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FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

DEPARTMENT OF ELECTRONIC & COMPUTER ENGINEERING TECHNOLOGY

DISSERTATION TOPIC:
Investigation and Mitigation of Technical Electric Power Losses within City Power Distribution Network: South African Case Study

QUALIFICATION: Magister Technologiae in Electrical Engineering (M-Tech)

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COMPILED BY: MR S.R Bakana (200670380)

Supervisor: Prof B. Twala
Abstract

The national grid is found more constrained, influenced by the growth in population and electrical usage, in addition to South Africa’s electricity sole power supplier (Eskom’s) load shedding scenario due to generating constraints. As the distribution network change its normal business, energy efficiency is the dominating term and the reduction of technical losses is one of the sections that needs attention in the emerging economy of South Africa. This dissertation evaluates different loads (residential, commercial and industrial), utilizing calculations through load factor improvement and simulation (DIGSILENT) methodologies in order to develop accurate and authentic results. These results are further analysed to develop optimum solution, mainly around improving the load factor with battery energy storage by peak shaving. The dissertation focuses on improving technical losses due to circulating current (I^2R), thereby improving the overall energy efficiency that can further boost the operational efficiency and planning equipment’s of the electrical network when a battery energy storage is involved.
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1 Chapter: Introduction

1.1 Perspective

South Africa, officially known as the Republic of South Africa, is located in the Southern African region of Africa. With a population of 53.1 million (2013: World Bank). The country is located between Atlantic and Indian Oceans, with geographical co-ordinates of 30.0000° S, 25.0000° E (2011: A. Mitchell). The history of the country is derived from the colonial rule of the past and (2009: R. Inglesi) the same colonial rule adopted a policy shift in the 1940’s, being informed by colour of the skin, termed as Apartheid.

The Apartheid government tried to remain relevant to their constituencies while accomplishing their power, through creation of an unequal society, which oppressed the rights of citizens and the right for the basic needs. By applying different development rates between the black and the white population and that lead to an unequal society. These inequalities being created were socially and income characterised by the government (2009: R. Inglesi).

In the 1970’s and 1980’s there were conferences in the United Nations, known as the “World Conference Against Racism”, which yielded to a significant movement that pressurised investors to disinvest from South African companies (2009: R. Inglesi). Early 1990’s the sanctions were withdrawn and the economy of the country started to rise (2009: R. Inglesi). The new government of democracy attracted a new market, that new market attracted new technology, new products and new investments (2009: R. Inglesi).

That boosted the economy in all sectors, particular the industrial sector, South Africa is considered the most industrialised region of the African continent, by observing the recorded growth that was above four percent and at a better stage compared to the time of colonialism (2009: R. Inglesi). While the economy appreciated, the government was faced with uncountable infrastructure and
service delivery backlogs. The bottleneck of electricity was amongst the priorities (2009: R. Inglesi).

Majority of the population by the time the new government took over had no access to basic needs (shelter, electricity and water) (2009: R. Inglesi). The alternative energy used was derived from paraffin, wood and gas, as the source of domestic energy (2009: R. Inglesi). The new government started to restructure the country by introducing efforts to eliminate inequalities and basic electricity services or bringing electricity to the people, remained their task to fulfil completely.

As electricity is critical to almost every aspect of the economy of South Africa and social development, (2005: H. Winkler) it depends on the way it is produced, transported and used. The challenge in South Africa is to provide affordable, adequate and reliable energy, even though the access to electricity has increased from one-third to two-thirds of the population since the new government of democracy (2005: H. Winkler). (2014: H. Trollip et al.) Energy demand has continuously growing steadily around the 3.5 percent per year.

Countries in the Sub-Saharan region are experiencing difficulties to supply sufficient electricity demand for their customers, mostly residential and industrial customers (2011: KPMG in South Africa’s Global Infrastructure and Project Group). Other countries where source of generation is hydro power, difficulties are experienced during drought seasons, as this model of generation depends on the rainfall. In South Africa, the case is different, as the reason corresponds with the growth of the industrial demand (2011: KPMG in South Africa’s Global Infrastructure and Project Group).

The South African electricity producer is amongst the largest generators of electricity in the continent and being 16th worldwide, and that makes it vitally important for the Southern African Developing Countries (SADC) region (2011: KPMG in South Africa’s Global Infrastructure and Project Group). South African Electricity Supply Industry (ESI) is only dominated by the state own entity,
Eskom, which ranks ninth in the world, in terms of electricity sales (2011: KPMG in South Africa’s Global Infrastructure and Project Group).

The state entity in South Africa generates equal to the approximately half of the electricity to supply the continent, Eskom generate 96% of South Africa’s electricity requirement (2005: A. Clark et al.). Eskom is in-charge of the high voltage transmission grid and supply almost half of its electricity direct to customers and the remaining power being sold to local distribution authorities (2005: A. Clark et al.). Below outlines the structure of the electrical power industry in South Africa.

![Power industry in South Africa](image)

**Figure 1-1:** Power industry in South Africa (2005: A. Clark et al.)

Eskom has ten large coal fired stations, mostly situated on coal mines in the north-east of South Africa, and own the only Africa’s nuclear station in Cape Town, known as Koeberg. There is uncertain hydro-electric on the Orange River (2005: A. Clark et al.). There are back up gas turbines and power stations own by municipalities and only account for the one percent of the total generation of electrical power, where the remaining three percent being produced by the private sector for own usage (2005: A. Clark et al.).
Eskom problems are problems same faced by municipalities and citizens in particular. Eskom as the largest power producer was forecasted in 2010 to 2030 and the demand was respectively 45 000 MW to 85 000 MW, this indicates more attention and alternatives needed to balance the current demand (2011: KPMG in South Africa’s Global Infrastructure and Project Group).

In an emerging economy like South Africa, research in electrical distribution industry has been given lesser attention and research in this sector is been negatively associated with scattered data and outdated one’s, including the unrecorded, even lack track in collecting data (2011: KPMG in South Africa’s Global Infrastructure and Project Group).

1.2 Municipal distributor (City Power Johannesburg)

City Power Johannesburg was founded in 2000 and subsequently in 2001 on the 19th of December, the National Electricity Regulator granted this independent municipal entity owned by the City of Johannesburg a distribution electrical licence (2014: City Power Draft Business Plan 2012 – 2016). It is found that a possible 300 000 customers are electrically connected to City Power’s grid and the customers are a mix from residential, commercial to industrial (2014: City Power Draft Business Plan 2012 – 2016). The business of City Power is characterised by purchase, distribution and sales of electricity within City of Johannesburg electricity boundaries.

As City Power supply electricity to City of Johannesburg, the areas supplied are shared with Eskom, for instance, Ivory Park, Soweto and Sandton are Eskom (2014: City Power Draft Business Plan 2012 – 2016). A map stipulating the areas supplied by both City Power and Eskom is presented by the below figure.
1.3 Electricity situation

Eskom problems are problems same faced by municipalities and citizens in particular. Eskom as the largest power producer was forecasted in 2010 to 2030 and the demand was respectively 45 000 MW to 85 000 MW (2011: KPMG in South Africa’s Global Infrastructure and Project Group), this indicate more attention and alternatives needed to balance the current demand.

The respond from Eskom yielded to the withdrawal of other equipment, normally withdrawals is performed for equipment due for maintenance as the equipment of electrical system cannot last for eternity and should be reliable. At this time, such withdrawals are conducted in order to share loads in different times and this sharing of power is known as load shedding.

The current black outs in South Africa, seems as a trending gesture from economical view point, as it was recorded in 2008 that the economical lost was approximate R50 billion due to load shedding (2008: R. Hartley) and (2008: Reuters “Eskom power crisis to remain for years”) stipulate that the current load shedding will last longer. Eskom as the electricity supply is pressured by the electricity demand in the country and the same pressure is felt by the
municipalities and bulk customers, hence it load shed. This is because of the generation problems (2015: Load shedding frequently asked questions).

The terms of black outs and load shedding, is simple defined by the (2015: Load shedding frequently asked questions) as the electrical system becomes unbalanced which can influence a trip that can last longer for restoration and the last measure resort to prevent the collapse of the electrical system, as the sharing occurs within the customers for the available electricity, respectively. The objective of load shedding is to remove load from power system where there are imbalances between the electricity available and the demand electricity.

With the current capacity constraints, saving electricity also means that the load on the national power system is reduced (2015: Load shedding frequently asked questions), saving electricity by using energy efficient appliances, switch off equipment when not in use, and using alternative sources of electrical energy has benefits such as less pollution, reduced electrical cost, better usage of natural resources (coal and fuel) and reduced tear and wear on the power stations transmission and distribution systems (2015: Load shedding frequently asked questions). Hence, saving electricity can assist to prevent the need for load shedding (2015: Load shedding frequently asked questions).

1.4 Distribution system

South Africa like any other developing world has been found in electricity crisis and normally termed load shedding, this crisis arises economic treats towards the country’s economic growth, as the country’s economy is electricity driven. After the new government of democracy, the utilization of the electrical energy increased and is still.

Electrical energy before utilized, is generated, transmitted through some resistance, transformed to a required level of utilization. What naturally occurs in practical is that the generated electricity is not equally delivered to the
destination required for the utilization as generated and that implies, between the source of electricity and the load there are losses accumulated.

The losses found in electrical system are unavoidable and cannot be ignored but only reduced through different approaches and on system components connected to the system reviewed. Before reducing these losses, firstly what constitute these losses should be understood, as this normally directs the determination of authentic approach and by understanding the formation of losses an investigation has to be undertaken, then later a mitigation approach is determined as a solution to reduce the losses.

With literature that mostly complement the transmission systems and where the literature in distribution systems are still based on the transmission literature, this research aims in contributing to the distribution system literature. Power losses are divided into two and referred to technical and non-technical power losses, where technical losses are found to be that influenced by the load current and the non-technical losses being influenced by theft and faulty meters.

The approach is to investigate the technical losses found in the distribution network and this research will focus only on the technical losses formation, what constitute them and how they can be reduced, using an approach that will address the energy crisis, while addressing the energy efficiency problem. This topic contributes towards the distribution system literature, where these losses are investigated in three different scenarios, which are the residential, commercial and industrial loads fed by the John Ware Substation 88/11 kV, the figure below simplifies the distribution block network of John Ware.
The distribution system loss has become a concern due to the growing load demand and the wide area it covers (1994: C.S. Chen et al.). Adding to that, applying a detailed system modelling is difficult and impractical, as the distribution system designs have numerous equipment and that lead to voluminous data being involved (1994: C.S. Chen et al.). Previously, researchers have developed different methodologies to find ways on how these losses are constituted and ways to reduce losses.

Power losses are differentiated into two forms and (2012: A. Ovon) has indicated that total losses equate to a sum of technical losses and non-technical losses (2012: A. Ovon). Where the technical loss being differentiated from non-technical loss by the character that influence that loss, which is loading and electrical equipment’s function and the non-technical loss being characterised by billing challenges and illegal connections and equipment theft.

The electric technical losses are found as the combination of the fixed and variable losses. Fixed losses are technical losses that do not change with load current, such as transformer no-load losses (2012: A. Ovon). Variable losses are technical losses that change with the load current, such as copper losses (2012: A. Ovon).
(2002: I. E. Davidson & A. Odubiyi), technical losses represent 6-8% of the cost of electricity generation and a 25% of the cost to deliver the electricity to the consumer. This losses are composed of several components, the ohmic loss in power distribution and losses due to leakage current, weak connections, distribution transformers, metering device, incorrect designing and by harmonics in power distribution network (2012: S. M. Bagher Sadati et al).

Non-technical losses do not depend on technical specification of equipment, sometimes known as management losses, these losses are due to incorrect operation, lack of inspection and care, lack of repair and proper equipment replacement (2012: S. M. Bagher Sadati et al). This research presents an approach concentrating only on the technical losses, how these losses are constituted then propose an integrated method in reducing these losses.

The research in summary, should determine the actual magnitude of distribution losses, their location and components constituting distribution losses. In most of the distribution feeders, losses occur for different reasons and are as (1980: D. I. H. Sun et al.), line losses on phase conductors; line losses on ground wire and ground; transformer core and leakage losses; excess losses due to lack of coordination of VAR elements; excess losses due to load characteristics and excess losses due to load imbalances on the phases.

As factors and components that constitute electric technical losses are known, then a respond on how to reduce these electric technical losses is essential and is achieved when (2012: M. Izadi et al.), re-conductoring in primary and secondary feeders; feeder reconfiguration; using high efficiency transformers; reduction of secondary network length with larger number and optimal location of distribution transformers; using distributed generation; sub-transmission substation placement near load centres; load balancing between three phases and feeders; load factor improvement with demand side management and voltage upgrade.
1.5 Conclusion

The end result of generation, transmission and distribution is normally understood as “utilization”, that when energy is carried and turned to a useful work, light, heat or combination at the utilization point (2014: A. P. Hanson). The utilization can result of over or under building of power system facilities and the stress of system equipment beyond their design capabilities (2014: A. P. Hanson). In this research, following is chapter 2, the background review and brings the limits for distribution loss standard practice and further apply and compare other research methods found for the technical loss reduction strategies.

The remainder of the research is organised as chapter 1 introduces the topic and its relevance in the electrical industry, chapter 2 is the review of the literature, where boundaries and interpretation for this study are perfectly indicated, chapter 3 is the heart of this research, all involved instruments and their motivates are articulated and known as methodology section of the research. Chapter 4 evaluate the different cases as in residential, commercial and industrial through result found and we close with remarks and conclusion in chapter 5 where observation is being drawn and justified for future work.
2 Chapter: Literature Review

Generation and transmission are almost exclusively three-phase. The secondary transmission is also three-phase, while the distribution to the ultimate consumer may be three-phase or single-phase and that is determined by the requirement from the consumer (2012: G. Singh). Distribution system begins either at the sub-station where power is delivered by overhead transmission lines and stepped down by transformers. Say a large area is involved, then primary and secondary distribution may be used (2012: G. Singh).

Distribution system may be divided into feeders, distributors, sub-distributors and service mains (2012: G. Singh). Feeders are the conductors which connect the sub-station to the distributors serving a certain chosen area (2012: G. Singh). The important distinction between feeders and distributors is that a current loading of a feeder is the same throughout its length, and a distributor has a distributed loading which results in variations of current along its entire length. In short, feeders are not direct tapping to consumer’s premises (2012: G. Singh).

The radial distribution has been used for centuries. This system employs a number of independent feeders branching out radially from a common supply i.e sub-station (2012: G. Singh). When distribution transformers are connected to the taps along the length of the feeder, the main disadvantage is that the consumer depends on one feeder, for instance, when a fault or breakdown occurs in a feeder, the power will be cut-off till the problem is resolved (2012: G. Singh).

The existing City Power electricity grid system is a combination of different methods being also applied by different municipalities. In simple, this implies that different methodologies exist throughout the network and a cognisance must be taken for future network development plans when implemented (2014: R. Swanepoel). Then for a system to maintain the continuity of supply, a ring main distributor system is employed and that is what is applied universally (2012: G. Singh). At City Power in substations an independent standby
transformer is there to carry the capacity of any feeder board at the station in case of an outage or and loss of a transformer (2014: R. Swanepoel).

2.1 Power in the distribution system circuits

The basic theory of transmission of energy describes the travel of energy in terms of the interaction of electric and magnetic field; the power system engineer is usually concerned with describing the rate of energy with respect to time (which is what defines power) in terms of voltage and current (1994: J. J. Grainger & W. D. Stevenson).

