women's Hostel ring has 2 incoming busses delivering energy to the network segment. There are 11 outgoing busses absorbing energy from the network segment. Ten of

these lines are customer connection termination connections and one of the lines feed busses lower down in the network layout. The Women's Hostel ring is a 380 V connection bus and classified as a low voltage (LV) network.

The energy balance equation for the Women's Hostel ring is given as:

$$
\begin{aligned}
\text{Total power loss} = \text{Jasmyn} + \text{Erika} - \\
\left(
\begin{array}{l}
\text{Jasmyn TRF1} + \text{Jasmyn TRF2} + \text{Magrietjie TRF1} + \text{Magrietjie TRF2} \\
\text{Magrietjie TRF3} + \text{Magrietjie TRF4} + \text{Tuksdorp} + \text{Erika TRF1} + \\
\text{Erika TRF2} + \text{Klaradyn Kitchen} + \text{Hilda}
\end{array}
\right)
\end{aligned}
\tag{4-5}
$$

The projected electrical energy absorbed in the Women's Hostel ring is given in Table 4-5.

Table 4-5: Projected total losses for the East Campus ring.

| Meter name	Bus name TO	Energy sum of meter	Network losses Bus name FROM			Type of loss	Meter losses			Customer connections Bus name TO		
			Min	Typical	Max		Min	Typical	Max	Min	Typical	Max
Erika	Women's Hostel Ring	74,280.5	371.4	1,114.2	1,857.0	MV	148.6	222.8	297.1			
Jasmyn	Women's Hostel Ring	221,624.3	1,108.1	3,324.4	5,540.6	MV	443.2	664.9	886.5			
Jasmyn TRF1	Customer Connection	12,668.4	25.3	139.4	253.4	LV	25.3	38.0	50.7	6.3	12.7	19.0
Jasmyn TRF2	Customer Connection	23,485.8	47.0	258.3	469.7	LV	47.0	70.5	93.9	11.7	23.5	35.2
Magrietjie TRF1	Customer Connection	32,033.6	64.1	352.4	640.7	LV	64.1	96.1	128.1	16.0	32.0	48.1
Magrietjie TRF2	Customer Connection	8,276.0	16.6	91.0	165.5	LV	16.6	24.8	33.1	4.1	8.3	12.4
Magrietjie TRF3	Customer Connection	21,117.6	42.2	232.3	422.4	LV	42.2	63.4	84.5	10.6	21.1	31.7
Magrietjie TRF4	Customer Connection	39,757.6	79.5	437.3	795.2	LV	79.5	119.3	159.0	19.9	39.8	59.6
Tuksdorp	Hilda ring	74,032.0	148.1	814.4	1,480.6	LV	148.1	222.1	296.1			
Erika TRF1	Customer Connection	37,756.2	75.5	415.3	755.1	LV	75.5	113.3	151.0	18.9	37.8	56.6
Erika TRF2	Customer Connection	37,960.8	75.9	417.6	759.2	LV	75.9	113.9	151.8	19.0	38.0	56.9
Klaradyn Kitchen	Customer Connection	18,385.6	36.8	202.2	367.7	LV	36.8	55.2	73.5	9.2	18.4	27.6
Hilda	Hilda ring	71,021.4	172.3	861.4	1,551.0	LV	90.7	453.5	816.3	18.0	90.2	162.0

Figure 4-9 shows a network breakdown of the Hilda ring bus.
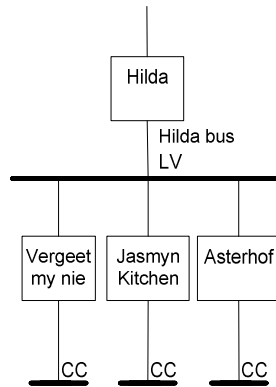
Figure 4-9: Hilda ring bus layout.

The Hilda ring has 1 incoming bus delivering energy to the network segment. There are 3 outgoing busses absorbing energy from the network segment. Three of these lines are customer connection termination connections. The Hilda ring is a 380 V connection bus and classified as a low voltage (LV) network.

The energy balance equation for the Hilda ring is given as:

$$\text{Total power loss} = \text{Hilda} - (\text{Vergeet My Nie} + \text{Jasmyn Kitchen} + \text{Asterhof}) \quad (4\text{-}6)$$

The projected electrical energy absorbed in the Hilda ring is given in Table 4-6.

Table 4-6: Projected total losses for the Hilda ring.

Meter name	Bus name TO	Energy sum of meter	Network losses Bus name FROM			Type of loss	Meter losses			Customer connections Bus name TO		
			Min	Typical	Max		Min	Typical	Max	Min	Typical	Max
Hilda	Hilda ring	71,021.4	172.28	861.4	1,551.0	LV	90.7	453.5	816.3	18	90.2	162
Vergeet My Nie	Customer Connection	24,651.8	49.3	271.2	493.0	LV	49.3	74.0	98.6	12.3	24.7	37.0
Jasmyn Kitchen	Customer Connection	19,275.5	38.6	212.0	385.5	LV	38.6	57.8	77.1	9.6	19.3	28.9
Asterhof	Customer Connection	18,115.6	36.2	199.3	362.3	LV	36.2	54.3	72.5	9.1	18.1	27.2

The actual measured results shown in Table 4-7 were obtained from the electrical distribution network layout as shown in Figure 4-2.

Table 4-7: Total actual energy measured

	Main/HB bus	West Campus Ring	East Campus Ring	North Campus Ring	Women's Hostel Ring	Hilda Ring
Energy absorbed by bus	3,752,637.7	533,628.1	795,236.1	826,526.3	305,473.6	71,021.4
Energy delivered. to bus	3,756,023.6	686,291.6	834,926.4	962,404.9	305,904.8	74,032.2
% Difference of energy absorbed. by bus	0.09	28.61	4.99	16.44	0.14	4.24
% Difference of energy delivered to bus	0.09	22.24	4.75	14.12	0.14	4.07
% Difference between energy absorbed and energy delivered	0	6.37	0.24	2.32	0	0.17

The difference in the energy absorbed and delivered must be less than 2.5 percent to be acceptable. This acceptance level is a value determine by Eskom and the smaller the acceptance level the higher the accuracy of the measured values. A percentage difference level less than 10 % needs further investigation and levels higher than 10 % are unacceptable.

The difference in the energy absorbed and delivered of the Main/HB bus, the East Campus ring, the North Campus Ring, Women's Hostel ring and the Hilda ring are less than 2% and this means that the total amount of electrical energy delivered and absorbed in segment of the electrical distribution network are acceptable. From Table 4-7 it can be concluded that the West Campus ring needs investigation.

Table 4-8 shows the projected values as well as the percentage difference between the projected energy absorbed and actual energy absorbed. One of the measures of identifying the problem areas in an electrical distribution network is to compare the projected energy

absorbed and the actual energy absorbed. If the percentage difference is less than 10 % the difference is normal. A percentage difference less than 30 % is assumed high and values higher than 30 % are abnormal. Table 4-8 shows that there is a high percentage difference at the West Campus ring and the North Campus ring. The percentage difference between the Main/HB bus, East Campus ring, Women's Hostel ring and the Hilda ring could be considered normal.

Table 4-8: Calculated technical losses

		Main/HB bus	West Campus Ring	East Campus Ring	North Campus Ring	Women's Hostel Ring	Hilda Ring
Total network losses	Min	15,231.1	1,067.3	1,590.5	1,653.1	610.9	172.3
	Typical	45,693.2	5,869.9	8,747.6	9,091.8	3,360.2	861.4
	Max	76,155.4	10,672.6	15,904.7	16,530.5	6,109.5	1,550.5
Meter losses	Min	6,092.4	1,067.3	1,590.5	1,653.1	610.9	90.7
	Typical	9,138.6	1,600.9	2,385.7	2,479.6	916.4	453.5
	Max	12,184.9	2,134.5	3,180.9	3,306.1	1,221.9	816.3
Customer connection losses	Min	133.3	266.8	397.6	413.3	115.7	18.0
	Typical	266.7	533.6	795.2	826.5	231.4	90.2
	Max	400.0	800.4	1,192.9	1,239.8	347.2	162.4
Bus / Transformer losses	Min	18,780.1	6,862.9	8,349.3	9,624.0	2,959.0	73.7
	Typical	46,950.3	10,294.4	12,523.9	14,436.1	4,438.6	368.4
	Max	75,120.5	13,725.8	16,698.5	19,248.1	5,918.1	663.1
Energy delivered to bus	Min	3,680,903.1	672,565.8	818,227.9	943,156.8	299,986.7	66,628.8
	Measured	3,756,023.6	686,291.6	834,926.4	962,404.9	305,904.7	74,032.1
	Max	3,831,144.1	700,017.4	851,624.9	981,653.0	309,822.9	81,435.2
Projected total loss for bus	Min	40,237.0	9,264.2	11,927.8	13,343.4	4,296.7	1,596.2
	Typical	102,048.8	18,298.8	24,452.4	26,834.0	8,946.6	1,773.5
	Max	163,860.7	27,333.3	36,977.0	40,324.5	13,596.6	1,950.9
Projected energy absorbed	Min	3,640,666.2	663,301.5	806,300.0	929,813.4	285,690.0	66,143.3
	Typical	3,653,974.8	667,992.8	810,474.0	935,570.9	286,958.1	73,492.6
	Max	3,667,283.4	672,684.1	814,647.9	941,328.5	288,226.3	80,841.9
Energy absorbed by bus	Min	3,677,585.0	522,955.5	779,331.4	809,995.7	299,364.1	63,919.3
	Measured	3,752,637.7	533,628.1	795,236.1	826,526.3	305,473.6	71,021.4
	Max	3,827,690.5	544,300.6	811,140.9	843,056.8	311,583.1	78,123.6
% Difference between energy absorbed and energy delivered		2.7	20.1	1.9	11.7	6.1	3.5

The typical value is the calculated value of the technical losses in the electrical distribution network. The minimum and maximum values are calculated percentage values of the typical value. This is done to be able to statistically calculate the problem areas in the

distribution network. Another approach is to determine the minimum and maximum values of the specific part of the network. This could however only be done if the minimum and maximum values do not differ significantly from the typical value.

In both Table 4-7 and Table 4-8 the West Campus ring is identified as a segment with a high percentage difference. This would identify the West Campus ring as a problem area. The North Campus Ring is also identified as a problem area using Table 4-8 and therefore it is identified as a potential problem area. Table 4-9 shows that the percentage difference calculated for the projected losses in the electrical distribution network are equal percentage values.

Table 4-9: Percentage difference of projected total losses

	Main/HB bus	West Campus Ring	East Campus Ring	North Campus Ring	Women's Hostel Ring	Hilda Ring
Total network losses	1.251	0.879	1.079	0.972	1.171	1.172
Meter losses	0.250	0.240	0.294	0.265	0.319	0.317
Customer connection losses	0.007	0.080	0.098	0.088	0.081	0.123
Bus / Transformer losses	1.285	1.541	1.545	1.543	1.547	1.501
Total projected percentage loss per bus	2.793	2.739	3.017	2.868	3.118	2.413

Using Table 4-9 a statistical approach is used in evaluating the different network segments in the electrical distribution network. This statistical approach would identify the different problem areas using structured mathematical techniques.

The calculation of the p value returns the two-tailed p value of a paired t test. The t test generates a standard score value for each bus value with respect to the minimum, typical and maximum value of each of the different busses on the electrical distribution network. It returns a p value for each bus on the distribution using the two-tailed probability for the normal distribution. This function is used to assess the likelihood that the actual measured electrical energy output for a specific bus and the estimated electrical energy for the same bus are derived from the same electrical energy input bus on the distribution network. A small numerical p value indicates statistical significance in the t test.

The f test statistical function used in the model returns the one-tailed probability that the variances in the actual measured electrical energy and the estimated electrical energy are

not significantly different. This function is used to determine whether the measured and estimated electrical energy have significantly different variances. A small numerical value indicates statistical significance in the f test.

The confidence interval in the model calculates the mean of the bus of both the measured and estimated electrical energy. It is used in the model to determine, with a particular level of confidence the lowest and highest electrical energy level of use for a particular bus in the electrical distribution network. This level of confidence is compared to the actual measured value of the electrical energy used by the bus and the confidence interval should be an order or more lower than the actual measured electrical energy to be assumed correct.

Table 4-10: Statistical evaluation

	Main/HB bus	West Campus Ring	East Campus Ring	North Campus Ring	Women's Hostel Ring	Hilda Ring
Determine p-value for Paired t-test	0.10951	0.00066	0.15337	0.00324	0.02204	0.00005
Significance (f test)	0.09260	0.12510	0.76200	0.22140	0.81700	0.02460
Standard deviation of population	72,417.7	73,963.1	13,334.6	60,743.6	10,882.1	23,276.5
Confidence interval for population mean	47,314.3	102,838.2	7,772.4	73,012.6	10,172.2	38,737.9
Measured value of bus	3752637.74	533628.06	795236.13	826526.26	305473.60	71021.43

These four statistical calculations can be subdivided into two groups namely statistical calculations and measured data verification. The statistical evidence group contains the t-test and f-test and the measured data verification group consists of the standard deviation and the confidence interval. From these two groups the final potential problem area identification is given in order of priority.

The significant busses for the t-test are the West Campus ring, the North Campus ring and the Hilda ring. The Women's Hostel ring indicates a lesser significant level. The Main/HB bus and the Woman's hostel ring are identified as not significant, but this insignificance could be as a result of problems lower down in the electrical distribution network.

Using the f-test as a measure of the different diversity in the projected energy absorbed and actual energy absorbed in the electrical distribution network the Main/HB bus and the Hilda ring are significant. A small level of significance is observed at the West Campus ring and the North Campus ring. The busses that are not significant in the f-test evaluation are the East Campus ring and the Women's Hostel ring.

Comparing the t-test and the f-test as shown in Table 4-12 would yield that for the electrical distribution network segment to be correct both tests must indicate a significant level and visa versa. Table 4-11 shows the scale used to identify the different electrical distribution network segments statuses.

Table 4-11: Scale used to identify statuses

Column 1	Column 2	Decision
√	√	No problem
—	√	Potential problem
×	√	Problem area
√	—	Potential problem
—	—	Problem area
×	—	Problem area
√	×	Problem area
—	×	Problem area
×	×	Problem area

Key:

√ - significant statistical evidence,

— - small significance, and

× - not significant statistical evidence.

Table 4-12: Statistical evidence

	t-test	f-test
Main/HB bus	×	√
West Campus Ring	√	—
East Campus Ring	×	×
North Campus Ring	√	—
Women's Hostel Ring	—	×
Hilda Ring	√	√

Using Table 4-12 the following conclusions could be made using the statistical evidence for the different network segments in the electrical distribution network:

Main/HB bus	- problem area, but lower down in the network segment
West Campus ring	- potential problem area
East Campus ring	- problem area
North Campus ring	- potential problem area
Women's Hostel ring	- potential problem area, possibly lower down in network segment
Hilda ring	- no problem

The busses energy that are smaller than an order of the standard deviation of the network segments area is the Main/HB bus, the West Campus ring, the East Campus ring, the North Campus ring and the Women's Hostel ring. This small order deviation of energy indicates that the energy measured is correct. The Hilda ring is an order higher or in the same order as the measured data indicating a problem area.

Using the confidence interval of the different network segments in the electrical distribution network the Main/HB bus, East Campus ring, North Campus ring and the Women's Hostel ring is smaller than the measured energy in the specific network segment indicating that the measured data values are correct. The West Campus ring and the Hilda ring is in the same order as the measure energy absorbed for the specific segment and this would be identified as a problem area.

Comparing the standard deviation and the confidence interval of the different network segments are shown in Table 4-13.

Table 4-13: Measuring data test

	Standard deviation	Confidence interval
Main/HB bus	√	√
West Campus Ring	√	×
East Campus Ring	√	√
North Campus Ring	√	√
Women's Hostel Ring	√	√
Hilda Ring	×	×

Key:

√ - smaller than an order of the measured energy absorb in the network segment, and

× - greater than an order of the measured energy absorb in the network segment.

Using Table 4-13 the following conclusions could be made using the statistical evidence for the different network segments in the electrical distribution network:

Main/HB bus   - no problem

West Campus ring   - potential problem area

East Campus ring   - no problem

North Campus ring   - no problem

Women's Hostel ring - no problem

Hilda ring   - potential problem area

The combined results of the statistical and measured data tests are given in Table 4-14.

Table 4-14: Combined results

	Statistical	Measured
Main/HB bus	—	√
West Campus Ring	√	—
East Campus Ring	×	√
North Campus Ring	√	√
Women's Hostel Ring	—	√
Hilda Ring	√	×

Key:

√ - no problem,

— - potential problem area, and

× - problem area.

Using Table 4-14 the following conclusions could be made using the statistical evidence for the different network segments in the electrical distribution network. The results were prioritized as follows:

1) Hilda ring – *problem area*
2) East Campus ring – *problem area*
3) West Campus ring – *potential problem area*
4) Woman's Hostel ring – *potential problem area on lower level*
5) Main/HB bus – *potential problem area on lower level*
6) North Campus ring – *no problem*

The problem identification at the Women's Hostel ring and the Main/HB bus should be solved automatically as the lower order network segment problems are solved.

4.2   Verification of developed model in Garsfontein/Retriever

From an area in the Garsfontein region in Pretoria, South Africa electrical measured data was used to verify whether the model developed could be used on a single line feeder. Electrical measured data from the different lots feeding from the feeder were taken on regular intervals and this data was used to verify the developed model. The electrical distribution network at Garsfontein consists of one segment. Figure 4-10 shows the layout

Garsfontein (Retriever)
incomer

Metering points at different lots
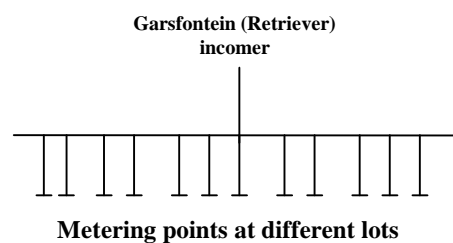
of the Garsfontein network.

Figure 4-10: Layout at Garsfontein network

Figure 4-11 shows the detailed layout of the network in the electrical distribution network of Garsfontein.
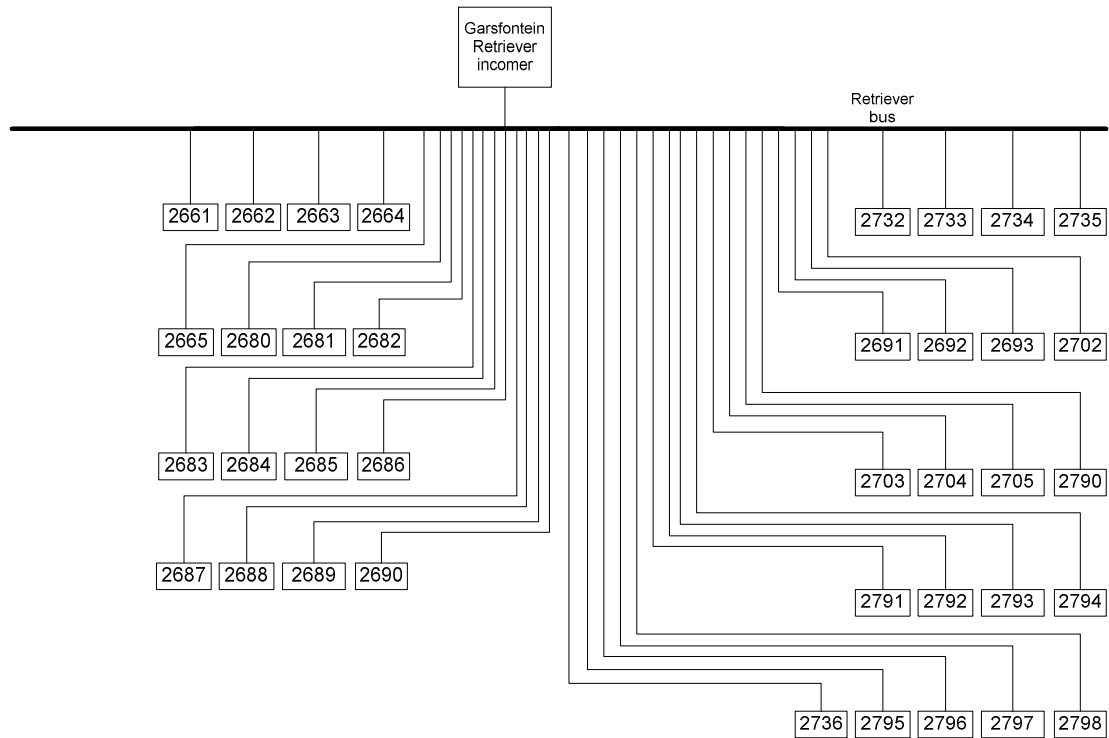
The Retriever bus has a single incoming bus delivering energy to the network. There are 37 outgoing customer connections terminations that give electrical energy to households. The Retriever bus is a 3.3kV connection bus and classified as a low voltage (LV) network.

The energy balance equation for the Retriever bus is given as:

$$Total\ power\ loss = \mathrm{Re}triever - \begin{pmatrix} Lot\ no.2661 + Lot\ no.2662 + Lot\ no.2663 + \\ Lot\ no.2664 + Lot\ no.2665 + Lot\ no.2680 + \\ Lot\ no.2681 + Lot\ no.2682 + Lot\ no.2683 + \\ Lot\ no.2684 + Lot\ no.2685 + Lot\ no.2686 + \\ Lot\ no.2687 + Lot\ no.2688 + Lot\ no.2689 + \\ Lot\ no.2690 + Lot\ no.2691 + Lot\ no.2692 + \\ Lot\ no.2693 + Lot\ no.2702 + Lot\ no.2703 + \\ Lot\ no.2704 + Lot\ no.2705 + Lot\ no.2790 + \\ Lot\ no.2791 + Lot\ no.2792 + Lot\ no.2793 + \\ Lot\ no.2794 + Lot\ no.2795 + Lot\ no.2796 + \\ Lot\ no.2797 + Lot\ no.2798 + Lot\ no.2732 + \\ Lot\ no.2733 + Lot\ no.2734 + Lot\ no.2735 + \\ Lot\ no.2736 \end{pmatrix} \qquad (4\text{-}7)$$

Chapter 4   Case studies of model

The network segment calculates the projected losses of the network segment for a day, week and month. The results of the different measured times in the network segment are given in Table 4-15 to Table 4-20.

The projected electrical energy absorbed in the Retriever bus for a month is given in Table 4-15.

Table 4-15: Projected total losses for the different months on the Retriever bus.