The unit of power being watt (W), the power in watts being absorbed by a load at any instant is the product of the instantaneous voltage drop across the load in volts and the instantaneous current into the load in ampere (1994: J. J. Grainger & W. D. Stevenson). When the terminals of the load are designated a and n, and if the voltage and current are expressed by

\[ v_{an} = V_{max} \cos(\omega t) \quad \text{and} \quad i_{an} = I_{max} \cos(\omega t - \theta) \]  

Equation 2-1

The instantaneous power is

\[ P = v_{an} \cdot i_{an} = V_{max} \cdot I_{max} \cdot \cos(\omega t) \cdot \cos(\omega t - \theta) \]  

Equation 2-2

The angle \( \theta \) in this equation is positive for current lagging the voltage and negative for leading current. Positive power (P) expresses the rate at which energy is being absorbed by some part of the system between point a and n. the instantaneous power is positive when both \( v_{an} \) and \( i_{an} \) are positive and becomes negative when \( v_{an} \) and \( i_{an} \) are in opposite in signs (1994: J. J. Grainger & W. D. Stevenson).

Positive power calculated as \( v_{an}i_{an} \) results when current is flowing in a direction of a voltage rise and means energy is being transferred from the load into the system to which load is connected (1994: J. J. Grainger & W. D. Stevenson) and negative power being energy being produced by the source (2002: J. D. Glover & M. S. Sarma).
2.1.1 Power in resistive load

For a network consisting of resistive load, voltage applied to the resistor and resultant current are calculated as follows respectively:

\[ v = V_{\text{max}} \sin(\omega t) \] ———— Equation 2·3
\[ i = I_{\text{max}} \sin(\omega t) \] ———— Equation 2·4

Where, \( V_{\text{max}} \) and \( I_{\text{max}} \) is maximum voltage and current, \( \omega \) is the angular velocity in radians/seconds (rad/s) (2002: J. D. Glover & M. S. Sarma). Power is then as:

\[ p = vi = V_{\text{max}} \cdot I_{\text{max}} \cdot (\sin^2 \omega t) \] ———— Equation 2·5

\[ (\sin^2 x) = \frac{1}{2} (\cos 2x) \]

Since \( \sin^2 x = \frac{1}{2} \cos 2x \), then:

\[ p = V_{\text{max}} \cdot I_{\text{max}} \left( \frac{1 - \cos 2\omega t}{2} \right) \] ———— Equation 2·6
The power here is continually changing and power in alternating circuits (AC) is taken as an average value of \( 1 - \cos 2\omega t \) that is equal to 1 (1995: M.E. El-Hawary), so:

\[
P_{\text{average}} = \frac{V_{\text{max}} I_{\text{max}}}{2}
\]

**Equation 2.7**

### 2.1.2 Power in an inductive load

When the networking being studied its load is considered purely inductive, the inductive voltage and current are expressed as below respectively:

\[
v = V_{\text{max}} \sin \omega t \quad \text{and} \quad i = -I_{\text{max}} \cos \omega t
\]
And the product produces an instantaneous power that is as follows:

\[ p = vi = V_{max} \sin \omega t \cdot -I_{max} \cos \omega t = -V_{max}I_{max} \left( \frac{\sin 2\omega t}{2} \right) \]

Equation 2.8

![Figure 2-4: Relationship between voltage, current and power (inductive load)](image)

The above inductive wave diagram illustrate a current lagging a voltage by 90°. The power in the inductive circuit consist of negative and positive pulses and the average of these pulses over a half-cycle is zero and that’s mean no heating occurs (2002: J. D. Glover & M. S. Sarma). Here the negative power is due to energy that has been stored in the magnetic field, being feed back to the circuit. When the power is negative, that means the power is consumed by inductor and when positive, then the inductor is returning back the power to the source.

### 2.1.3 Power in a capacitive load

![Figure 2-5: Capacitive load](image)
When the voltage:

\[ v(t) = V_{\text{max}} \sin \omega t \]  

Equation 2-9

is applied across capacitance \( C \), the current will be given by:

\[ i(t) = I_{\text{max}} \cos \omega t \]  

Equation 2-10

And the resulting power will be:

\[ p = v(t) \cdot i(t) = V_{\text{max}} \sin \omega t \cdot I_{\text{max}} \cos \omega t = V_{\text{max}} I_{\text{max}} \left( \frac{\sin 2\omega t}{2} \right) \]  

Equation 2-11

Figure 2-6: Relationship between voltage, current and power (capacitive load)

Figure 2-6 illustrate the waveform diagram for an AC capacitive load circuit and the current is leading the voltage by 90°. When the voltage and current are positive then power is positive, while when one of both is negative the power is negative. The power wave is a series of identical positive and negative pulses whose average value over a half-cycle of voltage is zero.

When the power is positive, that means that power is supplied by the circuit to charge the capacitor and when the power change to negative value, that’s mean the capacitor is discharging, thus supplying the energy stored in the capacitor back to the circuit. The signs minus (−) and plus (+) represents the direction of power, to where is flowing. Since this interchange of energy dissipates no
average power, no heating will occur and then no power is lost (2002: J. D. Glover & M. S. Sarma).

2.1.4 Circuit of resistance and reactance

In a general case, where the current is differing in phase from the applied voltage, the current will lag voltage by angle $\theta$. There, by letting the instantaneous voltage to be:

$$v(t) = V_{\max} \sin \omega t$$

Then the instantaneous current to be:

$$i(t) = I_{\max} \sin(\omega t - \theta)$$

Therefore by multiplying both instantaneous voltage and current, the resulting instantaneous power will be:

$$p(t) = v(t) \cdot i(t) = V_{\max} \sin \omega t \cdot I_{\max} \sin(\omega t - \theta)$$

**Equation 2-12**

$$p(t) = \frac{1}{2}V_{\max}I_{\max} (\cos \theta - \cos(2\omega t - \theta))$$

**Equation 2-13**

$$p(t) = \frac{1}{2}V_{\max}I_{\max} \cos \theta - \frac{1}{2}V_{\max}I_{\max} \cos(2\omega t - \theta)$$

**Equation 2-14**

The instantaneous power is divided as shown into two components, where there is a constant part and the variation part that depends on time. The outlines based on (1994: J. J. Grainger & W. D. Stevenson) are $\frac{1}{2}V_{\max}I_{\max} \cos \theta$, is constant irrespective of time. $\frac{1}{2}V_{\max}I_{\max} \cos(2\omega t - \theta)$, here there is variation of the component of power at twice the supply frequency, because the average value of the component over one complete cycle is zero, and then it does not contribute towards average value drawn from the supply.

Hence the average power over a cycle is shown as follows:

$$P_{\text{average}} = \frac{1}{2}V_{\max}I_{\max} \cos \theta = \left[\left(\frac{V_{\max}}{\sqrt{2}}\right) \cdot \left(\frac{I_{\max}}{\sqrt{2}}\right)\right] \cos \theta$$

**Equation 2-15**
Using the effective root mean square (rms) values of voltage and current and substituting:

\[ V_{\text{max}} = \sqrt{2} \cdot (V_{\text{rms}}), \text{and} \ I_{\text{max}} = \sqrt{2} \cdot (I_{\text{rms}}) \]  

And the results are,

\[ P_{\text{average}} = V_{\text{rms}} \cdot I_{\text{rms}} \cdot \cos \theta \]  

Equation 2-16

The rms values of both voltage and current are represented in the above average power formula and because of this rms values, (2002: J. D. Glover & M. S. Sarma) refer to this average power as active (real) power. This active power is denoted by letter P. used in production of heat or work and measured in units of watt (W), kilowatt (kW), Megawatt (MW), etc. In inductive and capacitive circuits the product of voltage and current is known as reactive power and not real power, as in this circuits the average power in purely inductive and capacitive is zero (2002: J. D. Glover & M. S. Sarma).

(2000: M. H. Shwehdi) have indicated the formula for the design of both three phase and single phase active power calculations, which are:

\[ P_{3\theta} = \sqrt{3} \cdot E_{LL} \cdot I \cdot \cos \theta = \sqrt{S_{3\theta}^2 - Q_{3\theta}^2} \]  

Equation 2-17

\[ P_{1\theta} = E_{LN} \cdot I \cdot \cos \theta = \sqrt{S_{1\theta}^2 - Q_{1\theta}^2} \]  

Equation 2-18

2.1.5 Reactive power

(2002: J. D. Glover & M. S. Sarma) has explained reactive power in a circuit, as a power exchanged between the source and the inductive or capacitive components in the circuit. In short this illustrates power drawn from the source then delivered back to the source (1994: J. J. Grainger & W. D. Stevenson). This power is measured in Volt-Amps-Reactive (VAR) as units and the symbol that denotes the power is letter Q. (2000: M. H. Shwehdi) indicate a reactive power formula that is used in design calculations, as follows:
\[ Q_{3\phi} = \sqrt{3} E_{LL} \cdot I \cdot \sin \theta = \sqrt{(S_{3\phi})^2 - (P_{3\phi})^2}, \]
and then for the single phase designs will be,

\[ Q_{1\phi} = E_{LL} \cdot I \cdot \sin \theta = \sqrt{(S_{1\phi})^2 - (P_{1\phi})^2}. \]

2.1.6 Total power

As defined above that \( P \) and \( Q \) represent real/active and reactive powers respectively. While the introduced letter here is \( S \) that denotes apparent power; the relationship of the \( P, Q \) and \( S \) in a complex view is as defined formula below:

\[ S = P \pm jQ. \]

This letter \( S \) can be represented in a form of a triangle referred as power triangle, below:

![Power triangle](image)

(1995: M. E. El-Hawary) says apparent power as in a complex power represents the required volt-amp capacity of a device required to supply a certain average power. When the load is not purely resistive, this apparent power is always greater than the average power; that is, the amount of power which must be supplied to a system is always greater than what the system is able to consume.
2.2 Distribution network nature of load

The end result of generation, transmission and distribution is normally understood as “utilization”, that when energy is carried and turned to a useful work, light, heat or combination at the utilization point. The utilization can result of over or under building of power system facilities and the stress of system equipment beyond their design capabilities. The modelling and analysis of the power system depends upon the load. To understand what is load, it will depend upon an analysis desired. [(2014: A. P. Hanson) & (2001: W. H. Kersting)]

The load is constantly changing in a distribution system and that is a problem. (2001: W. H. Kersting). The closer to the customer, the better is the load pronounced, as is ever-changing. A typical of feeder circuit might serve numerous loads of all types. Mostly light and medium industrial customers are feed directly from bulk transmission system, while other consumers, including residential and commercial loads, which will be served by the secondary of distribution transformers that are in turn connected to a distribution feeder circuit. (2001: R. R. Shoults & L. D. Swift)

(2001: W. H. Kersting) disagree about the notion of “steady state” load and argue that it is first necessary to look at the load of an individual customer, in order to come to procedures with load. When an electrical appliance is switched on and off, the load seen by the distribution feeder changes and terms associated with such changing load are defined below:-

**Demand load**: load average over a specific period of time

**Maximum demand load**: greatest of all demands that occur during a specific time.

**Average demand load**: the average of the demands over a specific period (day, week, month, etc).
*Diversified demand load*: sum of demands imposed by a group of loads over a particular period.

*Maximum diversified demand*: maximum of the sum of the demands imposed by a group of loads over a particular period.

*Maximum non-coincident demand*: for a group of loads, the sum of the individual maximum demand without any restriction that they occur at the same time.

*Demand factor*: ratio of maximum demand to connected load.

*Utilization factor*: ratio of the maximum demand to rated capacity.

*Load factor*: ratio of the average demand of any individual customer or group of customers over a period to the maximum demand over the same time.

*Diversity factor*: ratio of the maximum non-coincident demand to the maximum diversified demand.

### 2.3 Electric technical losses outline

The distribution system is basically unbalanced and there are necessary components of the system developed for a better distribution analysis, such components are (1991: T. H. Chen et al.):-Conductors, Co-generators, and Transformers, Demand or load and Capacitors. Other components such as network protectors, fuses, automatic switches, etc., while necessary in contingency analysis, they are not important in power flow, short circuit studies and therefore are not presented in this research.

For the focus of this literature, conductors will be covered in more details with relevant losses associated with. Electric technical losses are being part of the electric losses of the system, which yield to: losses in drivers, by corona effect, in the iron of the transformer, by eddy current, in connectors and dielectric (2006: M. P. dos Santos). (2012: City Power quarterly report September) define
technical losses as being mainly created due to heat losses and other technical deficiencies and are generally worse in overloaded and ill maintained networks

2.3.1 Conductors in a power distribution system

Whether urban, suburban or even rural, all parts of the distribution can be underground, including the main feeder (2006: T. A. Short). Proper selection of conductor sizes normally limits cable losses on phase conductors. Single and two phase system causes additional losses on ground wires and ground, also by unbalanced loads (1980: D. I. H. Sun et al.).

Conductor losses are from the line current flowing through the resistance of the conductors. Like any resistive losses, line losses are a function of the current squared multiplied by the resistance ($I^2R$) (2006: T. A. Short). A cable has dielectric losses, which are due to dipole movement within polymer or charge carriers within the insulation. Technical losses are due to current flowing in the electrical system and generate the following losses in a conductor (2012: J. P. Navani et al.).

*Copper losses* – those are due to $I^2R$ losses, cause by the infinite resistance of a conductor.

*Dielectric losses* – this losses result from the heating effect on the dielectric material between conductors.

*Induction and Radiation losses* – are produced by the electromagnetic fields surrounding conductors.

The conductor losses (copper losses) are a result of a circulation current through an imperfect conductor such as copper. The characteristic impedance that produces a voltage drop along the conductor proportional to the current flow is found in conductor’s material. From the impedance, only a resistive component that contributes to the active power losses. In order to calculate conductor losses, measured current load is based to the formula as below:-
\[ P_{\text{loss}} = I \cdot \left( I \cdot \frac{r}{l} \right) \cdot L = I^2 R \]

Where,

\( I = \) is the current

\( \frac{r}{l} = \) is the resistance per kilometre

\( L = \) is length of the cable in kilometres

As the system solved is three phase system, the losses for each phase are calculated separately according to the measured current as below:

\[ P_{\text{Total loss}} = P_{\text{lossa}} + P_{\text{lossb}} + P_{\text{lossc}} \]

\[ = I_a^2 \cdot R_a + I_b^2 \cdot R_b + I_c^2 \cdot R_c \]

As these technical losses are defined as the relationship between the squared current and the resistance, which the resistance parameter is further articulated under the understanding that the conductor being reviewed is being a feeder that is an underground cable. Understanding underground cable can be simply outlined as insulated conductors which are positioned together and ultimately delivered with layers of insulation to provide clear mechanical support and including heat dissipation functions (2006: A. Von Meier).

Heat dissipation is found being a challenge for undergrounds cables. These conductors which are used for underground cables are regularly Aluminium or Copper, where copper is associated with high costs while it contains lower resistance than aluminium. (2006: A. Von Meier) indicates that also the copper low resistance is naturally desirable in power conductors to mitigate technical losses, while particularly of the increase in the conductors heat which affects the cable in carrying current.

Below an AC equivalent circuit of a cable is being presented by a single line structure. Here capacitance cannot be ignored because there is a proven close
proximity of conductors in cables and that is indicated by the equivalent circuit being used in representing the cable.