Meter Name	Bus name TO	Energy sum of meter	Network losses Bus name FROM			Type of loss	Meter losses			Customer connections Bus name TO		
			Min	Typical	Max		Min	Typical	Max	Min	Typical	Max
Retriever Month 1	Retriever bus 1	41,289.6	123.4	535.8	948.2	CC	162.3	243.4	324.5	20.6	41.3	61.9
Retriever Month 2	Retriever bus 2	39,085.0	118.6	510.9	903.1	CC	160.4	240.6	320.8	19.5	39.1	58.6
Retriever Month 3	Retriever bus 3	40,116.8	121.5	523.7	926.0	CC	162.9	244.4	325.8	20.1	40.1	60.2
Retriever Month 4	Retriever bus 4	40,469.0	121.9	527.0	932.2	CC	162.0	243.0	324.0	20.2	40.5	60.7
Retriever Month 5	Retriever bus 5	40,406.3	122.8	528.4	934.0	CC	167.6	251.4	335.2	20.2	40.4	60.6
Retriever Month 6	Retriever bus 6	39,931.5	101.6	482.6	863.7	CC	79.9	119.8	159.7	20.0	39.9	59.9

CC – Customer Connections

The projected electrical energy absorbed in the Retriever bus for a week is given in Table 4-16.

Table 4-16: Projected total losses for on a weekly base for the Retriever bus.

Meter name	Bus name TO	Energy sum of meter	Network losses Bus name FROM			Type of loss	Meter losses			Customer connections Bus name TO		
			Min	Typical	Max		Min	Typical	Max	Min	Typical	Max
Retriever Week 1	Retriever bus 1	8896.2	27.0	116.3	205.6	CC	36.4	54.6	72.8	4.4	8.9	13.3
Retriever Week 2	Retriever bus 2	9009.1	27.6	118.2	208.8	CC	37.6	56.4	75.3	4.5	9.0	13.5
Retriever Week 3	Retriever bus 3	9526.1	28.7	124.1	219.5	CC	38.0	57.1	76.1	4.8	9.5	14.3
Retriever Week 4	Retriever bus 4	9222.2	23.2	110.9	198.7	CC	18.4	27.7	36.9	4.6	9.2	13.8

CC – Customer Connections

The projected electrical energy absorbed in the Retriever bus for consecutive days are given in Table 4-17.

Table 4-17: Projected total losses for seven days on the Retriever bus.

Meter name	Bus name TO	Energy sum of meter	Network losses Bus name FROM			Type of loss	Meter losses			Customer connections Bus name TO		
			Min	Typical	Max		Min	Typical	Max	Min	Typical	Max
Retriever Day 1	Retriever bus 1	2,543.9	7.7	33.1	58.6	CC	10.2	15.3	20.4	1.3	2.5	3.8
Retriever Day 2	Retriever bus 2	2,496.7	7.5	32.6	57.6	CC	10.1	15.2	20.2	1.2	2.5	3.7
Retriever Day 3	Retriever bus 3	2,484.1	7.5	32.4	57.4	CC	10.1	15.1	20.2	1.2	2.5	3.7
Retriever Day 4	Retriever bus 4	2,493.9	7.6	32.6	57.7	CC	10.2	15.3	20.5	1.2	2.5	3.7
Retriever Day 5	Retriever bus 5	2,558.5	7.8	33.6	59.3	CC	10.8	16.1	21.5	1.3	2.6	3.8
Retriever Day 6	Retriever bus 6	2,719.3	6.8	32.7	58.6	CC	5.4	8.2	10.9	1.4	2.7	4.1
Retriever Day 7	Retriever bus 7	2,583.5	7.9	33.9	59.9	CC	10.8	16.2	21.6	1.3	2.6	3.9

CC – Customer Connections

The actual measured results shown in Table 4-18 to Table 4-20 were obtained from the electrical distribution network layout as shown in Figure 4-11. These tables show the monthly, weekly and daily actual measured energy for the Retriever bus.

Table 4-18: Total actual monthly measured energy

	Energy abs. by bus	Energy del. to bus	% Difference of energy abs. by bus	% Difference of energy del. to bus
Retriever Month 1	41,289.6	41,796.3	0.0123	0.0121
Retriever Month 2	39,085.0	39,836.2	0.0192	0.0189
Retriever Month 3	40,116.8	41,105.7	0.0247	0.0241
Retriever Month 4	40,469.0	41,336.7	0.0214	0.0210
Retriever Month 5	40,406.3	40,540.5	0.0033	0.0033
Retriever Month 6	39,931.5	43,392.9	0.0867	0.0798

Table 4-19: Total actual weekly measured energy

	Energy abs. by bus	Energy del. to bus	% Difference of energy abs. by bus	% Difference of energy del. to bus
Retriever Week 1	8,896.2	9,171.6	0.0310	0.0300
Retriever Week 2	9,009.1	9,294.8	0.0317	0.0307
Retriever Week 3	9,526.1	9,805.0	0.0293	0.0284
Retriever Week 4	9,222.2	9,497.4	0.0298	0.0290

Table 4-20: Total actual daily measured energy

	Energy abs. by bus	Energy del. to bus	% Difference of energy abs. by bus	% Difference of energy del. to bus
Retriever1 Day 1	2,537.3	2,588.3	0.0201	0.0197
Retriever1 Day 2	2,508.6	2,558.8	0.0200	0.0196
Retriever1 Day 3	2,503.3	2,553.4	0.0200	0.0196
Retriever1 Day 4	2,513.8	2,564.3	0.0201	0.0197
Retriever1 Day 5	2,568.7	2,621.0	0.0203	0.0199
Retriever1 Day 6	2,773.0	2,816.6	0.0157	0.0155
Retriever1 Day 7	2,587.9	2,640.6	0.0203	0.0199

The difference in the energy absorbed and delivered must be less than 2% to be acceptable. This acceptance level is the predefined level determined by the user and the smaller the acceptance level the higher the accuracy of the measured values. A percentage difference level less than 10% needs further investigation and levels higher than 10% is unacceptable meaning inaccurate input values.

The difference in the energy absorbed and delivered to the Retriever/Garsfontein region based on the monthly, weekly and daily measured values over the period of time of all the data under investigation is less than 2%. This means that the total amount of electrical energy delivered and absorbed in segment of the electrical distribution network is acceptable.

Table 4-21 to Table 4-23 shows the projected values as well as the percentage difference between the projected energy absorbed and actual energy absorbed by the monthly, weekly and daily measured values. One of the measures in identifying problem areas in the electrical distribution network is to compare the projected energy absorbed and the actual energy absorbed. If the percentage difference is less than 10% the difference is normal. A percentage difference less than 30% is assumed high and values higher than 30% are abnormal. Table 4-21 shows that there is no significant difference between the monthly projected energy absorbed and the actual energy absorbed. The weekly and daily projected energy absorbed and actual energy absorbed as shown in Table 4-22 and Table 4-23 shows that the percentage difference is less than 10 percent in both cases and this could be considered normal.

Table 4-22: Calculated technical losses for the monthly values

		Retriever Month 1	Retriever Month 2	Retriever Month 3	Retriever Month 4	Retriever Month 5	Retriever Month 6
Total network losses	Min	102.5	98.7	100.9	101.2	102.5	79.9
	Typical	494.0	471.0	482.6	485.7	487.9	439.2
	Max	885.5	843.4	864.3	870.2	873.2	798.6
Meter losses	Min	162.3	160.4	162.9	162.0	167.6	79.9
	Typical	243.4	240.6	244.4	243.0	251.4	119.8
	Max	324.5	320.8	325.8	324.0	335.2	159.7
Customer connection losses	Min	20.6	19.5	20.1	20.2	20.2	20.0
	Typical	41.3	39.1	40.1	40.5	40.4	39.9
	Max	61.9	58.6	60.2	60.7	60.6	59.9
Bus / Transformer losses	Min	20.9	19.9	20.6	20.7	20.3	21.7
	Typical	41.8	39.8	41.1	41.3	40.5	43.4
	Max	62.7	59.8	61.7	62.0	60.8	65.1
Energy delivered to bus	Min	40,960.4	39,039.5	40,283.6	40,509.9	39,729.7	42,525.0
	Measured	41,796.3	39,836.2	41,105.7	41,336.7	40,540.5	43,392.9
	Max	42,632.3	40,632.9	41,927.9	42,163.4	41,351.3	44,260.7
Projected total loss for bus	Min	306.3	298.6	304.4	304.1	310.6	201.4
	Typical	820.5	790.5	808.2	810.5	820.2	642.4
	Max	1,334.7	1,282.5	1,312.0	1,316.9	1,329.8	1,083.3
Projected energy absorbed	Min	40,654.1	38,740.9	39,979.2	40,205.8	39,419.1	42,323.6
	Typical	40,975.8	39,045.7	40,297.5	40,526.1	39,720.3	42,750.5
	Max	41,297.6	39,350.4	40,615.9	40,846.4	40,021.4	43,177.4
Energy absorbed BY bus	Min	40,463.8	38,303.3	39,314.4	39,659.7	39,598.2	39,132.9
	Measured	41,289.6	39,085.0	40,116.8	40,469.0	40,406.3	39,931.5
	Max	42,115.4	39,866.7	40,919.1	41,278.4	41,214.4	40,730.2
Percentage difference		0.8	0.1	0.4	0.1	1.7	6.6

Table 4-23: Calculated technical losses for the weekly values

		Retriever1 Week 1	Retriever1 Week 2	Retriever1 Week 3	Retriever1 Week 4
Total network losses	Min	22.4	22.9	23.8	18.4
	Typical	107.2	108.9	114.3	101.4
	Max	191.9	194.9	204.8	184.4
Meter losses	Min	36.4	37.6	38.0	18.4
	Typical	54.6	56.4	57.1	27.7
	Max	72.8	75.3	76.1	36.9
Customer connection losses	Min	4.4	4.5	4.8	4.6
	Typical	8.9	9.0	9.5	9.2
	Max	13.3	13.5	14.3	13.8
Bus / Transformer losses	Min	4.6	4.6	4.9	4.7
	Typical	9.2	9.3	9.8	9.5
	Max	13.8	13.9	14.7	14.2
Energy delivered to bus	Min	8988.2	9108.9	9608.9	9307.4
	Measured	9171.6	9294.8	9805.0	9497.4
	Max	9355.0	9480.7	10001.1	9687.3
Projected total loss for bus	Min	67.9	69.7	71.5	46.2
	Typical	179.8	183.7	190.7	147.8
	Max	291.7	297.6	309.9	249.4
Projected energy absorbed	Min	8920.3	9039.2	9537.4	9261.2
	Typical	8991.8	9111.2	9614.3	9349.6
	Max	9063.3	9183.1	9691.3	9437.9
Energy absorbed BY bus	Min	8718.2	8828.9	9335.6	9037.7
	Measured	8896.2	9009.1	9526.1	9222.2
	Max	9074.1	9189.3	9716.6	9406.6
Percentage difference		1.1	1.1	0.9	1.4