![Cable equivalent circuit](image)

**Figure 2-8: Cable equivalent circuit**

Where,

\[ V_1 = \text{source voltage} \]

\[ P_{in(cable)} \text{ And } P_{out(cable)} = \text{input and output power respectively} \]

\[ P_{losses(cable)} = \text{power lost in the cable} \]

\[ R_{(cable)} \text{ And } L_{(cable)} = \text{conductor resistance and inductance respectively} \]

\[ C_1 \text{ And } C_2 = \text{shunt capacitances of the cable.} \]

### 2.3.1.1 Resistance

The resistance of the conductor is proportional to the active power loss in underground cables (1995: M. E. El-Hawary). This active power loss mostly depends on the resistance, which the resistance here is characterised by the distance it supply to, where is referred to as the length and further the cross sectional area and the resistivity of the material that the cable is made of. The resistance of a uniform conductor at a specific temperature can be understood from the formula below:

\[ R_T = \frac{\rho_T l}{A} \Omega \]

---

**Equation 2-24**
Where,

\[ \rho_T = \text{Resistivity of a conductor material at a defined temperature (T)} \] [this equal to 0.028 \times 10^{-6} \text{ ohm meter in Aluminium and 0.018 \times 10^{-6} ohm meter in copper at room temperature of 20^\circ C} (2005: \text{G. Atkinson-Hope}).]

\[ l = \text{length of the cable} \]

\[ A = \text{cross-sectional area of the cable} \]

\[ T = \text{temperature} \]

This then indicates that the longer the distance is in the cable or a conductor, there will be higher resistance and ultimately the higher is the active power losses. This relationship is indirect for a cross-sectional area of the conductor, because the higher the cross sectional area gives smaller resistance and ultimately lower active power losses compared to a smaller diameter conductor.

Determining the resistivity of the cable depends highly on the material whether Aluminium or Copper is. As the resistance is affected by the temperature, a better conducting material yields to lower resistivity and ultimately lower active power losses. (1992: \text{E. Benedict et al.}) Further justify that the resistivity of the metal in cables is affected by temperature and this influence an increase in temperature in the material causing an increase in losses.

The resistivity in a cable is then defined below in a formula,

\[ \rho_1 = \frac{\rho_2 (T_2 - T_0)}{T_1 - T_0} \]

\[ T_0 = \text{Reference temperature} \]

\[ \rho_1 \text{ And } \rho_2 = \text{resistivity’s at temperature } T_1 \text{ and } T_2 \text{ respectively.} \]
2.3.1.2 Inductance

The magnetic field of the conductor is generated by a flow of current through the conductor and this magnetic field interacts with surrounding conductors and the conductor, this generate a flux linkage between the conductors and such flux linkages are defined as the inductance of the wire. In a mathematical definition of inductance, below formula define an inductance per phase of an underground cable.

\[
L_{\text{cable}} = \frac{(0.05 + 0.2 \ln \frac{d}{r})}{\text{km}} \text{mH} \quad \text{Equation 2.26}
\]

Where,

\( L_{\text{cable}} \) = Inductance of the cable

\( d \) = Distance between the conductors

\( r \) = Radius of the conductor

The inductive reactance is then defined as,

\[
X_L = 2\pi f_1 L_{\text{cable}}
\]

As \( X_L \) = is the inductive reactance

\( f_1 \) = source frequency

\( L_{\text{cable}} \) = Inductance of the cable

2.3.1.3 Capacitance

When two conductors are running in parallel for a defined distance, there will be a capacitance created between any pair of conductors. This capacitance in a single conductor is then defined as below:
\[ C = \frac{2\pi\varepsilon_r \varepsilon_0}{\ln \left( \frac{D}{d} \right)} \text{ F/m} \quad \text{--- Equation 2-27} \]

Where,

\( C \) = The capacitance,

\( \varepsilon_r \) = Relative permeability of the insulation,

\( \varepsilon_0 \) = Permeability of the free space \((8.854 \times 10^{-12})\),

\( D \) = total diameter with sheath

\( d \) = conductor diameter

And the capacitive reactance can be expressed as below:

\[ X_c = \frac{1}{2\pi f_1 C} \Omega \]

Although in practical sense, the above parameters values are normally obtained from manufactures name plates and tables. These parameters are not generally calculated.

2.3.2 Transformers in a power distribution system

In order to logically define the transformer losses, an addition of power dissipated by the cores magnetizing inductance and winding impedance will yield to transformer losses. The power dissipated by the cores magnetizing inductance is the iron loss found in a transformer and result as a function of the applied voltage and mostly referred to as no-load losses and are even induced when there is no-load current.

The winding impedance also referred as copper loss, these losses are a function of the winding current and known as load losses. These types of losses in a transformer can be calculated for any operating condition when few parameters of the transformer are known.
Core losses of transformers are sensitive to magnitude of system voltage, and then the quality of a distribution transformer affects core losses (1980: D. I. H. Sun et al.). Power is lost in the core of the transformer through hysteresis and eddy current (2006: T. A. Short).

*Hysteresis* – the core heat up from the friction of the molecules, because of magnetic dipoles change of direction.

*Eddy current* – they cause resistive losses in the core material. The flux induces eddy currents have a tendency to oppose the change in flux density.

Transformer losses make up an appreciable portion of utility’s overall losses and that makes transformer losses as important purchase criteria (2006: T. A. Short).

2.4 Electric technical losses

The impression of this research is to investigate the City Power distribution network, a distribution network that its design configuration is categorised as multi ring, meshed and few radial feeds. Distribution generated total losses are defined and also divided into two as follows (2012: A. Ovon), which the total losses is all unit energy flowing into the electrical network, minus units recorded in the billing system as sales:–

*Non-technical losses*: energy being supplied and not sold or not metered beyond the point of supply. *Technical losses*: losses due to loading and electrical characteristic of the electric network.

As power is generated in power stations, it pass through complex components of the power system like transformers, overheard lines, underground cables and other equipment’s then reaches the end user (2013: J. Parmar). These components based on their design and characteristic has factors that lead to a generated unit not matching with the end users unit (2013: J. Parmar).
Good understanding is required for events of the factors that contribute to distribution network losses (2011: KPMG in South Africa’s Global Infrastructure and Project Group). For the research focus, questions on what constitute this technical loss as defined and how to reduce the technical loss is the attention. This research of electric technical loss study in a distribution network provides understanding according to (2012: M. Izadi et al.), factors and components that contribute to the generation of electric power losses and are summed as seen by:-

*Ohmic in the conductor of primary and secondary network: Ohmic loss in the windings of distribution: Iron loss in the core of distribution transformers: Ohmic loss in service cables between secondary feeders and customers and Ohmic loss in leakage currents of shunt equipment, such as insulators and arrestors.*

This research in summary, should determine the actual magnitude of distribution losses, their location and components constituting distribution losses. In most of the distribution feeders, losses occur for different reasons and are as defined below (1980: D. I. H. Sun et al):-

*Line losses on phase conductors: Line losses on ground wire and ground: Transformer core and leakage losses: Excess losses due to lack of coordination of VAR elements: Excess losses due to load characteristics and Excess losses due to load imbalances on the phases*

While factors and components that constitute electric technical loss are known, then a respond on how to reduce these electric technical losses is essential and is achieved when (2012: M. Izadi et al):-

*Re-conductoring in primary and secondary feeders: Feeder reconfiguration: Using high efficiency transformers: Reduction of secondary network length with larger number and optimal location of distribution transformers: Using distributed generation: Sub-transmission substation placement near load centres: Load balancing between three phases and feeders: Load factor improvement with demand side management and Voltage upgrade.*
The electric technical losses are found as the combination of the fixed and variable losses. Which fixed losses are technical losses that do not change with load current, such as transformer no-load losses and variable losses are technical losses that change with the load current, such as copper losses (2011: KPMG in South Africa’s Global Infrastructure and Project Group).

The distribution network is divided into three sections, for simplicity and better analysis. The sections are categorised based on what dominate the load of the feeder, as commercial, residential and light industrial load. Important factors to consider when investigating technical losses are the effect of circulating current due to the interconnection of electricity supply network, the voltage regulation, phase balancing and the power factor (2004: J. W. Fourie).

2.5 Reasons for technical losses occurrence

2.5.1 Lengthy distribution lines

In practically 11 KV lines, are extended over long distances to feed loads scattered over large areas. Thus the primary and secondary distributions lines in the areas are largely radial laid usually extend over long distances. These results in high line resistance and therefore high $I^2R$ losses in the line (2013: J. Parmar). The size of the conductors should be selected on the basis of kVA x kM capacity of standard conductor for a required voltage regulation but different loads are usually scattered and generally fed by radial feeders. The conductor size of these feeders should be adequate (2013: J. Parmar).

2.5.2 Installation of distribution transformers away from load centers

Distribution Transformers are not located at load center on the Secondary Distribution System. In most of cases, distribution transformers are not located centrally with respect to consumers. Consequently, the farthest consumers obtain an extremity low voltage even though a good voltage levels maintained at the transformers secondary. This again leads to higher line losses. (The reason for the line losses increasing as a result of decreased voltage at the consumers
end, therefore in order to reduce the voltage drop in the line to the farthest consumers, the distribution transformer should be located at the load center to keep voltage drop within permissible limits (2013: J. Parmar).

2.5.3 Low power factor of primary and secondary distribution system

In most low voltage distribution circuits normally the power factor ranges from 0.65 to 0.75. A low power factor contributes towards high distribution losses. For a given load, if the power factor is low, the current drawn in is high and the losses proportional to square of the current will be more. Thus, line losses owing to the poor PF can be reduced by improving the power factor. This can be done by application of shunt capacitors.

Shunt capacitors can be connected either in secondary side (11 KV side) of the 88/11 KV power transformers or at various point of distribution line. The optimum rating of capacitor banks for a distribution system is 2/3rd of the average kVAR requirement of that distribution system. A more appropriate manner of improving this PF of the distribution system and thereby reduce the line losses is to connect capacitors across the terminals of the consumers having inductive loads. By connecting the capacitors across individual loads, the line loss is reduced from 4 to 9% depending upon the extent of PF improvement (2013: J. Parmar).

2.5.4 Bad workmanship

Bad workmanship contributes a significant role towards increasing distribution losses. Joints are a source of power loss. Therefore the number of joints should be kept to a minimum. Proper jointing techniques should be used to ensure firm connections. Connections to the transformer bushing-stem, drop out fuse, isolator, and LV switch etc. should be periodically inspected and proper pressure maintained to avoid sparking and heating of contacts. Replacement of deteriorated wires and services should also be made timely to avoid any cause of leaking and loss of power (2013: J. Parmar).
2.5.5 **Feeder phase current and load balancing**

One of the easiest loss savings of the distribution system is balancing current along three-phase circuits. Feeder phase balancing also tends to balance voltage drop among phases giving three-phase customers less voltage unbalance. Amperage magnitude at the substation doesn't guarantee load is balanced throughout the feeder length. Feeder phase unbalance may vary during the day and with different seasons.

Feeders are usually considered “balanced” when phase current magnitudes are within ten and similarly, balancing load among distribution feeders will also lower losses assuming similar conductor resistance. This may require installing additional switches between feeders to allow for appropriate load transfer. Bifurcation of feeders in balancing the load to reduce losses might be a solution. (2013: J. Parmar)

2.5.6 **Load factor effect on losses**

Power consumption of customer varies throughout the day and over seasons. Residential customers generally draw their highest power demand in the evening hours. Same commercial customer load generally peak in the early afternoon. Because current level (hence, load) is the primary driver in distribution power losses, keeping power consumption more level throughout the day will lower peak power loss and overall energy losses.

Load variation is called load factor and it varies from 0 to 1 (2013: J. Parmar). Load Factor is the average load in a specified time period over the peak load during that time period. Lower power and energy losses are reduced by raising the load factor, which, evens out feeder demand variation throughout the feeder. The load factor has been increase by offering customers “time-of-use” rates.

Companies use pricing power to influence consumers to shift electric-intensive activities during off-peak times (such as, electric water and space heating, air
conditioning, irrigating, and pool filter pumping) (2013: J. Parmar). With financial incentives, some electric customers are also allowing utilities to interrupt large electric loads remotely through radio frequency or power line carrier during periods of peak use. Utilities can try to design in higher load factors by running the same feeders through residential and commercial areas (2013: J. Parmar).

2.5.7 Transformer sizing and selection

Distribution transformers use copper conductor windings to induce a magnetic field into a grain-oriented silicon steel core. Therefore, transformers have both load losses and no-load core losses. Transformer copper losses vary with load based on the resistive power loss equation ($P_{\text{loss}} = I^2R$). For some utilities, economic transformer loading means loading distribution transformers to capacity—or slightly above capacity for a short time—in an effort to minimize capital costs and still maintain long transformer life (2013: J. Parmar).

However, since peak generation is usually the most expensive, total cost of ownership (TCO) studies should take into account the cost of peak transformer losses. Increasing distribution transformer capacity during peak by one size will often result in lower total peak power dissipation—more so if it is over-loaded. Transformer no-load excitation loss (iron loss) occurs from a changing magnetic field in the transformer core whenever it is energized.

Core loss varies slightly with voltage but is essentially considered constant. Fixed iron loss depends on transformer core design and steel lamination molecular structure. Improved manufacturing of steel cores and introducing amorphous metals (such as metallic glass) have reduced core losses (2013: J. Parmar).

One method of reducing fixed losses is to switch off transformers in periods of low demand. If two transformers of a certain size are required at a substation during peak periods, only one might be required during times of low demand so
that the other transformer might be switched off in order to reduce fixed losses (2012: G. Singh). This will produce some offsetting increase in variable losses and might affect security and quality of supply as well as the operational condition of the transformer itself. However, this trades-offs will not be explored and optimized unless the costs of losses are taken into account (2013: J. Parmar).

2.5.8 Other reasons for technical losses

Unequal load distribution among three phases in LV system causing high neutral currents; leaking and loss of power; over loading of lines; abnormal operating conditions at which power and distribution transformers are operated; low voltages at consumer terminals causing higher drawl of currents by inductive loads; poor quality of equipment used in agricultural pumping in rural areas, cooler air-conditioners and industrial loads in urban areas (2013: J. Parmar).

2.6 Reducing technical electric losses

Many distribution pockets of low voltage are surrounded by higher voltage feeders. At this lower voltage, more conductor current flows for the same power delivered, resulting in higher I^2R losses. Converting old LV feeders to higher voltage, the investment cost is high and often not economically justifiable but if parts of the LV primary feeders are in relatively good condition, installing multiple step-down power transformers at the periphery of the low volt area will reduce copper losses by injecting load current at more points (i.e., reducing overall conductor current and the distance traveled by the current to serve the load) (2013: J. Parmar).

Reduce the number of transformation steps. Transformers are responsible for almost half of network losses. High efficiency distribution transformers can make a large impact on reduction of distribution losses (2013: J. Parmar). Design the distribution network system in such a way that if it is possible than large consumer gets direct power line from feeder (2013: J. Parmar).
In HVDS there are less distribution losses due to minimum length of distribution line, High quality of Power supply with no voltage drop, less burn out of motor due to less voltage fluctuation and good quality of power, to avoid overloading of transformer (2013: J. Parmar). By overloading of distribution feeder, distribution losses will be increase. The higher the load on a power line, the higher its variable losses.

It has been suggested that the optimal average utilization rate of distribution network cables should be as low as 30% if the cost of losses is taken into account (2013: J. Parmar). By using the higher the cross-section area of conductor / cables the losses will be lower but the same time cost will be high so by forecasting the future load an optimum balance between investment cost and network losses should be maintained (2013: J. Parmar).