Table 4-24: Calculated technical losses for the daily values

		Retriever1 Day 1	Retriever1 Day 2	Retriever1 Day 3	Retriever1 Day 4	Retriever1 Day 5	Retriever1 Day 6	Retriever 1 Day 7
Total network losses	Min	6.4	6.3	6.3	6.3	6.5	5.4	6.6
	Typical	30.5	30.0	29.9	30.1	31.0	29.9	31.2
	Max	54.7	53.8	53.5	53.8	55.4	54.4	55.9
Meter losses	Min	10.2	10.1	10.1	10.2	10.8	5.4	10.8
	Typical	15.3	15.2	15.1	15.3	16.1	8.2	16.2
	Max	20.4	20.2	20.2	20.5	21.5	10.9	21.6
Customer connection losses	Min	1.3	1.2	1.2	1.2	1.3	1.4	1.3
	Typical	2.5	2.5	2.5	2.5	2.6	2.7	2.6
	Max	3.8	3.7	3.7	3.7	3.8	4.1	3.9
Bus / Transformer losses	Min	1.3	1.3	1.3	1.3	1.3	1.4	1.3
	Typical	2.6	2.6	2.6	2.6	2.6	2.8	2.6
	Max	3.9	3.8	3.8	3.8	3.9	4.2	4.0
Energy delivered to bus	Min	2,536.6	2,507.7	2,502.3	2,513.0	2,568.6	2,760.3	2,587.8
	Measured	2,588.3	2,558.8	2,553.4	2,564.3	2,621.0	2,816.7	2,640.7
	Max	2,640.1	2,610.0	2,604.5	2,615.6	2,673.4	2,873.0	2,693.5
Projected total loss for bus	Min	19.1	18.9	18.9	19.1	19.9	13.6	20.0
	Typical	51.0	50.2	50.1	50.5	52.3	43.6	52.7
	Max	82.8	81.5	81.3	81.9	84.7	73.6	85.3
Projected energy absorbed	Min	2,517.4	2,488.8	2,483.5	2,494.0	2,548.7	2,746.7	2,567.8
	Typical	2,537.3	2,508.6	2,503.3	2,513.9	2,568.7	2,773.1	2,588.0
	Max	2,557.3	2,528.5	2,523.2	2,533.7	2,588.8	2,799.4	2,608.1
Energy absorbed BY bus	Min	2,493.0	2,446.8	2,434.4	2,444.0	2,507.3	2,664.9	2,531.8
	Measured	2,543.9	2,496.7	2,484.1	2,493.9	2,558.5	2,719.3	2,583.5
	Max	2,594.8	2,546.7	2,533.8	2,543.8	2,609.7	2,773.7	2,635.2
Percentage difference		0.3	0.5	0.8	0.8	0.4	1.9	0.2

In Tables 4-16 to Table 4-18 the percentage differences for the monthly, weekly and daily values are less than 10 percent indicating that the energy usage for this residential area is normal. Table 4-19 to Table 4-21 shows that the percentage difference calculated over the

different periods for the projected losses in the electrical distribution network are almost equal to the percentage values.

Table 4-24: Percentage monthly difference of projected total losses

	Retriever Month 1	Retriever Month 2	Retriever Month 3	Retriever Month 4	Retriever Month 5	Retriever Month 6
Total network losses	1.206	1.206	1.198	1.198	1.228	1.027
Meter losses	0.594	0.616	0.606	0.600	0.633	0.280
Customer connection losses	0.101	0.100	0.100	0.100	0.102	0.093
Bus / Transformer losses	0.102	0.102	0.102	0.102	0.102	0.102
Total projected percentage loss per bus	2.002	2.025	2.006	2.000	2.065	1.503

Table 4-25: Percentage weekly difference of projected total losses

	Retriever1 Week 1	Retriever1 Week 2	Retriever1 Week 3	Retriever1 Week 4
Total network losses	1.192	1.195	1.189	1.085
Meter losses	0.607	0.619	0.594	0.296
Customer connection losses	0.099	0.099	0.099	0.099
Bus / Transformer losses	0.102	0.102	0.102	0.102
Total projected percentage loss per bus	2.000	2.016	1.983	1.581

Table 4-26: Percentage daily difference of projected total losses

	Retriever1 Day 1	Retriever1 Day 2	Retriever1 Day 3	Retriever1 Day 4	Retriever1 Day 5	Retriever1 Day 6	Retriever1 Day 7
Total network losses	1.204	1.197	1.194	1.196	1.205	1.079	1.207
Meter losses	0.603	0.604	0.605	0.610	0.628	0.294	0.626
Customer connection losses	0.100	0.100	0.099	0.099	0.100	0.098	0.100
Bus / Transformer losses	0.102	0.102	0.102	0.102	0.102	0.102	0.102
Total projected percentage loss per bus	2.009	2.002	2.000	2.007	2.035	1.572	2.035

Using Table 4-27 to Table 4-29 statistical approaches was used to evaluate the network over a monthly, weekly and daily period in the electrical distribution network. This statistical approach would identify the different problem areas using structured mathematical techniques.

The calculation of the p value returns the two-tailed p value of a paired t test. The t test generates a standard score value for each bus value with respect to the minimum, typical and maximum value of each of the different busses on the electrical distribution network. It returns a p value for each bus on the distribution using the two-tailed probability for the normal distribution. This function is used to assess the likelihood that the actual measured electrical energy output for a specific bus and the estimated electrical energy for the same bus are derived from the same electrical energy input bus on the distribution network. A small numerical p value indicates statistical significance in the t test.

The f test statistical function used in the model returns the one-tailed probability that the variances in the actual measured electrical energy and the estimated electrical energy are not significantly different. This function is used to determine whether the measured and estimated electrical energy have significantly different variances. A small numerical value indicates statistical significance in the f test.

The standard deviation could not be calculated in this network segment layout as there is only one bus and therefore the deviation if been calculated will tend to infinite. The confidence interval in the model calculates the mean of the bus of both the measured and estimated electrical energy. It is used in the model to determine, with a particular level of confidence the lowest and highest electrical energy level of use for a particular bus in the electrical distribution network. This level of confidence is compared to the actual measured value of the electrical energy used by the bus and the confidence interval should be an order or more lower than the actual measured electrical energy to be assumed correct. As there is only one bus under investigation the confidence interval is large. These results therefore are also omitted in the determination of the problem areas for the particular time interval.

Table 4-27: Statistical evaluation of the monthly data

	Retriever Month 1	Retriever Month 2	Retriever Month 3	Retriever Month 4	Retriever Month 5	Retriever Month 6
Determine p-value for Paired t-test	0.5987	0.8254	0.9820	0.8993	0.2396	0.3537
Significance (ftest)	586.27	531.07	554.83	551.42	662.35	1646.82
Confidence interval for population mean	41289.59	39084.97	40116.78	40469.03	40406.30	39931.52
Measured value of bus	41796.33	39836.21	41105.74	41336.65	40540.47	43392.88

Table 4-28: Statistical evaluation of the weekly data

	Retriever1 Week 1	Retriever1 Week 2	Retriever1 Week 3	Retriever1 Week 4
Determine p-value for Paired t-test	0.8778	0.8672	0.9073	0.8034
Significance (ftest)	132.10	134.84	138.64	146.96
Confidence interval for population mean	8896.17	9009.09	9526.12	9222.19
Measured value of bus	9171.60	9294.82	9805.02	9497.39

Table 4-29: Statistical evaluation of the daily data

	Retriever1 Day 1	Retriever1 Day 2	Retriever1 Day 3	Retriever1 Day 4	Retriever1 Day 5	Retriever1 Day 6	Retriever1 Day 7
Determine p-value for Paired t-test	0.7761	0.9883	0.9410	0.9356	0.9671	0.7129	0.9060
Significance (ftest)	34.74	34.60	35.44	35.68	35.20	48.25	35.16
Confidence interval for population mean	2543.91	2496.75	2484.10	2493.91	2558.51	2719.31	2583.51
Measured value of bus	2588.32	2558.83	2553.40	2564.32	2621.00	2816.67	2640.65

These statistical calculations can be subdivided into two group's namely statistical calculations and measured data verification. The statistical evidence group contains the t-test and f-test and the measured data verification group consists of the standard deviation and the confidence interval. The data verification group for this network segment was omitted as discussed above. From the statistical evidence group the network segment is identified as a problem area or a network segment working properly.

None of the weekly and daily statistical t-test calculated values were significant. The results from the t-test for month 5 and month 6 were more significant indicating a potential change in the network (a network correction). Using the f-test as a measure of the different diversity in the projected energy absorbed and actual energy absorbed in the electrical distribution network the monthly, weekly and daily values were not significant.

Comparing the t-test and the f-test as shown in Table 4-27 to Table 4-29 would yield that for the electrical distribution network segment to be correct both tests must indicate a

significant level and visa versa. From these statistical results the daily and weekly measured values seems to be inaccurate and no statistical evidence could be found to conclude that the network segment is operating correctly. For the monthly data the measured values are more accurate over a longer period of time and data collected over a month is the shortest time that could be used to identify potential problem areas. As new meters were installed in month 5 and month 6 the data collected for these months indicates a high level of significance, indicating that the network problems are solved of the first four months.

CHAPTER 5: CONCLUSIONS

5.1   Introduction

The main objective of this dissertation was discussed in chapter 1 and included a subset of specific objectives. This chapter will conclude with the value of the developed strategy as well as recommendation regarding future work based on the dissertation.

5.2   Conclusion on the objectives

The main objective of this dissertation was to develop a strategy to minimize electrical energy losses. To derive a strategy a model was constructed to identify the problem areas in an electricity distribution network and this was used to develop a strategy to minimize electricity losses in an electricity distribution network. The model calculated the technical losses and used it to derive the non-technical losses in the electricity distribution network. In evaluating an electrical distribution network technical and economical grounds were used. The technical evaluation was done on distribution feeders that supply customers with electricity and these distribution feeders were used to ensure continuity and quality of service. The economical performance of a distribution network was evaluated by the ratio of the amount of electricity delivered to the customer and the global cost of the electricity distribution network. This dissertation used the technical evaluation ground to develop a strategy that identified the different problem areas in an electrical distribution network. By solving these problem areas the technical evaluation improved and the amount of electricity delivered to the customer increased, therefore improving the economical benefit of the customer. The main objective was achieved by addressing a series of specific objectives.

- Conclusion on the model constructed to determine the technical losses

  An indirect approach was used to calculate the technical losses to be able to use a minimum amount of parameters needed from the field. The calculation of the technical losses in the model was calculated using a percentage estimation of the loss parameters defined for the different segments in the distribution network. The percentage

calculations in the model define a minimum and maximum percentage parameter for the different network segments in the distribution network. These parameters are used to calculate the losses of each segment in the electrical distribution network as a percentage of the input electrical energy to the network segment.

- Conclusion on determining a method to calculate the non-technical losses

    As discussed in chapter 3 non-technical losses in distribution networks cannot be calculated as these losses are due to human intervention in the distribution network. This was shown using the model developed for the determination of electrical energy losses in an electrical distribution network. Therefore the total electrical energy supplied to the distribution network includes the non-technical losses as a parameter.

- Conclusion on determining a procedure to identify the problem areas

    Problem areas were identified using the statistical methods as discussed in chapter 3. The investigation of the problem areas and the problem solving of the areas was done using inspection teams finding the causes of the electrical losses in electrical distribution network. As problems are identified in the problem areas procedures are followed to correct the different problems.

- Conclusion on constructing a matrix to prioritize the problem areas

    In chapter 4, four statistical calculations were used to determine a matrix in order to prioritize the problem areas in an electrical distribution network. The four statistical calculations were subdivided into two groups and from these two groups the final potential problem area identification was given in order of priority.

Addressing the specific objectives has ensured that all material necessary to meet the main objective has been covered. Energy supply companies will definitely benefit if they implement this strategy to minimize electrical energy losses in an electrical distribution network as it will identify the problem areas more accurately than currently been done. Using the procedures identified in the dissertation will ensure an effective identification of problem areas and rectifying the problems. It can be concluded that with the strategy

developed in this dissertation electrical supply companies will be able to estimate energy losses in their electrical distribution networks. They will surely benefit from these reductions in energy generation and system capacity as well as, reductions will occur in the cost of energy to the consumer.

5.3   Conclusions at the main campus of the University of Pretoria

The results obtain from the measured electrical data at the main campus of the University of Pretoria was used to proof that the model can identify potential problems in the electrical distribution network. In chapter 4 table 4-12 and table 4-13 were used to conclude that using the statistical evidence for the different network segments in the electrical distribution network problem areas in the electrical distribution network could be identified. The results from chapter 4 are prioritized as follows:

1) Hilda ring – *problem area*
2) East Campus ring – *problem area*
3) West Campus ring – *potential problem area*
4) Woman's Hostel ring – *potential problem area on lower level*
5) Main/HB bus – *potential problem area on lower level*
6) North Campus ring – *no problem*

The problem identification at the Women's Hostel ring and the Main/HB bus should be solved automatically as the lower order network segment problems are solved. It is therefore concluded that the model develop could identify potential problems in the electrical distribution network and a strategy could then be derived to resolve the problems.