Re-conductoring of distribution line according to load; Identification of the weakest areas in the distribution system and strengthening /improving them; Reducing the length of LV lines by relocation of distribution sub stations or installations of additional new distribution transformers; Installation of lower capacity distribution transformers at each consumer premises instead of cluster formation and substitution of distribution transformers with those having lower no load losses such as amorphous core transformers; Installation of shunt capacitors for improvement of power factor; Installation of single-phase transformers to feed domestic and nondomestic load in rural areas; due to feeder renovation program T&D loss may be reduced from 60-70 % to 15-20 % respectively (2013: J. Parmar). Required to adopt preventive maintenance program of line to reduce losses due to faulty / leakage line parts and required to tight of joints, wire to reduce leakage current.

While factors and components that constitute electric technical loss are known, then a respond on how to reduce these electric technical losses is essential and is achieved when (2003: C. L. T. Borges & D. M. Falcao) power factor correction; voltage upgrade; re-conductoring in primary and secondary feeders; feeder
reconfiguration; using high efficiency transformers; reduction of secondary network length with larger number and optimal location of distribution transformers; sub-transmission substation placement near load centres; load balancing between three phases and feeders; load factor improvement with demand side management.

In improving the efficiency of the distribution system, the reconfiguration for loss minimisation was firstly proposed by (1975: M & H Back) using a discrete branch and bound technique. This method allow that all the network switches be closed to form a meshed system and again opened successively to restore the radial configuration. While conscious that the method of reconfiguration involves approximations. With the advancement by (1989: D. Shirmohammadi & H. W. Hong.), a proposal to overcome these approximations was introduced. With this method switches are opened one by one, based on an optimal flow pattern.

A method for optimal operation of distribution system was developed by (1996: G. J. Peponis et al.), where loss minimization is obtained by installation of shunt capacitors and reconfiguration of the distribution network. (1996: S. K. Salam) articulated the results of distributed generation on voltage regulation and power losses in distribution systems. Then a technique to evaluate the impact of distributed generation size and placement on losses, reliability and voltage profile of distribution systems.

(2002: I. E. Davidson & N. M. Ijumba), have presented an optimization model with distributed generation for loss minimization. (2000: J. Mutale et al.), have presented a methodology to measure the impact of distributed generation on power loss minimization, through observing loss allocation coefficient. (2006: M. A. Kashem et al.), represented techniques in a distribution feeder by optimizing distributed generation model in terms of size, location and operating point of distribution generation in order to minimize losses.

Sensitivity analysis for power losses in term of distributed generation size and operating point has been performed by (2008: X. P. Zhang) in a paper that
articulate issues of energy loss minimization in electricity systems with large renewable generation. (1991: D. Pavlov et al.), reported on enhancement of the operational efficiency of electric power utilities, and energy storage units were reported to be diverse and flexible in solving distribution system challenges as part of the distributed generation solution.

While at first, pumped hydroelectric energy storage were used for that purpose and later on, old lead acid battery storage systems were revised. The battery storage system has been proven to be a system that its art internally and externally is not a disturbance in disconnecting critical loads. This is achieved, through its fast de-coupler that separate network in case of overcurrent conditions in direction of the supply network or and under-voltage and under-frequency; bus bar fast switch over which is a method helping to quickly restore sensitive or critical loads and under-frequency and under-voltage load shedding where mostly used as a method of restoring power balance.

Battery storage system also referred as energy storage system is mostly applied in industrial networks for active power balance, peak load lopping or and load levelling and frequency control. (1989: M. W. Gustufson & J. S. Baylor) defined load factor as the ratio of the average load during a designated period to the peak or maximum load occurring in that period. The magnitude of this factor should be between 0 and 1 and minimizing technical losses using a load factor it then implies improving the load factor and that is achieved through peak load reduction as a peak load is determined by power or current, consequently reducing the I²R losses.

The research presents a method of calculating load factor using (2012: S. Pande & J. G. Ghodekar) approach of dividing the distribution network load factor for distributors or and feeders and transformers, the focus of this research will be minimization of technical losses utilizing a battery storage system, as the battery storage system is found with beneficial characteristics that brings high energy density, fast load following, air emission credits, good efficiency of energy storage
and this characteristics have been emphasised by the fact that energy storage has real possibility to be implemented in future.

Technical losses can also be reduced by introducing a battery storage system as part of the distributed generation solution to enhance the operational efficiency of power utility which is found diverse and flexible. With the ignored or lightly mentioned literature, in regards to impacts of peak shaving by the battery energy storage system, (2008: A. Nourai et al.), presented a paper that evaluated the load levelling of the battery energy storage system that reduces transmission and distribution losses, because of the sensitiveness to the ratio of the off peak load and peak load. This ratio is not like load factor, it is not dependent on load profiles.

The level of loss minimization when implementing battery energy storage systems depends on the maximum storage designed size for a particular load levelling, because when the load peaks again a designed system of loss reduction should keep the load as a base for such integrated battery energy storage system. The literature available with regards to battery energy storage system as a means to reduce technical losses of a power system presents that losses are reduced when a number of small loads are shifted to multiple sites rather than a larger load shift at a single site.

Since these losses are proportional to the square of the current flow, using energy storage to shift some of this current or load from peak to off peak periods decreases the net resistive losses, which can offset some of the storage losses. (2008: A. Nourai et al.) indicates that not only concentrating on the squared current relationship which assist in reducing transmission and distribution losses, through shifting a traction of load from the peak to off-peak periods.

There are other two factors that enhance the loss minimization and increasing its value which are the resistance of transmission and distribution wires and transformers being lowered at off-peak periods, yielding low temperature and that of cost in energy and losses, is generally lower during off-peak periods. A
A theoretical approach is being evaluated for this research to reduce technical losses with the analogy that the load levelling approach reduces peak current as per the literature.

An evaluation of technical losses here is to be presented by a ratio of peak power and maximum power during that period, improving this ratio for loss minimization with the implementation of the battery energy storage system for peak shaving purposes. This research appears to be one of the literatures to minimize losses in a distribution network, through load factor improvement by peak shaving of a battery storage plant. This graph indicates a level where system demand is handled efficiently when storage system is incorporated into the distribution network.

![Figure 2-9: Illustration of the system demand when handled efficiently.](image)

Basically the storage is charged from the base load generation during morning hours as this graph shows a daily curve that simplifies off peak hours as indicated by red to be charging period for the storage system and that is achieved when demand is low and typically is during early hours of the day and towards midnight of that day. While the demand is rising during the day, the generation
plant belongs to mid merit category, which accounts for the demand as (2006: A. Joseph & M. Shahidehpour) presented for this graph.

As from the graph, a system incorporated with the storage system during peak, compared when there is no storage, it is cut through during that high demand period, and a storage system is activated to supply the peak for a few hours of the day. We then observe that when the generation profile with storage is taken, there is a much controlled demand graph, as storage take care of peak shaving, after it performs the shaving it get charged again.

Since distribution technical losses are proportional to the square of the load current and shaving any amount of load from peak to off-peak yields in a total reduction of technical loss in the conductor of the distribution network (2008: A. Nourai et al.). When a battery storage system is added in the distribution network, is connected parallel to the load. As the electricity is delivered to the load, the resistance of the power system varies because this distribution takes places at different times of load demands.

![Figure 2-10: Schematic of battery storage in a distribution system with current curve](image)

The storage operation is simplified by the graph where during low demands, the storage charges and then increases the peak during off-peak. At this period, energy is sold at lesser rates as compared during peak periods and this energy as is stored to the battery, only a particular amount can be stored based on its design and that is regulated by the battery regulate.

As the storage is fully charged, it then starts discharging during the peak periods, where loads are at their maximum and expensive tariffs period. The
storage in response to charge back to the system during the peak periods allow the load connected to the power system being reduced as shown in the above figure. Cutting the load during peak periods or shifting the load from off-peak to peak periods reduce the current and as this losses are proportional to the square of the reduced current, that means a reduced technical loss.

The focus at this level is on the high energy storage technologies found for distribution level energy management applications. Before choosing a specific energy storage technology, a set of clear selection criteria by (2010: A. Palo) helps in making an appropriate decision while for this research this section helps us in understanding the selection and only the capacity and charging period was a concentration for this level of reducing technical losses.

As the criteria’s will have a different significant as per the application, the following criteria’s are not in priority order:-

- Application type
- Size (energy density)
- Technology maturity
- Dependability
- Mobility
- Siting requirements
- Capital cost
- Operations and Maintenance (O&M) cost
- Life time
- Efficiency
- Environmental issues
- Disposal

As the above criteria the electricity storage technologies compared for this research are below presented not as numerical importance of the technology but as the available technology of the large battery storage systems:-
1. Flow batteries:
   - Zinc Bromine (ZnBr) Batteries
   - Polysulfide Bromide (PSB) Batteries
   - Vanadium Redox Battery (VRB)

2. Sodium Sulphur (NaS) batteries

3. Electrochemical capacitors (super capacitors)

4. Lithium-ion (Li-ion) batteries

5. Nickel-Cadmium (Ni-Cd) batteries

6. Lead acid batteries

7. Metal air batteries

8. Pumped storage

9. Compressed Air Energy Storage (CAES)

10. High-energy flywheels

Figure 2-11 represents the comparison of these energy storage technologies for largest power and duration periods expected to be applied for.
2.7 Conclusion

This research proposes to evaluate different loads of the distribution system, that of residential, commercial and industrial customers. The evaluation is presented in the next chapter as the investigation part of technical losses, how to calculate this losses in a system and a simple approach in approximating technical losses by investigating the load factors of this different customers.

The heart of the paper include minimization of the found technical losses from load factor, the minimization of technical losses has been presented by different researchers and indeed are practical. What differentiate this study is the level at which the system proposed to reduce this losses, is found to be the most flexible and diverse amongst all available in improving load factor, while battery storage system found advantageous in improvement of load factor, with the current load shedding it can also be a proper solution for minimizing load shedding, as the
system mechanism charge during off peak periods and discharge stored energy back to the grid during peak times.

This chapter covers the importance of power loss reduction, and further outlines reasons that constitute the technical losses in a power distribution system. The chapter has outlined the proposed methods for reducing losses, while the proposal still need to be tested if is necessary option for the distribution system of City Power Johannesburg (2012: City Power quarterly report September).
3 Chapter: Proposed Power Loss Reduction Technique: Design, Simulate and Analysis

3.1 Importance of efficient use of energy

Most of the events that lead to an inefficiency of electrical energy usage are mainly influenced by losses in the distribution network, this losses are separated as technical and non-technical as defined from the literature and this research only evaluates the technical losses generated by a conductor or a feeder.

Using the load factor and the load loss factor in determining the generated technical losses of defined distributors or feeder from John Ware Substation, then implement a sizeable battery storage system within the station in order to reduce the peak load through substituting the supply with the storage power which was bought during off-peak periods (cheaper tariffs).

The manipulation of replacing supply of power during defined period of a distribution network, influence the flow of energy in the feeders in proportion to its length and conductor characteristics, that in our context mitigate a technical losses found in that distribution network.

The identification of the problems that cause technical losses also creates opportunities for improving the efficiency of the distribution network through battery storage systems. This chapter has a model being constructed to calculate technical losses and the process to mitigate technical losses in a distribution network and will be discussed.

3.2 Universal outline of the functions of the strategy

Technical losses are determined by a model that is constructed in a manner that will quantify the technical losses in a distribution network. The model is characterised by attaining the load profiles of a defined feeder in the distribution network and that is utilised in calculating a value of the technical loss generated
by that feeder, which is achieved through evaluating the load profiles by determining the load factor it generates in the feeder of the distribution network.

The process of mitigating the technical losses is within the boundaries of applying a battery storage system and not defining technology but the characteristics of storage and discharging in a level of reducing technical losses, while is assumed to be well defined by a load factor before and after a storage was implemented in the distribution feeder network.

### 3.3 Value system

In this dissertation a model is developed to investigate technical losses using load profiles in evaluating the load factor and another process adopted is that of reducing technical losses in a distribution system by improving the load factor using battery storage to improve load factor. These model and process include factors and parameters that contribute to technical losses in a distribution network and how is reduced as technical losses are unavoidable in a distribution network.

Utilizing the factors and the parameters found, introduces the model together with processes to be found in a quantifiable level in term of generated technical losses and how much are technical losses reduced when storage is used as an expansion. This can enable the distribution electricity organisations to estimate and reduce technical losses at their system provided load profiles are used. While at a customer’s level a sense of continuity of supply and found increasing the life span of the system can make organisations to gain confident from their end users.
3.4 Functional analysis

This figure illustrates the functional diagram of the model. The circle units (C) are articulated below:

C1 – Data downloaded from Spectrum Power HIS, implemented for a section of the distribution network, particular for defined feeders of different loads (residential, commercial and industrial).

C2 – Method which calculates the technical loss of the section in a distribution network

C3 – Measured data received from the implemented section of the distribution network to determine technical loss of that section.

C4 – Method which simulate the section of the distribution network in order to determine technical loss in the studied section.

C5 – Combined determination of technical losses being compared when determined from C2, C3 and C4
C6 – Method which reduces technical losses found in the studied section of the distribution network.

3.5 Development of the strategy

The strategy encouraged to be utilized in developing a process that needs together to investigate and mitigate technical losses in a distribution network, is established in several distinct logics. The integral part of this strategy is the calculations of technical losses within a distribution network and it will be a first logic to be evaluated. The calculations are completed utilizing the Microsoft Excel calculations with programmed language to analyse each section as differentiated by its load (commercial, residential and industrial).

After the calculations of technical losses, another correlation measured when conducting a measurement is used to draw conclusions for the correctness of technical loss in the evaluated section of the distribution network and such correlation are drawn from measured technical losses from meters connected in the substation and those reading the load consumption, in order to produce a difference that will be technical losses at the said feeder as is a conductor of the distribution network.

After the investigation, a mitigation process is implemented and being tested on the DigSILENT power factory simulation tool, mostly used for electrical power system power flow and load flow analysis and other functions that are not going to be discussed on this study, while paramount in the distribution power systems. The functional block diagram below describe an authentically approach in finalizing a strategy that respond on the quantity to be evaluated when using load profiles to determine a load factor that assist in determining a technical loss and with a mitigating process that allow technical losses to be minimized.
This strategy uses the measured data in the distribution network that is from different sources, where the measured data is firstly used in order to understand the load profiles as they determine the character of the load curve that lead in determining a load factor for a certain load being evaluated and that measurements are understood from the downloaded actual currents values from the Spectrum Power HIS gram, while for the correlation of the calculated technical losses will be from measured actual values of meters within the substation that is measuring feeders power flow.

This download measured data is then exported to Microsoft Excel spreadsheet in understanding that a load profile can be developed from that data in line with calculating load factor of a particular load for technical loss determination. The section studies are also remodelled on power system software tool, known as DigSILENT, which analyse the power flows and allow an evaluation of these technical losses when a battery storage system is added or not in the distribution network.

The involvement of the battery storage system in the distribution network is evaluated when the battery system is being connected on the serving substation to the feeders involved for different loads. The comparison of the calculated
technical losses using a load factor before a battery storage system, the same calculation is used even to calculate a feeder load factor when the peak demand has been reduced by the introduction of a battery storage system, where a change in load factor will assist in concluding an authentically mitigation of technical losses in a distribution network.

Following within this chapter and section, are discussions leading to the methodology utilized at this level of literature to evaluate and mitigate technical losses within a distribution system.