5.4   Conclusions at the Tshwane Metropolitan Council

The aim of this case study was to determine the minimum period that would be sufficient to identify a potential problem in an electrical distribution network. The results obtained from the Tshwane Metropolitan Council indicate that the weekly and daily statistical t-test calculations were inconclusive because of the short period of time that the energy was

monitored. Using the f-test over the different periods of time as a measure of the different diversity in the projected energy absorbed and actual energy absorbed in the electrical distribution network the monthly, weekly and daily values were not significant.

Comparing the t-test and the f-test as shown in Table 4-27 to Table 4-29 the statistical results of the daily and weekly measured values seems to be inaccurate and no statistical evidence could be found to conclude that the network segment is operating correctly. For the monthly data the measured values are more accurate over a longer period of time and it can be concluded that the data collected over a month is the shortest period of time that could be used to identify potential problem areas in a electrical distribution network.

5.5   Recommendation and Future work

This section includes a recommendation for using the strategy developed in energy management programs as well as defining the scope for future work based on this material.

5.5.1.   Recommendation on the integration of the strategy into energy management programs

The starting point when looking at the strategy to minimize energy losses must be to determine the extent of the losses in the electrical distribution network. If no method is presently used to identify losses then a new action plan should be discussed using the model developed in this dissertation. Senior management in the energy management department should discuss this action plan and get line managers as well as employees involved in the initiative to get the electrical energy losses decreased.

The next step is to identify the electrical network layout as accurately as possible. With the network layout not correctly identified the model developed will not identify sections operating correctly. This network layout could then be used as the input for the model and the data can be collected and analyzed using the strategy presented in this dissertation.

The integral part of using the model and saving electrical energy is the plan to solve the problem areas. Management support and a plan to solve the potential problems areas is

vital in the practical implementation of the strategy to ensure that as soon as the problem area is identified by the model that the necessary actions are taken to ensure that the problem are been resolved.

5.5.2. Future work

If this dissertation had to be rewritten based on existing knowledge and experience, nothing would be changed. The length of this dissertation may be longer as more case studies would be included to reiterate the working of the strategy to minimize the electrical losses in an electrical distribution network. The purpose of this dissertation was to develop a strategy to minimize the electrical losses in an electrical distribution network and therefore the electrical data obtained from the University of Pretoria and Tshwane Metropolitan Council was used to identify problem areas and to develop the strategy to minimize electrical losses.

An area that could be investigated further is the possibility to expand the strategy to water networks and production line networks. These networks could be investigated as this dissertation can be implemented in every area that is energy related.

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Appendix A: General module Source Code