3.6 Determine load profiles

The distribution network data needs to be specified by firm parameters in a direction to identify the different sections of feeders in a substation, that is advised by the generation of load profiles of different loads and these parameters should be such to indicate the feeder name, the amount of loading on that feeder in terms of current values and the type of network load is the electrical energy sent to.

It is not necessary at this level of the research to also define the parameters beyond the feeder at the low voltage of the distribution network, at these level an identified assumption is that electrical energy flow from one transformer through a current carrying conductor to another transformer and the evaluation is only conducted between the transformers where a technical loss is investigated and mitigated for analysed magnitudes of currents flowing in that conductor, which is basically an evaluation of \( I^2R \).

In determining these profiles, further being assumed is the period that the technical loss is being analysed, where two seasons being evaluated that of summer and winter is that November – January and June – August being the seasons respectively and the period measured in a time that has one hour intervals for ninety days (90). These data should be translated to a spread sheet and the following table shows a typical imported data for a particular period of
feeders in a station evaluated, shown only a daily spreadsheet data in the interval of one hour for the 6th June 2015.

"Table 3-1: Is the electrical data for Commissioner feeder (6 June 2015)."

<table>
<thead>
<tr>
<th>Distributor Name</th>
<th>Period (Hour)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>12:00:00 AM</td>
<td>72.46</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>01:00:00 AM</td>
<td>72.46</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>02:00:00 AM</td>
<td>72.46</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>03:00:00 AM</td>
<td>72.46</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>04:00:00 AM</td>
<td>73.24</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>05:00:00 AM</td>
<td>72.07</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>06:00:00 AM</td>
<td>89.65</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>07:00:00 AM</td>
<td>86.72</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>08:00:00 AM</td>
<td>96.48</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>09:00:00 AM</td>
<td>100.39</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>10:00:00 AM</td>
<td>101.17</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>11:00:00 AM</td>
<td>101.17</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>12:00:00 PM</td>
<td>100.39</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>01:00:00 PM</td>
<td>100.39</td>
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<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>02:00:00 PM</td>
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<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>03:00:00 PM</td>
<td>100.39</td>
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<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>04:00:00 PM</td>
<td>98.44</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>05:00:00 PM</td>
<td>94.73</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>06:00:00 PM</td>
<td>86.33</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>07:00:00 PM</td>
<td>77.15</td>
</tr>
<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>08:00:00 PM</td>
<td>73.63</td>
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<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>09:00:00 PM</td>
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<tr>
<td>JOHNWAR 11 COMMISSIONER ST</td>
<td>11:00:00 PM</td>
<td>73.63</td>
</tr>
</tbody>
</table>

These data is generated in an automatically manner and the software is aware of the feeder name and parameters set to be downloaded, only the current values were found to be authentically as they can represent the power in all levels of time, where the power found were neglected in support that is generalised for the whole feeder and cannot be accessed to a level of generating per different times, hence the ignorance as these research seeks to understand from some degree of the loading of the said feeder.

It is said these all because if this can be misspelled or interpreted the investigation and mitigation of technical losses within a distribution network.
will be incorrect in defining this research and cannot be accounted by the level of this study, that of using load factor in calculating and also evaluating it when a storage as a mitigation process is involved.

### 3.7 Investigation of technical losses

The subject to investigate technical losses within a distribution network should be viewed at a level where from the collected data of the feeder load its load profile is been simulated from the exported values on the spreadsheet. Where an algorithm to evaluate these technical losses have been discussed in the literature, an adopted method to investigate the losses is that defined when using a measured value of current to determine a power loss that its resistance remain constant as per the design of the network and being in proportion to the distance is the load being feed.

The current values as duplicated by the table above are indicating the two situations where the cable is at full load (during peak periods) and when at normal load (during off – peak periods). In that, technical losses can be determined by using an average load to the maximum load within the same period in evaluating its load factor. While the study will be focusing at calculating technical losses by firstly determining the load factor, which should not cast a wall to further investigate technical losses where transformers are included.

With nature of load as it cannot be easily controlled, because it involves the human behaver change. While achieving this change can yields to good results in defining energy efficiency in technical terms. As these loads differ, the investigation of technical losses will involve three loads being categorised and such tasks require proper understanding of load patterns in their corresponding ideal curves. At this level of data collected to investigate the technical losses, their loads should be divided that can be easily compared to its design and capacity to carry and the movements taken place at the end users premises.
This technical loss investigation also includes the system components design values from name plates or and manufactures cable sheets and here only the cable designs where considered and the specification used where those manufactured by CBI electric African cables (2015: CBI electric African cable). What was assumed is the condition at which this cable operates, where the period is being installed and joints that are in the feeders amongst the underground where not taken to consideration.

It was not necessary to also determine the dielectric and sheath losses that are influenced by the insulation of the cable, where only the copper losses were evaluated in order to conclude and average the whole technical loss in a cable, because copper losses are the mostly found in large magnitude of technical loss in a cable of a distribution network when compared to other losses found in a cable and also account for a bigger percentage as from the literature.

The conductor losses (copper losses) are a result of a circulation current through an imperfect conductor such as copper. The characteristic impedance that produces a voltage drop along the conductor proportional to the current flow is found in conductor’s material. From the impedance, only a restive component that contributes to the active power losses. The conductor losses are quantified as below:

\[
P_{\text{loss}} = I \cdot \left( I, \frac{\ell}{l} \right) \cdot L = I^2 R\quad \text{Equation 3.1}
\]

Where,

\[ I = \text{is the measured current} \]

\[ \frac{\ell}{l} = \text{is the resistance per kilometre} \]

\[ L = \text{is length of the cable in kilometres} \]

As the system solved is three phase system, the losses for each phase are calculated separately according to the measured current as below:
\[ P_{total\ loss} = P_{loss\ a} + P_{loss\ b} + P_{loss\ c} \]  
\[ = I_a^2.R_a + I_b^2.R_b + I_c^2.R_c \]  

Equation 3.2

Equation 3.3

3.7.1 Identify load

The load will be identified when the investigation of technical losses is being conducted, saying this because the data used when investigating technical losses, will be the same data used for analysing the type of load. The loads to be identified and that will be evaluated on these research are those of commercial, residential and industrial as defined by their character of loading from literature.

These loads where assumed that are those of smaller currents being residential load, medium currents for commercial and higher currents representing the industrial loads. These assumptions are aware of the nature of loads and their corresponding designs as mix customers might be found in one feeder, that is being generalised by the assumption of differentiating currents as per viewed by its load character.

Categorising these loads as conducted simultaneously with the technical loss investigation, will differentiate the technical losses being generated as per the load and that will be strategically responding to the highest technical loss generator in terms of its load per feeder and the lesser generator.

By understanding the load and its technical loss, the efficient usage of that feeder supplying the load can be easily determined and that also minimise risks, planning for efficiency of the network and increase opportunities for loads that still need to be connected to the grid, as a proposed algorithm to determine those losses that can yield to situations where load factors for these different loads can be defined.
3.7.2 Evaluation of the load factor

The literature defines load factor as a ratio of the average load to maximum load within the same period, these indicate that a load factor of a distribution network, in the feeder particular can be determined in periods that will have an hour interval for day, week, month and year. With the created spreadsheet when preparing for the investigation of technical losses and identifying the loads to be evaluated, respectively in evaluating the load factor these can be determining the average load and maximum load current values for a defined period either week, month (seasonal) and year.

The load factors as defined from literature with its algorithm, below formulas are in logic where load factor is used to determine technical losses of a distribution network and also vary the load factor when mitigating technical losses. When load profile is generated, technical losses generated for that load are calculated by the utilization of the calculated load factor from the extracted data to calculate the load loss factor for that load profile.

As load differs, the load factor should differ for the said customers of residential, commercial and industrial, and here in this research, what is being presented, is based on the assumptions that lesser current from load profiles indicate residential or both residential and commercial customers and for higher currents load profile, assumed is for industrial loads.

This assumption makes sense here, because of lack of data for specific loads, as distributors are not dedicated to a particular load customer but what it can handle. Below indicate steps to follow in determining technical losses, the steps outlined in this document are to be used to calculate the loss components for the various categories in the distribution systems which are the line losses.

\[
LF \ (load \ factor) = \frac{\text{Average load}}{\text{Maximum load}} \quad \text{Equation 3.4}
\]

\[
LLF \ (load \ loss \ factor) = \frac{\text{Actual loss (during period)}}{\text{Loss at maximum current}} \quad \text{Equation 3.5}
\]
In order to calculate losses, it is then required to calculate the exact relationship between load factor and load loss factor and is given by the empirical equation below. For presenting results, it was assumed that the value of the coefficient of k to be 0.08, as (1989: M.W. Gustafson & J.S. Baylor) indicates that this value is constant when no analysis is performed. Previous work has proven the exponential value to range within 1.91 to 1.93 and a recommended 1.912 if no analysis is performed independently by the utility and for simplifying this study, this value will be 2, as depicted by some of the literature.

$$LLF = K \cdot LF + (1 - K) \cdot LF^2$$  \hspace{1cm} \text{Equation 3·6}

Where $K$ is the coefficient

The line losses are calculated below.

$$\text{Line technical loss in a month} = I^2 \cdot R \cdot L \cdot LLF \cdot 24 \cdot 30 \times 10^{-9}$$  \hspace{1cm} \text{Equation 3·7}

Where,

- $I$ is the load current in amp,
- $R$ is the resistance of the conductor in ohms per kilometer,
- $L$ is the length of the feeder in kilometre and
- The $LLF$ being the load loss factor

The term Load Factor is mostly used in defining a load and this definition indicate the status to the utilities facilities being utilized. As most designs of the power system are designed to handle the maximum demand, the utilities standpoint is that its load factor should be ideal at 1.00 (2001: W. H. Kersting). At other level the customers can also be encouraged to improve their load factor through penalties when low load factor is produced by their load profiles.
3.8 Mitigate technical losses

As the technical loss in a distribution system is inevitable, strategies employed for this subject in reducing losses is guided within the parameters of a battery storage system employed to perform peak shaving. The parameters for the battery storage system are mostly factored by the size, space and design. With only size that indicate the performance of the battery storage and time (hours) to guide when to charge and discharge.

As the research question is also in respond to the minimisation of technical losses, what the study opted to ignore with regards to the mitigation of technical losses using a battery storage system, is the availability of the space and feasible design of the system, as at this level of study only the load factor effect is being observed from before and after the battery storage is involved. Methods used in calculating technical losses by varying load factor with a battery storage system are also employed in verifying technical losses of a distribution system when battery storage is charging and discharging.

3.9 Software usage (DIgSILENT)

For decades the program DIgSILENT Power Factory 15.1 has been utilized for calculations via a computer aided engineering tool for industrial, utility and commercial analysis of the electrical power systems. This analysis is achieved as the tool is equipped with advanced intergraded and interactive software package that are charged to investigations of the electrical power systems to reach the main objectives that will address the planning and operation optimization (2014: DIgSILENT GmbH).

The software package is capable in predictions of real life steady state load flows findings in complex electrical networks. The DIgSILENT Power Factory is as advanced as an application for simultaneous analysis of power network and control systems and that makes it to lead the measurements of load flows, short-circuits levels, active network losses and parameters of the network. This
A software tool has a built-in capability that is DIgSILENT Programming Language (DPL), which mostly simplifies the applications of methods.

### 3.10 Strategy to investigate and mitigate technical electric power losses

For a distribution network to also perform at its highest efficiency, it will need an approach that can be assisting in power loss reduction, while the network is not affected and the continuity of electricity supply is maintained. This research approach is maintaining a standard, where comparison is that from residential, commercial and light industrial loads. Power loss will then be calculated, measured and simulated, to further demonstrate the workable strategy in developing a method of electric technical power reduction.

The precise aims of this research are to investigate what constitute technical loss on a distribution network being identified at City Power distribution network and develop an approach to reduce the said constituted losses, for better efficiency of the distribution network. To investigate what load (residential, commercial and industrial) constitute more losses and how this losses are constituted, that will require an approach to reduce losses in different loads as per this study.

Then document the two objectives of investigation and mitigation processes into three approaches, which are those of calculations, measurements and simulation to further do the comparison and give authentic results for this study. The method approach is determined by the analysis on categorised loads which are residential, commercial (small businesses) and industrial. This approach while it can be complex as one distributor can carry all types of loads and these loads vary hugely (1994: C. S. Chen et al.).

The proposed method is into three levels, where the first phase is to calculate the technical losses, then measure the generated technical losses and lastly simulate the distribution network in determining technical losses. While the second phase being the mitigation of this technical losses, here the same process followed for
determining the technical losses is applied when a battery storage system is added, as is being the hypothesis that it reduces technical losses. With the battery storage system involved only the simulation will be used to justify the objectives of technical loss reduction.

The following approach for this research, in order to conclude and recommend regarding technical losses constitution and reduction methods in a distribution system through load factor improvement is defined by the flow chart below.

![Flow Chart: Technical Loss Evaluation](image)

**Figure 3-3: Technical loss evaluation**

### 3.11 Limitations of the strategy

This strategy has limitations in investigating the technical losses and mitigating of these technical losses. On the investigation side, the limitation was the current measuring method of electrical power, as these values determine the curve of the load identified. The measuring parameter is that only the load current can be analysed in simplifying the load characteristics, while the measurements is continuously recorded.
The limitations for the profiles were segmented into two seasons, the summer and winter (November to January and June to August respectively). This strategy is then only focusing within the season while narrowed to an analysis of a daily profile in generalising the whole season. The seasonal measurements for the investigation of technical losses were only conducted for distributors or feeders (conductors) and the technical losses found in transformers within the same distribution network studied, were ignored in performing this analysis.

The limitations within the mitigations of the technical losses are the application of the Distributed Generation (DG) Battery Storage System. As the focus to reduce the technical losses is directed to DG, this then limits only up to a storage system. DG systems generate power locally to satisfy customer needs or demands, the appropriate size and placement of DG can hugely reduce technical losses in the system. The DG includes improvement in supply quality, reliability and reduces the green house effects. As the DG is the topical area of research and interest in this area is growing rapidly.

The size of DG ranges from little kilowatts to thousands of megawatts. As the DG are scattered across the distribution system, for the level of this research, only units that are connected in the distribution network, particularly to the station bus bar are to be analysed. The DG in order to analyse its diversity in reducing the technical losses, only four (4) hours was a limit for the DG to store and release power. The parameter here is not to design the battery storage plant but to view its significant when added in a distribution system and only a load factor is being calculated as a measure to investigate and mitigate technical losses.

Another factor that can limit the application of the model is when misunderstanding the status of the distribution network. By this, the definition of the layout and different measuring points in the distribution network are included. As to defining the layout and the state at which this distribution network is at, can be done firstly by collecting and analysing the information and
data, engage with relevant patrons (engineers, technicians, system planners) regarding the distribution network, view the network first hand and confirm the different segments and lastly by determining if there are any errors in the system.

3.12 Verification of the strategy

Like any other environment, here as more emphasis is positioned on the efficient utilization of electrical power, the energy efficient phenomenon is easily achieved through a measurement and verification process. At this level and for the efficient utilization of electrical energy, it is not only to distribute the electrical power in the distribution network but to pay attention in measuring and verifying the flow of power regarding the reduction of technical losses.