Source code for general module:

```
Public Sub ModelCalc()

    ApplyFormat
    CalcBusValues
    CalcLosses
    Correlation
    Statistics
    filedatagenerate

End Sub

Sub transformers()

"Determine if their are transformers on the bus
'Move to correct sheet
Sheets("MeterParameters").Select
Range("A1").Select

'Get meter names for busses on simulation
Dim counter As Integer 'counter for array
counter = Sheets("RingMatrix").Range("E1").value
Dim BusNames(65000, 5) As String

'array of meter names and connection on network
Dim testvalue(3) As String 'test value of bus
Dim LossValues(65000, 9) As Double     'Values of losses of network, meter, and customer
Dim LostTest(9) As Double
i = 0
h = 0
BusNames(i, 1) = ""
BusNames(i, 2) = ""
Dim valueadd As Boolean
valueadd = False
For x = 1 To counter     'Meters bus name FROM
testvalue(1) = ActiveCell.Offset(1 + x, 1).Range("A1").value
testvalue(2) = ActiveCell.Offset(1 + x, 2).Range("A1").value
testvalue(3) = ActiveCell.Offset(1 + x, 3).Range("A1").value

'Get the test values of the losses into a test array
For a = 1 To 3
LostTest(a) = ActiveCell.Offset(1 + x, 4 + a).Range("A1").value
Next a
For a = 4 To 9
LostTest(a) = ActiveCell.Offset(1 + x, 5 + a).Range("A1").value
Next a
For j = 0 To i
If (testvalue(1) = BusNames(j, 1)) And (testvalue(1) <> testvalue(2)) Then
```

```
valueadd = True
For a = 1 To 9
LossValues(i, a) = LossValues(i, a) + LostTest(a)
Next a
End If
Next j

If (valueadd = False) And (testvalue(1) <> testvalue(2)) Then
i = i + 1
BusNames(i, 1) = testvalue(1)
BusNames(i, 2) = testvalue(3)
For a = 1 To 9
LossValues(i, a) = LostTest(a)
Next a

Else
valueadd = False
End If
For j = 0 To h
If (testvalue(2) = BusNames(j, 3)) And (testvalue(1) <> testvalue(2)) Then
valueadd = True
End If
Next j
If valueadd = False And testvalue(1) <> testvalue(2) Then
Module5 - 2
h = h + 1
BusNames(h, 3) = testvalue(2)
BusNames(h, 4) = testvalue(3)
Else
valueadd = False
End If
Next x
If i = h Then
For j = 1 To i
For k = 1 To i
If (BusNames(j, 1) = BusNames(k, 3) And BusNames(j, 2) = BusNames(k, 4)) Then
BusNames(j, 5) = "CC"
Else
If (BusNames(j, 1) = BusNames(k, 3) And BusNames(j, 2) <> BusNames(k, 4)) Then
If (BusNames(j, 2) = "ST" Or BusNames(j, 4) = "ST") Then
BusNames(j, 5) = "DS"
Else
If (BusNames(j, 2) = "MV" Or BusNames(j, 4) = "MV") Then
BusNames(j, 5) = "DT"
Else
If (BusNames(j, 2) = "LV" Or BusNames(j, 4) = "LV") Then
BusNames(j, 5) = "CC"
End If
End If
End If
End If
```

```
End If
Next k
Next j
Else
ending "RingMatrix", "Fault in bus setup. Please revise your setup."
End If

'Move to correct sheet
Sheets("RingMatrix").Select
Range("A1").Select
For j = 1 To i
ActiveCell.Offset(j, 10).Range("A1").value = BusNames(j, 5)
Next j

'Move to correct sheet
Sheets("Correlation").Select
Range("A1").Select
For j = 1 To i
ActiveCell.Offset(1 + j, 0).Range("A1").value = BusNames(j, 1)
For a = 1 To 9
ActiveCell.Offset(1 + j, a).Range("A1").value = LossValues(j, a)
Next a
Next j
End Sub


Sub ApplyFormat()
'Clear all data
clearall
Dim workdir As String 'Working directory for the simulation
workdir = Sheets("procedure and macros").Range("F1").value + "\"

'Copy the MeterParameter values to RingMatrix sheet
Sheets("MeterParameters").Select
Range("A3:C3").Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Sheets("RingMatrix").Select

Range("A2").Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False

'Move to correct sheet
Sheets("RingMatrix").Select
Range("A1").Select

'Get meter names
Dim MyArray(65000) As String 'array of meter names
Dim counter As Integer 'counter for array
counter = Sheets("RingMatrix").Range("E1").value - 1
```

```
For x = 0 To counter
MyArray(x) = ActiveCell.Offset(1 + x, 0).Range("A1").value
Next x


'Enter headings
Sheets("RingMatrix").Select
Range("A2").Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Sheets("Data").Select
Selection.PasteSpecial Paste:=xlAll, Operation:=xlNone, SkipBlanks:=True _
, Transpose:=True
Range("A2").Select

'Move to correct sheet
Sheets("Data").Select 'Sheet name
Range("A2").Select 'Move to correct position

'Get external text files into sheet
For x = 0 To counter
With ActiveSheet.QueryTables.Add(Connection:= _
"TEXT;" + workdir + MyArray(x) + ".txt", _
Destination:=ActiveCell)
.name = MyArray(x)
.FieldNames = True
.RowNumbers = False
.FillAdjacentFormulas = False
.PreserveFormatting = True
.RefreshOnFileOpen = True
.RefreshStyle = xlOverwriteCells
.SavePassword = False
.SaveData = True
.AdjustColumnWidth = True
.RefreshPeriod = 50
.TextFilePromptOnRefresh = False
.TextFilePlatform = xlWindows
.TextFileStartRow = 1
.TextFileParseType = xlDelimited
.TextFileTextQualifier = xlTextQualifierDoubleQuote
.TextFileConsecutiveDelimiter = False
.TextFileTabDelimiter = True
.TextFileSemicolonDelimiter = False
.TextFileCommaDelimiter = False
.TextFileSpaceDelimiter = False
.TextFileColumnDataTypes = Array(9, 1, 9, 9, 9, 9)
.Refresh BackgroundQuery:=False
End With
ActiveCell.Offset(0, 1).Range("A1").Select
Next x
```

```
'Enter headings
Sheets("RingMatrix").Select
Range("A2").Select
Range(Selection, Selection.End(xlDown)).Select


Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Sheets("DataCalc").Select
Selection.PasteSpecial Paste:=xlAll, Operation:=xlNone, SkipBlanks:=True _
, Transpose:=True
Range("A2").Select

'Calculate the sum
For x = 0 To counter
ActiveCell.FormulaR1C1 = "=SUM(Data!RC:R[65534]C)"
ActiveCell.Offset(0, 1).Range("A1").Select
Next x

'Copy values of meter sums to RingMatrix
Range("A2").Select
Range(Selection, Selection.End(xlToRight)).Select
Selection.Copy
Sheets("RingMatrix").Select
Range("D2").Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=True

'Copy meters to monthsheet
Sheets("RingMatrix").Select
Range("A2").Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Sheets("Month checksheet").Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False
Range("B6:C61").Select
Application.CutCopyMode = False
Selection.Borders(xlDiagonalDown).LineStyle = xlNone
Selection.Borders(xlDiagonalUp).LineStyle = xlNone
With Selection.Borders(xlEdgeLeft)
.LineStyle = xlContinuous
.Weight = xlThin
.ColorIndex = xlAutomatic
End With
With Selection.Borders(xlEdgeTop)
.LineStyle = xlContinuous
.Weight = xlThin
.ColorIndex = xlAutomatic
End With
With Selection.Borders(xlEdgeBottom)
```

```
.LineStyle = xlContinuous
.Weight = xlThin
.ColorIndex = xlAutomatic
End With
With Selection.Borders(xlEdgeRight)
.LineStyle = xlContinuous
.Weight = xlThin
.ColorIndex = xlAutomatic
End With
With Selection.Borders(xlInsideVertical)
.LineStyle = xlContinuous
.Weight = xlThin
.ColorIndex = xlAutomatic
End With
With Selection.Borders(xlInsideHorizontal)
.LineStyle = xlContinuous
.Weight = xlThin
.ColorIndex = xlAutomatic
End With
Range("A1:G1").Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
ActiveSheet.PageSetup.PrintArea = "$A:$G"
ending "RingMatrix", "All data files imported"
End Sub

Sub CalcBusValues()
Dim workdir As String 'Working directory for the simulation
workdir = Sheets("procedure and macros").Range("F1").value + "\"

'Move to correct sheet
Sheets("RingMatrix").Select
Range("A1").Select

'Get meter names for busses on simulation
Dim counter As Integer 'counter for array
counter = Sheets("RingMatrix").Range("E1").value - 1
Dim BusNames(65000) As String 'array of meter names
Dim BusValue(65000, 2) As Double 'array of meter values
Dim testvalue As String 'test value of bus
i = 0
BusNames(i) = ""
Dim valueadd As Boolean
Dim test As Double
valueadd = False
For x = 0 To counter 'Meters bus name FROM
testvalue = ActiveCell.Offset(1 + x, 1).Range("A1").value
test = ActiveCell.Offset(1 + x, 3).Range("A1").value
For j = 0 To i
If testvalue = BusNames(j) Then
```

```
BusValue(j, 1) = BusValue(j, 1) + test
valueadd = True
End If
Next j
If valueadd = False Then
i = i + 1
BusNames(i) = testvalue
BusValue(i, 1) = test
Else
valueadd = False
End If
Next x

'Calculate the sum of the bus
For x = 0 To counter 'Meters bus name TO
testvalue = ActiveCell.Offset(1 + x, 2).Range("A1").value
test = ActiveCell.Offset(1 + x, 3).Range("A1").value
For j = 0 To i
If testvalue = BusNames(j) Then
BusValue(j, 2) = BusValue(j, 2) + test
valueadd = True
End If
Next j

If valueadd = False Then
i = i + 1
BusNames(i) = testvalue
BusValue(i, 1) = test
Else
valueadd = False
End If
Next x

For j = 1 To i
ActiveCell.Offset(j, 6).Range("A1").value = BusNames(j)
ActiveCell.Offset(j, 7).Range("A1").value = BusValue(j, 1)
ActiveCell.Offset(j, 8).Range("A1").value = BusValue(j, 2)
Next j

'Difference for power delevired - power absorbed by system
ActiveCell.Offset(1, 9).Range("A1").Select
ActiveCell.FormulaR1C1 = "=RC[-1]-RC[-2]"
Selection.Copy
ActiveCell.Offset(0, -1).Range("A1").Select
Selection.End(xlDown).Select
ActiveCell.Offset(0, 1).Range("A1").Select
Range(Selection, Selection.End(xlUp)).Select
ActiveSheet.Paste

"Calculate % difference of power delivered and power absorbed
Dim teller As Integer  'Value of bus ring to determine difference percentage
```

```
Sheets("Procedure and macros").Select
teller = Range("G1").value
Sheets("RingMatrix").Select
Range("O2").Select
ActiveCell.FormulaR1C1 = "=abs(RC[-5]/RC[-7]*100)"
Range("P2").Select
ActiveCell.FormulaR1C1 = "=abs(RC[-6]/RC[-7]*100)"
ActiveCell.Offset(0, -1).Range("A1:B1").Select
Selection.Copy

For a = 1 To teller - 1
ActiveCell.Offset(1, 0).Range("A1").Select
ActiveSheet.Paste
Next a

'End message
ending "RingMatrix", "All calculations done"
End Sub

Sub filedatgenerate()

'Move to correct sheet
Sheets("RingMatrix").Select
Range("A1").Select

'Copy meters to datamatrix.dat
Range("A2").Select
Workbooks.OpenText Filename:= _
workdir + "datamatrix.dat", Origin:= _
xlWindows, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(1, 1)
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Windows("GW11kV sub general.xls").Activate
Range("A2:C2").Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Windows("datamatrix.dat").Activate
Range("A1").Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False
Application.CutCopyMode = False
ActiveWorkbook.SaveAs Filename:= _
workdir + "datamatrix.dat", FileFormat:= _
xlText, CreateBackup:=False
ActiveWorkbook.Close
Range("A1").Select
```

```
'End message
ending "RingMatrix", "File saved"
End Sub


Sub CalcLosses()
"Calculate segment losses
'Get meter names
Dim naam(2) As String 'bus name FROM and, bus name TO
Dim CalcArray(1, 6) As Double 'factor min,factor max,sum of meter,loss calc
Dim counter As Integer 'counter for array
counter = Sheets("RingMatrix").Range("E1").value
Dim factor As String
For x = 1 To counter

'Get sum value of meter
Sheets("RingMatrix").Select
Range("A1").Select
CalcArray(1, 3) = ActiveCell.Offset(x, 3).Range("A1").value 'Get meter sum value
Sheets("MeterParameters").Select
Range("A1").Select
naam(1) = ActiveCell.Offset(1 + x, 1).Range("A1").value
naam(2) = ActiveCell.Offset(1 + x, 2).Range("A1").value
factor = ActiveCell.Offset(1 + x, 3).Range("A1").value 'Get bus factor value

"Calculate ALL meter losses of the network
If (naam(1) <> "") And (naam(1) <> naam(2)) Then

'Determine factor value to calculate network losses
If factor = "ST" Then CalcArray(1, 1) = Sheets("Procedure and
            macros").Range("C4").value 'Min
value of factor
If factor = "ST" Then CalcArray(1, 2) = Sheets("Procedure and
            macros").Range("D4").value   'Max value of factor
If factor = "MV" Then CalcArray(1, 1) = Sheets("Procedure and
            macros").Range("C6").value    'Min value of factor
If factor = "MV" Then CalcArray(1, 2) = Sheets("Procedure and
            macros").Range("D6").value    'Max value of factor
If factor = "LV" Then CalcArray(1, 1) = Sheets("Procedure and
            macros").Range("C8").value    'Min value of factor
If factor = "LV" Then CalcArray(1, 2) = Sheets("Procedure and
            macros").Range("D8").value    'Max value of factor
End If

If naam(1) = "" Then
factor = "CC" 'Customer connection losses
CalcArray(1, 1) = Sheets("Procedure and macros").Range("C9").value 'Min value of factor
CalcArray(1, 2) = Sheets("Procedure and macros").Range("D9").value 'Max value of factor
End If

"Calculate other losses
If ((naam(1) <> "") And (naam(1) = naam(2))) Or (factor = "OT") Then
```

```
factor = "OT"
CalcArray(1, 1) = Sheets("Procedure and macros").Range("C11").value
'Min value of factor
CalcArray(1, 2) = Sheets("Procedure and macros").Range("D11").value
'Max value of factor
End If

'Calculate the loss of segment
CalcArray(1, 4) = CalcArray(1, 3) * CalcArray(1, 1) / 100
'Minimum calculated loss of the meter on the segment
CalcArray(1, 6) = CalcArray(1, 3) * CalcArray(1, 2) / 100
'Maximum calculated loss of the meter on the segment
CalcArray(1, 5) = CalcArray(1, 3) * ((CalcArray(1, 1) + CalcArray(1, 2)) / 2) / 100
'Typical calculated loss of the meter on the segment

'Enter calculations in cells
ActiveCell.Offset(1 + x, 4).Range("A1").value = CalcArray(1, 3)
ActiveCell.Offset(1 + x, 5).Range("A1").value = CalcArray(1, 4)
ActiveCell.Offset(1 + x, 6).Range("A1").value = CalcArray(1, 5)
ActiveCell.Offset(1 + x, 7).Range("A1").value = CalcArray(1, 6)
ActiveCell.Offset(1 + x, 8).Range("A1").value = factor

'Calculate meter losses
'Add more accuracy to the meter losses 1%, 2% because some meters differ
CalcArray(1, 1) = Sheets("Procedure and macros").Range("C10").value
'Min value of factor
CalcArray(1, 2) = Sheets("Procedure and macros").Range("D10").value
'Max value of factor
CalcArray(1, 4) = CalcArray(1, 3) * CalcArray(1, 1) / 100
'Minimum calculated loss of the meter on the segment
CalcArray(1, 6) = CalcArray(1, 3) * CalcArray(1, 2) / 100
'Maximum calculated loss of the meter on the segment
CalcArray(1, 5) = CalcArray(1, 3) * ((CalcArray(1, 1) + CalcArray(1, 2)) / 2) / 100
'Typical calculated loss of the meter on the segment

'Enter calculations in cells
ActiveCell.Offset(1 + x, 9).Range("A1").value = CalcArray(1, 4)
ActiveCell.Offset(1 + x, 10).Range("A1").value = CalcArray(1, 5)
ActiveCell.Offset(1 + x, 11).Range("A1").value = CalcArray(1, 6)

'Calculate customer connection losses on bus name TO
If naam(2) = "" Then
CalcArray(1, 1) = Sheets("Procedure and macros").Range("C9").value 'Min value of factor
CalcArray(1, 2) = Sheets("Procedure and macros").Range("D9").value 'Max value of factor
CalcArray(1, 4) = CalcArray(1, 3) * CalcArray(1, 1) / 100 'Minimum calculated loss
                             of the meter on the segment
CalcArray(1, 6) = CalcArray(1, 3) * CalcArray(1, 2) / 100 'Maximum calculated loss
                             of the meter on the segment
CalcArray(1, 5) = CalcArray(1, 3) * ((CalcArray(1, 1) + CalcArray(1, 2)) / 2) / 100

'Typical calculated loss of the meter on the segment
```

```
'Enter calculations in cells
ActiveCell.Offset(1 + x, 12).Range("A1").value = CalcArray(1, 4)
ActiveCell.Offset(1 + x, 13).Range("A1").value = CalcArray(1, 5)
ActiveCell.Offset(1 + x, 14).Range("A1").value = CalcArray(1, 6)
End If
Next x
transformers

'Get counter for bus
Sheets("Procedure and macros").Select
counter = Range("G1").value 'Get the counter for about of busses on the network

"Calculate transformer losses and bus losses
Sheets("RingMatrix").Select
Range("A1").Select
For x = 1 To counter
CalcArray(1, 3) = ActiveCell.Offset(x, 8).Range("A1").value    'Get meter sum value
factor = ActiveCell.Offset(x, 10).Range("A1").value      'factor of the bus
If factor = "DS" Then
CalcArray(1, 1) = Sheets("Procedure and macros").Range("C5").value 'Min value of factor
CalcArray(1, 2) = Sheets("Procedure and macros").Range("D5").value 'Max value of factor
End If
If factor = "DT" Then
CalcArray(1, 1) = Sheets("Procedure and macros").Range("C7").value 'Min value of factor
CalcArray(1, 2) = Sheets("Procedure and macros").Range("D7").value 'Max value of factor
End If
If factor = "CC" Then
CalcArray(1, 1) = Sheets("Procedure and macros").Range("C9").value 'Min value of factor
CalcArray(1, 2) = Sheets("Procedure and macros").Range("D9").value 'Max value of factor
End If
CalcArray(1, 4) = CalcArray(1, 3) * CalcArray(1, 1) / 100 'Minimum calculated loss
                                        of the meter on the segment
CalcArray(1, 6) = CalcArray(1, 3) * CalcArray(1, 2) / 100 'Maximum calculated loss
                                        of the meter on the segment
CalcArray(1, 5) = CalcArray(1, 3) * ((CalcArray(1, 1) + CalcArray(1, 2)) / 2) / 100

'Typical calculated loss of the meter on the segment
'Enter calculations in cells
ActiveCell.Offset(x, 11).Range("A1").value = CalcArray(1, 4)
ActiveCell.Offset(x, 12).Range("A1").value = CalcArray(1, 5)
ActiveCell.Offset(x, 13).Range("A1").value = CalcArray(1, 6)
Sheets("Correlation").Select
Range("A1").Select
ActiveCell.Offset(1 + x, 10).Range("A1").value = CalcArray(1, 4)
ActiveCell.Offset(1 + x, 11).Range("A1").value = CalcArray(1, 5)
ActiveCell.Offset(1 + x, 12).Range("A1").value = CalcArray(1, 6)
Sheets("RingMatrix").Select
Range("A1").Select
Next x

'End message
```

```
ending "MeterParameters", "Losses calculated"
End Sub

Public Sub ending(sheet As String, message As String)
Sheets(sheet).Select
Range("A1").Select
MsgBox message
End Sub


Public Sub clearall()
Sheets("Month checksheet").Select
Range("B6:C65536").Select
Selection.Clear
Range("A1").Select
Sheets("RingMatrix").Select
Range("A2:IV65536").Select
Selection.Clear
Range("A1").Select
Sheets("DataCalc").Select
Range("A1:IV65536").Select
Selection.Clear
Range("A1").Select
Sheets("Data").Select
Range("A1:IV65536").Select
Selection.Clear
Selection.QueryTable.Delete
Range("A1").Select
Sheets("MeterParameters").Select
Range("E3:IV65536").Select
Selection.Clear
Range("A1").Select
Sheets("Correlation").Select
Range("A3:IV65536").Select
Selection.Clear
Range("A1").Select
Sheets("Statistics").Select
Range("A1:IV65536").Select
Selection.Clear
Range("A1").Select
End Sub
Sub Correlation()

'Get bus data from RingMatrix
Sheets("RingMatrix").Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Range("H2:H65535").Select
Selection.Copy
Sheets("Correlation").Select
Range("X3").Select
```

```
ActiveSheet.Paste
Sheets("RingMatrix").Select
Range("I2").Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Range("I2:I65535").Select
Application.CutCopyMode = False
Selection.Copy
Sheets("Correlation").Select
Range("O3").Select
ActiveSheet.Paste
Range("A1").Select

'Calculated min and max power limits for power delivered and absorbed by bus
Dim busse(6) As Double 'Calculated the max and min limitsof the power absorbed and
        delivered
Dim calc(24) As Double 'All the values n the sheet in numerical order
Dim counter As Integer
counter = Sheets("Procedure and macros").Range("G1").value
For x = 1 To counter
busse(2) = ActiveCell.Offset(1 + x, 14).Range("A1").value
busse(1) = busse(2) - (Sheets("Procedure and macros").Range("G13").value / 100 *
busse(2))
busse(3) = busse(2) + (Sheets("Procedure and macros").Range("H13").value / 100 *
busse(2))
busse(5) = ActiveCell.Offset(1 + x, 23).Range("A1").value
busse(4) = busse(5) - (Sheets("Procedure and macros").Range("G13").value / 100 *
busse(5))
busse(6) = busse(5) + (Sheets("Procedure and macros").Range("H13").value / 100 *
busse(5))

'Paste into cell
ActiveCell.Offset(1 + x, 13).Range("A1").value = busse(1)
ActiveCell.Offset(1 + x, 15).Range("A1").value = busse(3)
ActiveCell.Offset(1 + x, 22).Range("A1").value = busse(4)
ActiveCell.Offset(1 + x, 24).Range("A1").value = busse(6)

'Get all cell values of bus in array
For a = 1 To 24
calc(a) = ActiveCell.Offset(1 + x, a).Range("A1").value
Next a

'Calculate the min total losses of the specific bus
ActiveCell.Offset(1 + x, 16).Range("A1").value = 0
For a = 0 To 3
ActiveCell.Offset(1 + x, 16).Range("A1").value = ActiveCell.Offset(1 + x, 16).Range(
"A1").value + ActiveCell.Offset(1 + x, 3 * a + 1).Range("A1").value
Next a

'Calculate the typical total losses of the specific bus
ActiveCell.Offset(1 + x, 17).Range("A1").value = 0
```

```
For a = 0 To 3
ActiveCell.Offset(1 + x, 17).Range("A1").value = ActiveCell.Offset(1 + x, 17).Range(
"A1").value + ActiveCell.Offset(1 + x, 3 * a + 2).Range("A1").value
Next a

'Calculate the maximum total losses of the specific bus
ActiveCell.Offset(1 + x, 18).Range("A1").value = 0
For a = 1 To 4
ActiveCell.Offset(1 + x, 18).Range("A1").value = ActiveCell.Offset(1 + x, 18).Range(
"A1").value + ActiveCell.Offset(1 + x, 3 * a).Range("A1").value
Next a
'Calculate the projected power absorbed by the bus
For a = 0 To 2
ActiveCell.Offset(1 + x, 19 + a).Range("A1").value = ActiveCell.Offset(1 + x, 13 + a
).Range("A1").value - ActiveCell.Offset(1 + x, 16 + a).Range("A1").value
Next a

'Calculate the difference in percentage between the projected and measured power
absorbed
'Assume the projected power absorbed as reference point
For a = 0 To 2
ActiveCell.Offset(1 + x, 25 + a).Range("A1").value = Abs(ActiveCell.Offset(1 + x, 19
+ a).Range("A1").value - ActiveCell.Offset(1 + x, 22 + a).Range("A1").value) /
ActiveCell.Offset(1 + x, 19 + a).Range("A1").value * 100
Next a
Next x

roundall

'End message
ending "Correlation", "Losses and absorbed power projected and values correlated"
End Sub

Public Sub roundall()
Sheets("RingMatrix").Select
Range("D2").Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.NumberFormat = "0.00"
Range("H2").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.NumberFormat = "0.00"
Range("A1").Select
Sheets("DataCalc").Select
Range("A2").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
```

```
Selection.NumberFormat = "0.0"
Range("A1").Select
Sheets("Data").Select
Range("A2").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.NumberFormat = "0.0"
Range("A1").Select
Sheets("MeterParameters").Select
Range("E3:O3").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.NumberFormat = "0.0"
Range("A1").Select
Sheets("Correlation").Select
Range("B3").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.NumberFormat = "0.0"
Range("A1").Select
End Sub

Sub Statistics()
Dim counter As Integer
Sheets("Procedure and macros").Select
counter = Range("G1").value

'Copy bus names to Statistics sheet
Sheets("Correlation").Select
Range("A3").Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Sheets("Statistics").Select
Range("A2").Select
ActiveSheet.Paste

'Copy bus values projected and measured to Statistics sheet
Sheets("Correlation").Select
Range("T3:Y3").Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Sheets("Statistics").Select
Range("B2").Select
```

```
ActiveSheet.Paste

"Transpose the busnames and insert a column space
Range("A2").Select
Range(Selection, Selection.End(xlDown)).Select
Application.CutCopyMode = False
Selection.Copy
Range("B1").Select
Selection.PasteSpecial Paste:=xlAll, Operation:=xlNone, SkipBlanks:=False _
, Transpose:=True
Range("A2").Select
Range(Selection, Selection.End(xlDown)).Select
Selection.ClearContents
'Transpose the bus values from a N X 6 matrix to a 6 X N matrix
Range("B2").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Application.CutCopyMode = False
Selection.Copy
Selection.End(xlDown).Select
ActiveCell.Offset(2, 0).Range("A1").Select
Selection.PasteSpecial Paste:=xlAll, Operation:=xlNone, SkipBlanks:=False _
, Transpose:=True
Range("B2").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Application.CutCopyMode = False
Selection.ClearContents
Selection.End(xlDown).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Cut
Selection.End(xlUp).Select
ActiveCell.Offset(1, 0).Range("A1").Select
ActiveSheet.Paste

'Computation text entered
Range("A2").Select
ActiveCell.Offset(7, 0).Range("A1").Select
ActiveCell.FormulaR1C1 = "Determine p-value for Paired t-test"
ActiveCell.Offset(1, 0).Range("A1").Select
ActiveCell.FormulaR1C1 = "Significance (ftest)"
ActiveCell.Offset(1, 0).Range("A1").Select
ActiveCell.FormulaR1C1 = "Standard deviation of population"
ActiveCell.Offset(1, 0).Range("A1").Select
ActiveCell.FormulaR1C1 = "Confidence interval for population mean"
ActiveCell.Offset(1, 0).Range("A1").Select
ActiveCell.FormulaR1C1 = "Measured value of bus"
ActiveCell.Offset(1, 0).Range("A1").Select

"Compute statistics
```

```
'Initial stat
Range("A1").Select
ActiveCell.Offset(8, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=TTEST(R[-7]C:R[-5]C,R[-4]C:R[-2]C,2,1)"
Range("B10").Select
ActiveCell.FormulaR1C1 = "=FTEST(R[-7]C:R[-5]C,R[-4]C:R[-2]C)"
Range("B11").Select
ActiveCell.FormulaR1C1 = "=STDEV(R[-9]C:R[-4]C)"
Range("B12").Select
ActiveCell.FormulaR1C1 = "=CONFIDENCE(R[-3]C,R[-1]C,COUNT(R[-10]C:R[-5]C))"
ActiveCell.Offset(-6, 0).Range("A1:IU1").Select
Application.CutCopyMode = False
Selection.Copy
ActiveCell.Offset(7, 0).Range("A1").Select
ActiveSheet.Paste
'Copy stat formula
For a = 1 To counter - 1
Range("B9:B12").Select
Selection.Copy
ActiveCell.Offset(0, a).Range("A1").Select
ActiveSheet.Paste
Next a

'Paste values as values and remove formulas
Range("B9:IV13").Select
Application.CutCopyMode = False
Selection.Copy
Range("B15").Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
False, Transpose:=False
Application.CutCopyMode = False
Selection.Cut
Range("B9").Select
ActiveSheet.Paste

'Rounding
Range("B9:IV9").Select
Selection.NumberFormat = "0.00000"
Range("B10:IV10").Select
Selection.NumberFormat = "0.0000"
Range("B11:IV13").Select
Selection.NumberFormat = "0.00"

'Delete rows of bus information
Range("A2:IV8").Select
Selection.EntireRow.Delete

'End message
ending "Statistics", "Statistics calculated"
End Sub
```