As the principle behind the investigation and mitigation of technical power losses, a structured strategy in responding to what constitute power losses and mitigate them with a load factor that is fine turned to manage the technical losses of a distribution network. The strategy applied then in verifying the problem subject is structured in the below figure.
This process is utilized in order to investigate technical losses of a distribution network and then mitigate them. For the next iteration of the verification strategy, the identified load factor for both the investigation and mitigation part if exceed 1.00, then it implies the system reviewed is inaccurate and should be reviewed and fine turned till the load factor perform between 0 to 1, because ideally this factor should be 1.

It is then assumed that the distribution network is correct if the load factor is lower than 1 and the process will be repetitive for the verification and measurements of technical losses within a distribution network. The strategy is to vary the load factor in both determining and reducing technical losses.
4 Chapter: Experimental Results

4.1 Overview

The main objective of this study is that of designing an efficient electrical distribution system, being efficient is evaluated by a battery storage system. In achieving the above purpose, an 11kV John ware substation feed by an 88kV transmission lines from Fordsburg Eskom incomer substation is selected. The method of including the battery storage system is used for mitigating the electrical technical losses.

Profiles of different feeders is being analysed by calculating load factor and by DIgSILENT power factory in quantifying the distribution technical losses of a selected station as per load. A single line diagram existing of Fordsburg substation connected to a step down station of John ware station is prepared and further plotted as from figure 4-1.

John ware 11kV substation delivers its power to a variety of customers and as some feeder has mixed customers and the assumptions here is that loads from Fox, Commissioner and Market distributors be of residential, commercial and industrial respectively. As these loads are being delivered by the same cable size and design with different delivering point, table 4-1 shown below is the technical specification for the 185mm² cable known as the distributor with its current limits.
A clear single line diagram showing 11kV John ware substation composed of three 88/11kV step down transformers, of which from the three is a standby that is shown by figure 4-2. The capacity of each transformer being 45MVA, giving a firm capacity for the John ware distribution station of 90MVA, this capacity then
is delivered to a variety of loads ranges from residential, commercial and industrial and as technically defined on the above table 4-1.

The design schematic diagram of John ware substation spells out the total operation of the stations in terms also where in blackouts conditions the five diesel generators which have a designed capacity of 20 MW each generator for 22kV bus bars which are two generators connected in parallel and the last three generators designed capacity being 15MW each for 11kV bus bars.

As the operation of this generators is highly costing, with the load shedding crisis and being a source from the distributed generation, these generators can reduce the affected customers during blackouts when synchronised back to the grid, as currently are not operational because of the maintenance needed, while at this level this diesel generators are out of service and processes of maintaining them back to service are still underway, the station is currently depending on the Eskom supply stepped down from 88/11kV John ware substation.

Figure 4-2: 88/11kV John ware substation
The loads feed by the station varies in sizes and total to fourteen distributors and where only three are selected. Customers then are designated based on their loads demands, where power reach their meters through a resistive path designed for such load and here the underground cable from John ware substation to the first delivery point, either ring main units or step down transformers, this power is transferred through a 185mm² copper cable and the technical losses will be evaluated only for conductor, mitigating the squared current of the technical loss ignoring the dielectric and sheath losses of the cable.

4.1.1 Case study: Market distributor (industrial load)

As on the methodology in chapter 3, the application of chapter 3 is in the form where firstly load profiles are developed with a Microsoft Excel and as figure 4-3, 4-4 and 4-5 with seasonal, weekly and daily load profiles respectively, being the load extracted from the Spectrum PowerCC HIS (Historical Information System) data being monitored by the software for 88/11kV John ware distribution station.

These load currents are then used to determine the load factor and after this are then used to calculate the technical losses in the corresponding feeder or distributor. As in the formula that the value of current is the measured value where here is taken from Spectrum PowerCC HIS data as a measuring tool.

![Figure 4-3: Seasonal load profiles (Market)](image)
Figure 4-3 indicate two graphs or load profiles; the load is measured by the current at an hourly interval for 90 days as a season, being from June to August and November to January as Winter and Summer respectively. As the distribution system has problems with data, the available data for such distributor was in different months of different years. The maximum current during winter is seen from the graph as **164.94 A** and with an average winter current as **115.29 A**.

As seems the current is reduced as the load reduces during the summer season, the observed currents as from figure 4-3 for summer were average being **113.91 A** and the maximum as **148.83 A**. As the profiles also shows a few deeps, those indicate some network breakdown or uncontinuous supply due to overload of the network and stolen cables as is most of the factor influences the non-technical losses at City Power.

![Figure 4-4: Week load profile (Market)](image)

Figure 4-4 is the weekly profiles for both winter and summer seasons. Indicated at the above figure 4-4 is the current measured per hours period interval for seven (7) days and the average current for winter and summer respectively are **111.15 A** and **117.06 A**. This current as measured values is utilized to determine the technical losses and the load factor.
The following calculations are based on figure 4-3 where seasonal comparison of the load with regards to technical loss evaluation, where figure 4-4 and 4-5 are illustrating the seasonal load at a reduced number of days for the same distributor and their corresponding magnitudes are presented by table 4-2.

4.1.1.1 Technical loss and load factor calculations

Average Load

\[ P_{\text{loss summer}} = 3I^2RL \]
\[ = 3 \times 113.91^2 \times 0.128 \times 2,180 \]
\[ = 10,862 \text{ kW} \]

\[ P_{\text{loss winter}} = 3I^2RL \]
\[ = 3 \times 115.29^2 \times 0.128 \times 2,180 \]
\[ = 11.127 \text{ kW} \]

Full Load

\[ P_{\text{loss summer and winter}} = 3I^2RL \]
\[ = 3 \times 393^2 \times 0.128 \times 2,180 \]
Maximum current losses

\[ P_{\text{loss summer}} = 3I^2RL \]

\[ = 3 \times 148,83^2 \times 0.128 \times 2,180 \]

\[ = 18,543 \text{ kW} \]

\[ P_{\text{loss winter}} = 3I^2RL \]

\[ = 3 \times 164,94^2 \times 0.128 \times 2,180 \]

\[ = 22,774 \text{ kW} \]

Load Factor

\[ LF_{\text{summer}} = \frac{\text{Average load}}{\text{Maximum load}} \]

\[ = \frac{10,862 \text{ kW}}{18,543 \text{ kW}} \]

\[ = 0.586 \]

\[ LF_{\text{winter}} = \frac{\text{Average load}}{\text{Maximum load}} \]

\[ = \frac{11.127 \text{ kW}}{22,774 \text{ kW}} \]

\[ = 0.489 \]
The load factor is calculated from the measured current shown in table 4-2 on the far rights and better load factor as defined that approaches unity, then from the table is seen that load factor is better when the load is analysed for a day of summer while poor at the winter season. The technical losses determined from the average current are much equal from all different levels as from table 4-2 above.

As the figure 4-6 of the Market distributor indicates the level of power losses being generated by the distribution circuit as the load factors for both seasons are poor, the technical losses as different, is much accumulated in winter and lesser in summer, the proposed mitigation strategy will both indicate a change in load factor and technical losses. The bar graph above on figure 4-6 is the reflection of technical losses from calculations and the results found as also
defined by table 4-2 leads to a conclusion that from measured values the distribution system generate technical losses and a poor load factor. When the system has poor load factor that’s simple mean it has high technical losses. The following section also determines these technical losses at a different angle where a simulation of the circuit is conducted to analyse the system. The results found from the calculations and simulations should be compared and emanate to an authentic conclusion.

4.1.1.2 **DiGILENT network modelling**

Firstly to get the technical loss generated by a system modelled by DiGILENT power factory, is achieved through setting up the equipment library and table 4-3 below reflect all parameters for load flows for John ware substation 88/11kV.

<table>
<thead>
<tr>
<th>Name</th>
<th>Rated Voltage kV</th>
<th>Rated Current kA (in ground)</th>
<th>Cables/OHL</th>
<th>R’</th>
<th>X’</th>
<th>R0’</th>
<th>X0’</th>
<th>Conductor Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium voltage 185mm² XLPE cable</td>
<td>11</td>
<td>0.393</td>
<td>Cable</td>
<td>0.128</td>
<td>0.094</td>
<td>0.755</td>
<td>0.116</td>
<td>Copper</td>
</tr>
</tbody>
</table>

The station depends strongly from the Fordsburg substation distributors that feeds John ware at three 45 MVA step down transformers that only two are operational and the one is there as a standby transformer. Table 4-4 is the technical data for the John ware transformers.
Table 4-4: Transformer type data (Market)

<table>
<thead>
<tr>
<th>Power Rated MVA</th>
<th>HV Rtd.Volt. (kV)</th>
<th>LV Rtd.Volt. (kV)</th>
<th>Z (uk) (%)</th>
<th>Cu losses kW</th>
<th>Vec.Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>88</td>
<td>11</td>
<td>17.9</td>
<td>30</td>
<td>Yyn0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tap Side</th>
<th>Add.V/tap (%)</th>
<th>Phase of du (deg)</th>
<th>Neu.tap</th>
<th>Min Tap</th>
<th>Max Tap</th>
<th>No. Load (cur. (%))</th>
<th>No Load loss (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV</td>
<td>1.5</td>
<td>0</td>
<td>10</td>
<td>1</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Once the equipment library is created, a network is built on the graphic grid and load flows calculations are determined on the DIgSILENT power factory.

4.1.1.3 Modelled technical losses

This case study assumes the cable carrying an industrial load. As the network in figure 4-2, set the initial operation condition in DIgSILENT window and after, conduct load flow studies of the network. The steady state results obtained from the load flow study is presented below:

Table 4-5: Simulated technical losses with corresponding load factor (Market)

<table>
<thead>
<tr>
<th>Season</th>
<th>$I_{\text{average}}$ A simulated</th>
<th>$P_{\text{loss}}$ kW from simulation</th>
<th>Load Factor from simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>118</td>
<td>11.656</td>
<td>0.629</td>
</tr>
<tr>
<td>Winter</td>
<td>120</td>
<td>12.055</td>
<td>0.529</td>
</tr>
<tr>
<td>Winter</td>
<td>Weekly</td>
<td>115</td>
<td>11.071</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>114</td>
<td>10.879</td>
</tr>
<tr>
<td>Summer</td>
<td>Weekly</td>
<td>122</td>
<td>12.460</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>116</td>
<td>11.264</td>
</tr>
</tbody>
</table>

As the results from simulation is presented by table 4-5, the technical losses found higher as compared to the previously calculated ones, including an improved load factor. With analysing these results to be at this level, one of the factors considered was simulating the entire network and extracting the
corresponding results of current flows at the selected distributor and relevant for this case was the Market distributor with better load factor when analysed on a day and get poor on the whole analysed winter season.

Figure 4-7: Market distributor simulated technical loss and load factor

Figure 4-7 is represent the bar graph of the technical losses in both winter and summer season where 52.9% and 62.9% load factor respectively that indicate accumulated technical losses at those season vary from 12.055 to 11.658 kW respectively.

4.1.1.4 Mitigation of technical losses

The mitigation of technical losses here referred to the evaluation of the distribution network on its average current from the load profiles when the battery storage system is involved, this evaluation is only tested under the DIgSILENT software and by calculations. The results found indicate the character of the battery storage system on a distribution network in both from revenue side and infrastructure of the network too. The table 4-6 and figure 4-8 and 4-9 below illustrates for both seasons when the system involve battery storage.
Figure 4-8 is a line graph representing the battery current, the distributor current and the difference total current when the battery storage is involved in performing its character of peak shaving. The battery designed capacity is 1MW having charging and discharging operational time of four (4) hours per day, which simple is 4MWh energy battery system connected to the 11kV bus bars at John ware substation, the bus bar is the one the Market load is connected to, which in simulation is named BB1 11.

The size selected of the battery storage was to test the load factor effect and use it to conclude and determine technical losses if changed or not. Well with the spell out from literature and the hypothesis of this research, the conclusion found at is that the load factor improves when storage is synchronised to the distribution grid and technical losses also are reduced. This is taken from the winter result figure 4-8 above indicates when the 7.756 A from the battery are injected to the system for a four hour period which means 30.303 Ah from the battery when is at unity power factor.

The peak is shaved and the total current indicate a new fine-tuned line showing a reduced in current peak when the battery is on the grid and again when it is
charging during the other remaining hours and is designed to operate only from 09:00 am to 12:00 pm as charging back to the grid in a day.

The Market distributor in summer when a battery storage current is injected together with the corresponding total current when the peak is shaved by the synchronised battery storage of 1MW is above represented by figure 4-9. Figure 4-9 is a weekly profile of the distributor and the analysis observed can be still applied to the whole season and table 4-6 below summarise the whole distributor when the battery storage is involved for a 4 hour period for both seasons.

**Figure 4-9:** Market distributor summer weekly profile with battery storage

**Table 4-6:** Market distributor connected to the battery storage

<table>
<thead>
<tr>
<th>Season</th>
<th>I(_{(\text{average})}) A with storage</th>
<th>P(_{\text{(loss)}}) kW with storage</th>
<th>Load Factor with storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>113.03</td>
<td>10.695</td>
<td>0.595</td>
</tr>
<tr>
<td>Winter</td>
<td>114</td>
<td>10.879</td>
<td>0.513</td>
</tr>
<tr>
<td>Winter</td>
<td>Weekly</td>
<td>109.86</td>
<td>10.103</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>109.66</td>
<td>10.067</td>
</tr>
<tr>
<td>Summer</td>
<td>Weekly</td>
<td>115.76</td>
<td>11.218</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>111.01</td>
<td>10.316</td>
</tr>
</tbody>
</table>
Table 4-6 is the results of both technical power losses and load factor defined when the battery storage system is involved and a reduced level of technical losses after storage indicates the diversity of storage system in varying the load factor of the system. The following section as it concludes is basically the comparison of the technical losses found in different approaches as defined by calculations, simulations and measurements, where again on simulation is the tested load with battery storage and an improved load factor and reduced technical losses.

4.1.1.5 Conclusion

The Market distributor is seasonally summed up by the table below. Table 4-7 is a reflection of different change in both load factor and technical losses when the distribution system has being also feed by the battery storage and when the battery storage is not.

Only these values are at a steady state condition of load flow results and except the calculated one as are represented in a technical manufactured data and measured data from the City Power distribution system of Market distributor circuit. The comparison of both load factor and technical losses comes with the great difference when the storage is involved and when is involved.

Table 4-7: Technical losses and load factor at Market distributor

<table>
<thead>
<tr>
<th>Season</th>
<th>( P_{\text{loss}} ) ( \text{kW} ) calculated</th>
<th>Load Factor calculated</th>
<th>( P_{\text{loss}} ) ( \text{kW} ) from simulation</th>
<th>Load Factor from simulation</th>
<th>( P_{\text{loss}} ) ( \text{kW} ) with storage with</th>
<th>Load Factor with storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>10.862</td>
<td>0.586</td>
<td>11.656</td>
<td>0.629</td>
<td>10.695</td>
<td>0.595</td>
</tr>
<tr>
<td>Winter</td>
<td>11.127</td>
<td>0.489</td>
<td>12.055</td>
<td>0.529</td>
<td>10.879</td>
<td>0.513</td>
</tr>
<tr>
<td>Winter</td>
<td>Weekly</td>
<td>10.335</td>
<td>0.524</td>
<td>11.071</td>
<td>0.561</td>
<td>10.103</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>10.305</td>
<td>0.663</td>
<td>10.879</td>
<td>0.700</td>
<td>10.067</td>
</tr>
<tr>
<td>Summer</td>
<td>Weekly</td>
<td>11.471</td>
<td>0.622</td>
<td>12.460</td>
<td>0.676</td>
<td>11.218</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>10.558</td>
<td>0.750</td>
<td>11.264</td>
<td>0.800</td>
<td>10.316</td>
</tr>
</tbody>
</table>
The pie chart for winter load factor indicates the different load factors found at the Market distributor as when using manufactures data through calculations as being 32% of the total compared load factors including when the battery storage is found at 33% and having a high load factor on the simulation with a 35% and being found when the storage is involved being reduced by 33% and an increase 77% when the battery storage is synchronised to the grid as per the design of 1MW for 4hour system without technology defined. Figure 4·10 represent the overall winter load factor from calculations and simulations.