Appendix B: General strategy Source Code

```
Sub Calc_Mean()
'Clear the contents of general
Sheets("General").Select
ClearMonth

'Variables to determine means of the different months
Dim GeneralNames(64000) As String
Dim GeneralValues(64000, 28) As Double
Dim GeneralCounter(64000) As Integer
Dim GeneralMean(64000, 28) As Double
Dim BusNames(64000) As String
Dim BusValues(64000, 28) As Double
Dim MonthCounter As Integer
Dim MonthNames(64000) As String
Dim ProjectedPower(64000, 255) As Double
Dim MeasuredPower(64000, 255) As Double

'Get the total of the months
Windows("General Model.xls").Activate
Sheets("Procedure and macros").Select
MonthCounter = Range("J1").Value

'Get the names of the different months
Windows("General Model.xls").Activate
Sheets("Procedure and macros").Select
Range("I1").Select
For a = 1 To MonthCounter
MonthNames(a) = ActiveCell.Offset(a, 0).Range("A1").Value
Next a
Windows("General Strategy.xls").Activate

'Get values of busses in the month
Dim BusTeller As Integer 'Count the busses in the month sheet
Dim GeneralTeller As Integer 'Count the busses in general
For k = 1 To MonthCounter

'Select the sheet
Sheets(MonthNames(k)).Select
BusTeller = CountValues(MonthNames(k)) 'Count the busses in the month sheet
Range("A2").Select

'Get bus values and names into array
For a = 1 To BusTeller
BusNames(a) = ActiveCell.Offset(a, 0).Range("A1").Value
For b = 1 To 28
BusValues(a, b) = ActiveCell.Offset(a, b).Range("A1").Value
Next b
```

```
Next a
Dim test As Boolean
For a = 1 To BusTeller
test = True
For b = 0 To GeneralTeller
If GeneralNames(b) = BusNames(a) Then
test = False
GeneralCounter(b) = GeneralCounter(b) + 1
For c = 1 To 28
GeneralValues(b, c) = GeneralValues(b, c) + BusValues(a, c)
Next c
ProjectedPower(b, k) = BusValues(b, 20)
MeasuredPower(b, k) = BusValues(b, 23)
End If
Next b
If test = True Then
GeneralTeller = GeneralTeller + 1
GeneralNames(GeneralTeller) = BusNames(a)
GeneralCounter(GeneralTeller) = 1
For c = 1 To 28
GeneralValues(GeneralTeller, c) = BusValues(a, c)
Next c

ProjectedPower(GeneralTeller, k) = BusValues(a, 20)
MeasuredPower(GeneralTeller, k) = BusValues(a, 23)
End If
Next a
Next k

'Calculate the mean
For a = 1 To GeneralTeller
For b = 1 To 28
GeneralMean(a, b) = GeneralValues(a, b) / GeneralCounter(a)
Next b
Next a

'Write names and means in General sheet
Sheets("General").Select
Range("A2").Select
For a = 1 To GeneralTeller
ActiveCell.Offset(a, 0).Range("A1").Value = GeneralNames(a)
For b = 1 To 28
ActiveCell.Offset(a, b).Range("A1").Value = GeneralMean(a, b)
Next b
ActiveCell.Offset(a, 29).Range("A1").Value = GeneralCounter(a)
Next a

'Rounding the general sheet
Range("B3:Y65536").Select
Selection.NumberFormat = "0.0"
Range("Z3:Z65536").Select
```

```
Selection.NumberFormat = "0.00000"
Range("AA3:AA65536").Select
Selection.NumberFormat = "0.0000"
Range("AB3:AC65536").Select
Selection.NumberFormat = "0.0"
Range("AD3:AD65536").Select
Selection.NumberFormat = "0"

"Do a f test on the months to determine the significance of the data
'Clear projected sheet
Sheets("Projected stats").Select
Range("A1:IV65536").Select
Application.CutCopyMode = False
Selection.ClearContents

'Enter month names in statistics sheet
Range("A1").Select
For a = 1 To MonthCounter
ActiveCell.Offset(0, a).Range("A1").Value = MonthNames(a)
Next a

'Enter values in projected statistics sheet
Range("A1").Select
For a = 1 To GeneralTeller
ActiveCell.Offset(a, 0).Range("A1").Value = GeneralNames(a)
For b = 1 To MonthCounter
ActiveCell.Offset(a, b).Range("A1").Value = ProjectedPower(a, b)
Next b
Next a

'Clear statistics sheet
Sheets("Measured stats").Select
Range("A1:IV65536").Select
Application.CutCopyMode = False
Selection.ClearContents

'Enter month names in statistics sheet
Range("A1").Select
Module1 - 3
For a = 1 To MonthCounter
ActiveCell.Offset(0, a).Range("A1").Value = MonthNames(a)
Next a

'Enter values in measured statistics sheet
Range("A1").Select
For a = 1 To GeneralTeller
ActiveCell.Offset(a, 0).Range("A1").Value = GeneralNames(a)
For b = 1 To MonthCounter
ActiveCell.Offset(a, b).Range("A1").Value = MeasuredPower(a, b)
Next b
Next a
```

```
ending "General", "The mean of the different busses was calculated"
End Sub
Sub Copy_data()

"Test if data must be replaced
Dim TestValue As Boolean
Windows("General Model.xls").Activate
Sheets("Procedure and macros").Select
TestValue = Range("D2").Value
If TestValue = True Then

"Copy the selected values of the model to the month sheet under investigation
Dim MonthName As String
Windows("General Model.xls").Activate
Sheets("Procedure and macros").Select
MonthName = Range("D1").Value

'Month data clear
Windows("General Strategy.xls").Activate
On Error GoTo ErrorHandler
Sheets(MonthName).Select
ClearMonth

'Copy correlation sheet values to sheet
Windows("General Model.xls").Activate
Sheets("Correlation").Select
Range("A3:Y65536").Select
Selection.Copy
Windows("General Strategy.xls").Activate
Sheets(MonthName).Select
Range("A3").Select
ActiveSheet.Paste

'Copy data from statistic evaluation for the month under investigation
Windows("General Model.xls").Activate
Sheets("Statistics").Select
Range("B2:IV5").Select
Selection.Copy
Windows("General Strategy.xls").Activate
Range("Z3").Select
Selection.PasteSpecial Paste:=xlAll, Operation:=xlNone, SkipBlanks:=False,
Transpose:=True
End If
ending MonthName, "Data copied to month " + MonthName
Exit Sub 'error handler exit
ErrorHandler:
ending "General", "Month name does not match month name in the strategy"
Exit Sub
End Sub

Public Sub ending(sheet As String, message As String)
```

```
Sheets(sheet).Select
Range("A1").Select
MsgBox message
End Sub

Sub ClearMonth()
Range("A3:IV65536").Select
Application.CutCopyMode = False
Selection.ClearContents
End Sub

Function CountValues(Month As String) As Integer
Sheets(Month).Select
Range("A1").Select
ActiveCell.FormulaR1C1 = "=COUNTA(R[2]C:R[65535]C)"
CountValues = Range("A1").Value
Selection.ClearContents
End Function
```