![Winter season load factor](image)

**Figure 4·10:** Winter season percentage load factor at Market distributor

The summer technical losses are reflected by the pie chart of figure 4·11. Where found at 33 percent from the calculated values and remain when simulated using the same parameter, this technical losses are further tested when the battery storage is synchronised to the 11kV grid as seen from the chart being much reduced with a 3% from 35% to 32% as the peak shaving period remain at four (4) hours with same parameter and tested both on DIgSILENT simulation package.
4.1.2 Case study: Commissioner distributor (commercial load)

As on the case from the previous section of Market distributor, load profiles are generated from the Microsoft Excel and further plotted seasonally, weekly and daily load currents as depicted by figure 4-12, 4-13 and 4-14 below. The current used to plot the profiles for these different periods was extracted from Spectrum PowerCC HIS as measuring load readings of the John ware substation.

These load currents are then used to determine technical losses and after this are then used to calculate the load factor in the corresponding feeder or distributor. As in the formula that the value of current is the measured value where here is taken from Spectrum PowerCC HIS data.
This load current profiles gives an overall of the distribution network with regards to the effect of the demand, this imply where there is much demand of electrical energy, the network accumulates more technical losses and such assumptions are carried with the justification of the squared current when determining its losses.

Then, therefore as in figure 4-12 for winter season the average current found to be 97.38 A and 81.15 A in summer, the percentage difference of 16.67% is seen from the profiles of this seasons and simply translate that current increases by 16.67 percentage from summer to winter season. The currents were measured in an interval of one hour per day of three months per season. These load currents are used to determine both average and maximum power losses of the period in season to give a corresponding load factor for the same period.
The weekly profiles as in figure 4-13 indicate a sinusoidal curve that its peak current is found at **130.47 A** for winter and **104.88 A** in summer. These loads indicate that of commercial customer, where most of the operation is during the day and lesser at night as the customer mostly reduces their consumption by the night time. The figure is in a plot between current and hourly measured time as per the consumption. While as in figure 4-14 below illustrates the profile for a day in both seasons, the demand in summer is seen uniform with a peak of **74.8 A** and **92.38 A** for winter season at a uniform peak between 06:00 am to 14:00 pm.

The following calculations are based on figure 4-12 where seasonal comparison of the load with regards to technical loss evaluation, where figure 4-13 and 4-14 are illustrating the seasonal load at a reduced number of days for the same distributor and their corresponding magnitudes are presented by table 4-8.

### 4.1.2.1 Technical loss and load factor calculations

**Average Load**

\[
P_{\text{loss summer}} = 3I^2 RL
\]

\[
= 3 \times 81.15^2 \times 0.128 \times 2,080
\]

\[
= 5.260 \text{ kW}
\]
\[ P_{\text{loss winter}} = 3I^2RL \]

\[ = 3 \times 97.34^2 \times 0.128 \times 2,080 \]

\[ = 7.568 \text{ kW} \]

**Full Load**

\[ P_{\text{loss summer and winter}} = 3I^2RL \]

\[ = 3 \times 393^2 \times 0.128 \times 2,080 \]

\[ = 123,362 \text{ kW} \]

**Maximum current losses**

\[ P_{\text{loss summer}} = 3I^2RL \]

\[ = 3 \times 108.01^2 \times 0.128 \times 2,180 \]

\[ = 9.766 \text{ kW} \]

\[ P_{\text{loss winter}} = 3I^2RL \]

\[ = 3 \times 135.55^2 \times 0.128 \times 2,180 \]

\[ = 15.381 \text{ kW} \]

**Load Factor**

\[ LF_{\text{summer}} = \frac{\text{Average load}}{\text{Maximum load}} \]

\[ = \frac{5.260 \text{ kW}}{9.766 \text{ kW}} \]

\[ = 0.539 \]
\[
LF_{\text{winter}} = \frac{\text{Average load}}{\text{Maximum load}}
\]

\[
= \frac{7.568 \text{ kW}}{15.381 \text{ kW}}
\]

\[
= 0.492
\]

**Table 4-8: Calculated technical losses with corresponding load factor (Commissioner)**

<table>
<thead>
<tr>
<th>Season</th>
<th>(I_{\text{calculated}})</th>
<th>(P_{\text{loss}}) (\text{kW})</th>
<th>Load Factor calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>81.15</td>
<td>5.260</td>
<td>0.539</td>
</tr>
<tr>
<td>Winter</td>
<td>97.34</td>
<td>7.568</td>
<td>0.492</td>
</tr>
<tr>
<td>Winter</td>
<td>Weekly</td>
<td>98.02</td>
<td>7.674</td>
</tr>
<tr>
<td>Winter</td>
<td>Daily</td>
<td>71.73</td>
<td>4.110</td>
</tr>
<tr>
<td>Summer</td>
<td>Weekly</td>
<td>86.15</td>
<td>5.928</td>
</tr>
<tr>
<td>Summer</td>
<td>Daily</td>
<td>80.36</td>
<td>5.158</td>
</tr>
</tbody>
</table>

The load factor is calculated from the measured current shown in table 4-8 on the far right and better load factor as defined that approaches unity, then from the table is seen that load factor is better when the load is analysed for a day of winter while still better at the summer season. The technical losses determined from the average current are much equal from all different levels as from table 4-8 above, with a slightly increase of losses for winter as load increase during this season as seen also from the previous case study of Market distributor.

![Figure 4-15: Technical losses with corresponding load factor (Commissioner)](image-url)
As the Commissioner distributor from its load currents measured, the load is then predicted to perform as that of the commercial load and with figure 4-15 indicating a bar chart that has much accumulation of technical losses in winter and lesser in summer when compared and the load factor for both seasons is much lesser different with 8.72% for both seasons with approximate 54% load factor in summer and 50% during winter period.

**4.1.2.2 DiSILENT network modelling**

Firstly to get the technical loss generated by a system modelled by DiSILENT power factory, is achieved through setting up the equipment library and table 4-9 below reflect all parameters for load flows for John ware substation 88/11kV.

<table>
<thead>
<tr>
<th>Name</th>
<th>Rated Voltage kV</th>
<th>Rated Current kA (in ground)</th>
<th>Cables/OHL</th>
<th>R'</th>
<th>X'</th>
<th>R0'</th>
<th>X0'</th>
<th>Conductor Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium voltage 185mm&lt;sup&gt;2&lt;/sup&gt; XLPE cable</td>
<td>11</td>
<td>0.393</td>
<td>Cable</td>
<td>0.128</td>
<td>0.094</td>
<td>0.755</td>
<td>0.116</td>
<td>Copper</td>
</tr>
</tbody>
</table>

The station depends strongly from the Fordsburg substation distributors that feeds John ware at three 45 MVA step down transformers that only two are operational and the one is there as a standby transformer. Table 4-10 is the technical data for the John ware transformers.

| Table 4-10: Transformer type data (Commissioner) |
Once the equipment library is created, a network is built on the graphic grid and load flows calculations are determined on the DlgsILENT power factory.

### 4.1.2.3 Modelled technical losses

This case study assumes the cable carrying a commercial load. As the network in figure 4-2, set the initial operation condition in DlgsILENT window and after, conduct load flow studies of the network. The steady state results obtained from the load flow study is presented below:

Table 4-11: Simulated technical losses with corresponding load flows (Commissioner)

<table>
<thead>
<tr>
<th>Season</th>
<th>I(average) A simulated</th>
<th>P(loss) kW from simulation</th>
<th>Load Factor from simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>83</td>
<td>5.502</td>
<td>0.597</td>
</tr>
<tr>
<td>Winter</td>
<td>100</td>
<td>7.987</td>
<td>0.501</td>
</tr>
<tr>
<td>Winter</td>
<td>Weekly</td>
<td>100</td>
<td>7.987</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>75</td>
<td>4.493</td>
</tr>
<tr>
<td>Summer</td>
<td>Weekly</td>
<td>90</td>
<td>6.470</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>83</td>
<td>5.502</td>
</tr>
</tbody>
</table>

As the results from simulation is presented by table 4-11, the technical losses found higher as compared to the previously calculated ones, including an improved load factor. With analysing these results to be at this level, one of the factors considered was simulating the entire network and extracting the corresponding results of current flows at the selected distributor and relevant for this case was the Commissioner distributor with better load factor when
analysed on both days of different seasons and get poor on the analysed winter as a whole season.

![Commissioner distributor simulated technical loss and load factor](image)

**Figure 4-16:** Commissioner distributor simulated technical loss and load factor

Figure 4-16 is representing the bar graph of the technical losses in both winter and summer season where 50.1% and 59.7% load factor respectively that indicate accumulated technical losses at those season vary from 7.987 kW to 5.502 kW respectively.

### 4.1.2.4 Mitigation of technical losses

The mitigation of technical losses here referred to the evaluation of the distribution network on its average current from the load profiles when the battery storage system is involved, this evaluation is only tested under the DIgSILENT software and by calculations. The results found indicate the character of the battery storage system on a distribution network in both from revenue side and infrastructure of the network too. The table 4-12 and figure 4-17 and 4-18 below illustrates for both seasons when the system involve battery storage.
Figure 4-17: Commissioner distributor winter weekly profile with battery storage

Figure 4-17 is a line graph representing the battery current, the distributor current and the difference total current when the battery storage is involved in performing its character of peak shaving. The battery designed capacity is 1MW having charging and discharging operational time of four (4) hours per day, which simple is 4MWh energy battery system connected to the 11kV bus bars at John ware substation, the bus bar is the one the Commissioner distributor load is connected to, which in simulation is named BB1 11.

The size selected of the battery storage was to test the load factor effect and use it to conclude and determine technical losses if changed or not. Well with the spell out from literature and the hypothesis of this research, the conclusion found at is that the load factor improves when storage is synchronised to the distribution grid and technical losses also are reduced. This is taken from the winter result figure 4-18 above indicates when the 7.756 Ah from the battery are injected to the system for a four hour period which means 30.303 A from the battery when is at unity power factor.
The peak is shaved and the total current indicate a new fine-tuned line showing a reduced in current peak when the battery is on the grid and again when it is charging during the other remaining hours and is designed to operate only from 09:00 am to 12:00 pm as charging back to the grid in a day.

![Commissioner distributor summer weekly profile with a battery storage](image)

**Figure 4-18**: Commissioner distributor summer weekly profile with battery storage

The Commissioner distributor in winter when a battery storage current is injected together with the corresponding total current when the peak is shaved by the synchronised battery storage of 1MW is above represented by figure 4-18. Figure 4-18 is a weekly profile of the distributor and the analysis observed can be still applied to the whole season and table 4-12 below summarise the whole distributor when the battery storage is involved for a 4 hour period for both seasons.

<table>
<thead>
<tr>
<th>Table 4-12: Commissioner distributor connected to the battery storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season</td>
</tr>
<tr>
<td>Summer</td>
</tr>
<tr>
<td>Winter</td>
</tr>
<tr>
<td>Winter Weekly</td>
</tr>
</tbody>
</table>
Table 4-12 is the results of both technical power losses and load factor defined when the battery storage system is involved and a reduced level of technical losses after storage indicates the diversity of storage system in varying the load factor of the system.

The following section as it concludes is basically the comparison of the technical losses found in different approaches as defined by calculations, simulations and measurements, where again on simulation is the tested load with battery storage and an improved load factor and reduced technical losses.

4.1.2.5 Conclusion

The Commissioner distributor is seasonally summed up by the table below. Table 4-13 is a reflection of different change in both load factor and technical losses when the distribution system has being also feed by the battery storage and when the battery storage is not.

Only these values are at a steady state condition of load flow results and except the calculated one as are represented in a technical manufactured data and measured data from the City Power distribution system of Commissioner Distributor circuit. The comparison of both load factor and technical losses comes with the great difference when the storage is involved.

<table>
<thead>
<tr>
<th>Season</th>
<th>Daily P(loss) kW</th>
<th>Load Factor calculated</th>
<th>Weekly P(loss) kW</th>
<th>Load Factor from simulation</th>
<th>Daily P(loss) kW with storage</th>
<th>Load Factor with storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>70.43</td>
<td>3.962</td>
<td>84.86</td>
<td>5.752</td>
<td>79.06</td>
<td>8.786</td>
</tr>
<tr>
<td>Winter</td>
<td>7.568</td>
<td>0.492</td>
<td>7.987</td>
<td>0.501</td>
<td>7.472</td>
<td>0.572</td>
</tr>
<tr>
<td>Winter Weekly</td>
<td>7.674</td>
<td>0.564</td>
<td>7.987</td>
<td>0.634</td>
<td>7.576</td>
<td>0.516</td>
</tr>
</tbody>
</table>

Table 4-13: Technical losses and load factor at Commissioner distributor
The pie chart for winter load factor indicates the different load factors found at the Commissioner distributor as when using manufactures data through calculations as being 33% of the total load factors including when the battery storage is found at 34% and having a low load factor on the simulation with a 33%.

When the storage is involved being improved to 34% and an increase of 76% of the load factor, when the battery storage is synchronised to the grid as per the design of 1MW for 4hour system without technology defined. Figure 4-19 represent the overall winter load factor from calculations and simulations and also when mitigation of technical losses is concern (battery storage system involved).

![Winter season Commissioner load factor](image)

**Figure 4-19:** Winter season percentage load factor at Commissioner distributor

The summer technical losses are reflected by the pie chart of figure 4-20. Where found at 33 percent from the calculated values and remain high when simulated using the same parameter, this technical losses are further tested when the battery storage is synchronised to the 11kV grid as seen from the chart being
much reduced with a 1% from 34% to 33% as the peak shaving period remain at four (4) hours with same parameter and tested both on DlgSILENT simulation package.

![Summer season technical losses](image)

**Figure 4.20:** Summer season percentage technical losses at Commissioner distributor

### 4.1.3 Case study: Fox distributor (residential load)

The application on this section is in the form where firstly load profiles are defined by a Microsoft Excel programme and as figure 4-21, 4-22 and 4-23 with seasonal, weekly and daily load profiles respectively, being the load extracted from the Spectrum PowerCC HIS (Historical Information System) data being monitored by the software for 88/11kV John ware distribution station.

These load currents are then used to determine the technical losses and after this are then used to calculate the load factor in the corresponding feeder or distributor. As in the formula that the value of current is the measured value where here is taken from Spectrum PowerCC HIS data.
Figure 4·21 indicate two graphs or load profiles: the load is measured by the current at an hourly interval for 90 days as a season, being from June to August and November to January as winter and summer respectively. The maximum current during winter is seen from the graph as 157 A and with an average winter current as 61 A.

As seems the current is reduced as the load reduces during the summer season, the observed currents as from figure 4·21 for summer were average is being 45 A and the maximum as 81 A. As the profiles also shows a few deeps, those indicate some network breakdown or uncontinuos supply due to overload of the network and stolen cables as is most of the factor influences the non-technical losses at City Power.
Figure 4.22 is the weekly profiles for both winter and summer seasons. Indicated at the above figure 4.22 is the current measured per hours period interval for seven (7) days and the average current for winter and summer respectively are 54 A and 47 A. This current as measured values is utilized to determine the technical losses and the load factor thereafter.