Appendix C: University of Pretoria Data Format Source Code

```
unit convert;
interface
uses
Windows, Messages, SysUtils, Classes, Graphics, Controls, Forms, Dialogs,
StdCtrls;
type
TForm1 = class(TForm)
Button1: TButton;
Button2: TButton;
Edit1: TEdit;
Label1: TLabel;
Button3: TButton;
Label4: TLabel;
Label2: TLabel;
Label3: TLabel;
Label5: TLabel;
Button4: TButton;
Button5: TButton;
procedure Button1Click(Sender: TObject);
procedure Button3Click(Sender: TObject);
procedure Button2Click(Sender: TObject);
procedure Button4Click(Sender: TObject);
procedure Button5Click(Sender: TObject);
private
{ Private declarations }
public
{ Public declarations }
end;
var

Form1: TForm1;
implementation
uses shematics;
{$R *.DFM}

procedure fileconverter(maand:string;format:string;var instruksie:string);
begin
instruksie := 'copy ' + maand + format + '.txt ' + format + '.txt';
end;
procedure getdataformatfile(leerto : string;leerfrom : string);
var
instruk, form : string;
i : integer;
leername, data : textfile;
begin
assignfile(data,leerto);
rewrite(data);
```

```
assignfile(leername,leerfrom);
reset(leername);
while not eof(leername) do
begin
readln(leername,instruk);
i := 1;
Page 1
convert
form := '';
repeat
form := form + instruk[i];
inc(i);
until instruk[i] = #9;
writeln(data,form);
end;
closefile(data);
closefile(leername);
end;

procedure TForm1.Button1Click(Sender: TObject);
var
name : string;
instruk, form : string;
leername, data : textfile;
begin
getdataformatfile('dataformat.dat','datamatrix.dat');
assignfile(data,'convertdata.bat');
rewrite(data);
assignfile(leername,'dataformat.dat');
reset(leername);
while not eof(leername) do
begin
readln(leername,instruk);
fileconverter(Edit1.Text,instruk,form);
writeln(data,form);
end;
closefile(data);
closefile(leername);
Label2.Color := clGreen;
end;
procedure Validate(leer : string);
var
A : string;
data, fop : textfile;
date1, date2, code : integer;
begin
date1 := 0;date2 := 1;
assignfile(data,leer);
reset(data);
assignfile(fop,'fop');
rewrite(fop);
```

```
readln(data,A);
while not eof(data) do
begin
val(A[1]+A[2],date1,code);
if (A[1] <> 'D') then
begin
if (date1 >= date2) then
begin
writeln(fop,A);
val(A[1]+A[2],date2,code);
end;
end;
readln(data,A);
end;
rewrite(data);
reset(fop);
while not eof(fop) do
begin
readln(fop,A);
writeln(data,A);
end;
closefile(data);
closefile(fop);
erase(fop);
end;

procedure TForm1.Button2Click(Sender: TObject);
var
A, name : string;
leername : textfile;

begin
assignfile(leername,'dataformat.dat');
reset(leername);
while not eof(leername) do
begin
readln(leername,A);
Validate(A+'.txt');
end;
Label3.Color := clGreen;
end;
procedure TForm1.Button3Click(Sender: TObject);
var
name : string;
A : string;
data, leername : textfile;
begin
assignfile(leername,'dataformat.dat');
reset(leername);
while not eof(leername) do
begin
```

```
readln(leername,A);
name := Edit1.Text + A + '.txt';
assignfile(data,name);
rewrite(data);
closefile(data);
end;
closefile(leername);
Label4.Color := clGreen;
end;
procedure TForm1.Button4Click(Sender: TObject);
var
A : string;
leername : textfile;
begin
assignfile(leername,'delmonthdata.bat');
rewrite(leername);
A := 'del ' + Edit1.Text +'*.txt';
writeln(leername,A);
convert
closefile(leername);
Label5.Color := clGreen;
end;
procedure TForm1.Button5Click(Sender: TObject);
var
RF:TForm2;
begin
RF:=TForm2.Create(self);
RF.ShowModal;
RF.Free;
end;
end.
```

Appendix D: Garsfontein/Retriever Data Format Source Code

```
Sub GarsfonteinDataFormat()
'
' GarsfonteinDataFormat Macro
Windows("Lys.xls").Activate
Sheets("Parameters").Select
Nommer = Range("B4").Value
File_Copy_Months (Nommer)
Data_Matrix ("Text file creater months")
End Sub

Sub File_Copy_Months(Original_sheet)
'Import headings into file
Windows("Lys.xls").Activate
Sheets("Text file creater months").Select
Rows("1:1").Select
Selection.Clear
ActiveCell.Offset(1, 0).Range("A1").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Clear
Windows("Garsfontein data.xls").Activate
Sheets(Original_sheet).Select
Range("G1").Select
Range(Selection, Selection.End(xlToRight)).Select
Selection.Copy
Windows("Lys.xls").Activate
Range("B1").Select
ActiveSheet.Paste

'Import data into file
Windows("Lys.xls").Activate
Sheets("Text file creater months").Select
Range("A2:IV65536").Select
Selection.Clear
Windows("Garsfontein data.xls").Activate
Sheets(Original_sheet).Select
Range("A2").Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
```

```
Windows("Lys.xls").Activate
Sheets("Text file creater months").Select
Range("A2").Select
ActiveSheet.Paste
Windows("Garsfontein data.xls").Activate
ActiveWindow.SmallScroll Down:=-18
Range("G2").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Application.CutCopyMode = False
Selection.Copy
Windows("Lys.xls").Activate
Range("B2").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
    :=False, Transpose:=False
Range("A2").Select
Selection.End(xlDown).Select
ActiveCell.Offset(1, 1).Range("A1").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Application.CutCopyMode = False
Selection.Clear
End Sub

Sub Data_Matrix(sheet As String)
Dim Naam(65000) As String
Dim Val(65000) As Double
Dim Interval(65000) As String
Windows("Lys.xls").Activate
Sheets(sheet).Select
Range("A1").Select

'Get months into array and write to different text files to import in model
For J = 1 To Sheets("Parameters").Range("B3").Value
Sheets(sheet).Select
Interval(J) = ActiveCell.Offset(0, J).Range("A1").Value

'Get parameters into array and write to different text files to import in model
For I = 1 To Sheets("Parameters").Range("B2").Value
Sheets(sheet).Select
Naam(I) = ActiveCell.Offset(I, 0).Range("A1").Value
Val(I) = ActiveCell.Offset(I, J).Range("A1").Value

Windows("FOP.txt").Activate
```

```
ActiveWorkbook.SaveAs Filename:=workdir + Naam(I) + ".txt", FileFormat:=xlText,
CreateBackup:=False
Call CreateAfile(Naam(I), Interval(J), Val(I))
Next I
Next J
End Sub
```