The following calculations are based on figure 4.21 where seasonal comparison of the load with regards to technical loss evaluation, where figure 4.22 and 4.23 are illustrating the seasonal load at a reduced number of days for the same distributor and their corresponding magnitudes are presented by table 4.14.

### 4.1.3.1 Technical loss and load factor calculations

**Average Load**

\[ P_{loss\ summer} = 3I^2RL \]

\[ = 3 \times 44.61^2 \times 0.128 \times 2,020 \]

\[ = 1.544 \text{ kW} \]

\[ P_{loss\ winter} = 3I^2RL \]

\[ = 3 \times 61.02^2 \times 0.128 \times 2,020 \]

\[ = 2.888 \text{ kW} \]
Full Load

\[ P_{loss\ summer\ and\ winter} = 3I^2RL \]
\[ = 3 \times 393^2 \times 0.128 \times 2020 \]
\[ = 119.803 \text{ kW} \]

Maximum current losses

\[ P_{loss\ summer} = 3I^2RL \]
\[ = 3 \times 80.86^2 \times 0.128 \times 2020 \]
\[ = 5.072 \text{ kW} \]

\[ P_{loss\ winter} = 3I^2RL \]
\[ = 3 \times 156.84^2 \times 0.128 \times 2020 \]
\[ = 19.081 \text{ kW} \]

Load Factor

\[ LF_{summer} = \frac{Average\ load}{Maximum\ load} \]
\[ = \frac{1.544 \text{ kW}}{5.072 \text{ kW}} \]
\[ = 0.304 \]

\[ LF_{winter} = \frac{Average\ load}{Maximum\ load} \]
\[ = \frac{2.888 \text{ kW}}{19.081 \text{ kW}} \]
\[ = 0.151 \]
Table 4-14: Calculated technical losses with corresponding load factor (Fox)

<table>
<thead>
<tr>
<th>Season</th>
<th>$I_{\text{average}}$ calculations</th>
<th>A calculations</th>
<th>$P_{\text{load}}$ kW calculations</th>
<th>Load calculations</th>
<th>Load Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>44.61</td>
<td>1.544</td>
<td>0.304</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>61.02</td>
<td>2.888</td>
<td>0.151</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>Weekly</td>
<td>54.35</td>
<td>2.291</td>
<td>0.243</td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td></td>
<td>42.86</td>
<td>1.425</td>
<td>0.850</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>Weekly</td>
<td>47.17</td>
<td>1.726</td>
<td>0.450</td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td></td>
<td>40.86</td>
<td>1.295</td>
<td>0.700</td>
<td></td>
</tr>
</tbody>
</table>

The load factor is calculated from the measured average current shown in Table 4-14 on the far rights and better load factor as defined that approaches unity, then from the table is seen that load factor is better when the load is analysed for a day of summer and winter and poor at the winter season and winter week. The technical losses determined from the average current are much equal from all different levels as from Table 4-14 above.

![Figure 4-24: Technical losses with corresponding load factor (Fox)](image)

As the figure 4-24 of the Fox distributor indicates the level of power losses being generated by the distribution circuit as the load factors for both seasons are poor, while better for summer when the two seasons are compared. The technical losses as different for both seasons, is much accumulated in winter and lesser in summer, the proposed mitigation strategy will both indicate a change in load factor and technical losses.
The bar graph above on figure 4-24 is the reflection of technical losses from calculations and the results found as also defined by table 4-14 as it leads to a conclusion that from measured values the distribution system generates technical losses and a poor load factor. When the system has poor load factor that’s simple mean it has high technical losses. The following section also determines these technical losses at a different angle where a simulation of the circuit is conducted to analyse the system. The results found from the calculations and simulations should be compared and proceed to an authentic conclusion.

4.1.3.2 *D*IGSILENT network modelling

Getting the technical loss generated by a system modelled in DIGSILENT power factory, that is achieved through setting up the equipment library and table 4-15 below reflect all parameters for load flows for John ware substation 88/11kV.

<table>
<thead>
<tr>
<th>Name</th>
<th>Rated Voltage kV</th>
<th>Rated Current kA (in ground)</th>
<th>Cables/OHL</th>
<th>R’</th>
<th>X’</th>
<th>R0’</th>
<th>X0’</th>
<th>Conductor Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium voltage 185mm² XLPE cable</td>
<td>11</td>
<td>0.393</td>
<td>Cable</td>
<td>0.128</td>
<td>0.094</td>
<td>0.755</td>
<td>0.116</td>
<td>Copper</td>
</tr>
</tbody>
</table>

The station depends strongly from the Fordsburg substation distributors that feeds John ware at three 45 MVA step down transformers that only two are operational and the one is there as a standby transformer. Table 4-16 is the technical data for the John ware transformers.

| Table 4-16: Transformer type data at John ware substation (Fox) |
Once the equipment library is created, a network is built on the graphic grid and load flows calculations are determined on the DIgSILENT power factory.

### 4.1.3.3 Modelled technical losses

This case study assumes the cable carrying a residential load. As the network in figure 4-2, set the initial operation condition in DIgSILENT window and after, conduct load flow studies of the network. The steady state results obtained from the load flow study is presented below:

<table>
<thead>
<tr>
<th>Season</th>
<th>( I_{\text{average}} ) A ( \text{simulated} )</th>
<th>( P_{\text{load}} ) kW from simulation</th>
<th>Load Factor from simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>45</td>
<td>1.571</td>
<td>0.340</td>
</tr>
<tr>
<td>Winter</td>
<td>50</td>
<td>1.939</td>
<td>0.189</td>
</tr>
<tr>
<td>Winter</td>
<td>Weekly 50</td>
<td>1.939</td>
<td>0.223</td>
</tr>
<tr>
<td></td>
<td>Daily 50</td>
<td>1.939</td>
<td>0.790</td>
</tr>
<tr>
<td>Summer</td>
<td>Weekly 45</td>
<td>1.571</td>
<td>0.460</td>
</tr>
<tr>
<td></td>
<td>Daily 45</td>
<td>1.571</td>
<td>0.788</td>
</tr>
</tbody>
</table>

As the results from simulation is presented by table 4-17, the technical losses found higher as compared to the previously calculated ones, including an improved load factor. With analysing these results to be at this level, one of the factors considered was simulating the entire network and extracting the corresponding results of current flows at the selected distributor and relevant for this case was the Fox distributor with better load factor when analysed on a day and get poor on the whole analysed winter season.
Figure 4-25 is representing the bar graph of the technical losses in both winter and summer season where 18.9% and 34% load factor respectively that indicate accumulated technical losses at those season vary from 1.939 kW to 1.571 kW respectively.

4.1.3.4 Mitigation of technical losses

The mitigation of technical losses here referred to the evaluation of the distribution network on its average current from the load profiles when the battery storage system is involved, this evaluation is only tested under the DIgSILENT software and by calculations. The results found indicate the character of the battery storage system on a distribution network in both from revenue side and infrastructure of the network too. The table 4-18 and figure 4-26 and 4-27 below illustrates for both seasons when the system involve battery storage.
Figure 4-26: Fox distributor winter weekly profile with a battery storage

Figure 4-26 is a line graph representing the battery current, the distributor current and the difference total current when the battery storage is involved in performing its character of peak shaving. The battery designed capacity is 1MW having charging and discharging operational time of four (4) hours per day, which simple is 4MWh energy battery system connected to the 11kV bus bars at John ware substation, the bus bar is the one the Fox load is connected to, which in simulation is named BB1 11.

The size selected of the battery storage was to test the load factor effect and use it to conclude and determine technical losses if changed or not. Well with the spell out from literature and the hypothesis of this research, the conclusion found at, is that the load factor improves when storage is synchronised to the distribution grid and technical losses also are reduced. This is taken from the winter result figure 4-26 above indicates when the 7.756 A from the battery are injected to the system for a four hour period which means 30.303 Ah from the battery when is at unity power factor.

The peak is shaved and the total current indicate a new fine-tuned line showing a reduced in current peak when the battery is on the grid and again when it is
charging during the other remaining hours and is designed to operate only from
09:00 am to 12:00 pm as charging back to the grid in a day happens out of the
morning shaving peak period.

The Fox distributor in summer when a battery storage current is injected
together with the corresponding total current when the peak is shaved by the
synchronised battery storage of 1MW as represented by figure 4-27. Figure 4-27
is a weekly profile of the distributor and the analysis observed can be still
applied to the whole season and table 4-18 below summarise the whole
distributor when the battery storage is involved for a 4 hour period for both
seasons.

**Table 4-18: Fox distributor connected to the battery storage**

<table>
<thead>
<tr>
<th>Season</th>
<th>$I_{(average)}$ A with storage</th>
<th>$P_{(ave)}$ kW with storage</th>
<th>Load Factor with storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>43.68</td>
<td>1.480</td>
<td>0.292</td>
</tr>
<tr>
<td>Winter</td>
<td>60.15</td>
<td>2.806</td>
<td>0.147</td>
</tr>
<tr>
<td>Winter</td>
<td>Weekly</td>
<td>53.06</td>
<td>2.184</td>
</tr>
<tr>
<td>Winter</td>
<td>Daily</td>
<td>41.57</td>
<td>1.340</td>
</tr>
<tr>
<td>Summer</td>
<td>Weekly</td>
<td>45.87</td>
<td>1.431</td>
</tr>
<tr>
<td>Summer</td>
<td>Daily</td>
<td>39.57</td>
<td>1.215</td>
</tr>
</tbody>
</table>
Table 4-18 is the results of both technical power losses and load factor defined when the battery storage system is involved and a reduced level of technical losses after storage indicates the diversity of storage system in varying the load factor of the system. The following section as it concludes is basically the comparison of the technical losses found in different approaches as defined by calculations, simulations and measurements, where again on simulation is the tested load with battery storage and an improved load factor and reduced technical losses.

4.1.3.5 Conclusion

The Fox distributor is seasonally summed up by the table below. Table 4-19 is a reflection of different change in both load factor and technical losses when the distribution system has being also feed by the battery storage and when the battery storage is not.

Only these values are at a steady state condition of load flow results and except the calculated one as are represented in a technical manufactured data and measured data from the City Power distribution system of Fox distributor circuit. The comparison of both load factor and technical losses comes with the great difference when the storage is involved.

Table 4-19: Technical losses and load factor at Fox distributor

<table>
<thead>
<tr>
<th>Season</th>
<th>$P_{load}$ kW calculations</th>
<th>Load Factor calculations</th>
<th>$P_{load}$ kW from simulation</th>
<th>Load Factor from simulation</th>
<th>$P_{load}$ kW with storage</th>
<th>Load Factor with storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>1.544</td>
<td>0.304</td>
<td>1.571</td>
<td>0.340</td>
<td>1.480</td>
<td>0.292</td>
</tr>
<tr>
<td>Winter</td>
<td>2.888</td>
<td>0.151</td>
<td>1.939</td>
<td>0.189</td>
<td>2.806</td>
<td>0.147</td>
</tr>
<tr>
<td>Winter</td>
<td>Weekly</td>
<td>2.291</td>
<td>0.243</td>
<td>1.939</td>
<td>0.223</td>
<td>2.184</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>1.425</td>
<td>0.850</td>
<td>1.939</td>
<td>0.790</td>
<td>1.340</td>
</tr>
<tr>
<td>Summer</td>
<td>Weekly</td>
<td>1.726</td>
<td>0.450</td>
<td>1.571</td>
<td>0.460</td>
<td>1.431</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>1.295</td>
<td>0.700</td>
<td>1.571</td>
<td>0.788</td>
<td>1.215</td>
</tr>
</tbody>
</table>
The pie chart for winter load factor indicates the different load factors found at the Fox distributor as when using manufactures data through calculations as being 31% of the total compared load factors including when the battery storage is found at 30% and having a low load factor on the simulation with a 39% and being found when the storage is involved being 30% and this indicates an increase of 70% when the battery storage is synchronised to the grid as per the design of 1MW for 4 hours system without technology defined. Figure 4-28 represent the overall winter load factor from calculations and simulations.

Figure 4-28: Winter season percentage load factor at Fox distributor

The summer technical losses are reflected by the pie chart of figure 4-29. Here found at 34 percent from the calculated values and remain the same when simulated using the same parameters, this technical losses are further tested when the battery storage is synchronised to the 11kV grid as seen from the chart being much reduced with a 2% from 34% to 32% as the peak shaving period remain at four (4) hours with same parameters and both conditions tested on DIgSILENT simulation package.
Figure 4-29: Summer season percentage technical losses at Fox distributor
5 Chapter: Conclusion and Future Work

5.1 Conclusion

As the current electricity challenges, saving power energy has grabbed much of the attention in the electricity industry worldwide. Hence the urgency of investigation and mitigation of power technical losses in a distribution network is hugely justifiable as it highlights the importance of this dissertation. An understanding of the practicality of electrical power utilization in an electrical network is validated and as in this study, a broader understanding is on how to use the available resources.

The objectives of this dissertation is to find the amount of technical losses generated in a conductor of a distribution system disregarding the dielectric and sheath losses generated within the same conductor and this technical losses are found by calculating the load factor. After technical losses are known through the load factor, the load factor is tested when the system incorporate a battery storage system. Because a storage that does peak shaving was proposition here as a solution for technical loss mitigation.

This dissertation establishes the proficiency of load factor in calculating the technical power losses of the distribution network. A method for power loss calculation was presented, the approach was simple to implement. The data used is readily available with the engineers of City Power Johannesburg. The results obtained can be used for financial loss calculations in contributing towards revenue collection.

The technical power losses in a distribution system are expected, while can be minimized to an optimal level. These technical power losses in a distribution system are caused by the physical properties of the system components. As the distribution network accumulate much losses as compared to the transmission network, reducing this technical losses in a distribution system can then make effort worthwhile.
One of the network configurations to be considered efficient and believed to have low power losses is the ring main circuits, while this is a general assumption that on ring main circuits there is low losses, the efficiency is not known when operating under contingency conditions. Hence losing a major component in a ring main network as that from John ware substation distributors lean towards increasing technical power losses; this will end up influencing the power shortage in the network. Conversely, electrical distribution networks can be enhanced more to work efficiently by utilizing specific techniques to minimize the technical power losses within the network.

The battery energy storage system has indicated positively in responding to the research question. While the specific task was that of evaluating technical losses with load factor, the load factor as shown from the previous chapter indicates the improvement and with Fox, Commissioner and Market distributors, after the storage of 1MW with 4MWh energy.

While only on the residential load of Fox distributor from the simulation when storage is synchronised back to the system, where a different in the load factor being further poor. This low load factor is not easily justified as is not aligned to the hypothesis of this dissertation. Further technical loss study in a distribution conductor should also consider the insulation as here were ignored both the dielectric and sheath losses as they are a total technical loss when added with the conductor losses that were calculated on this dissertation in proving the diversity of the load factor.

Conductor losses was the concentration of this dissertation through being evaluated by a load factor when the battery storage system was involved and when was not, as an innovative method of varying the ratio of average current (load) and maximum current (load) in reducing the peak load and at a higher level relevant to this study is that of mitigating the technical losses within a distribution system through peak shaving by applying the battery storage
system on the same period and only Market and Commercial distributors that proved positive and Fox distributor being negative on the hypothesis.

Other literature have evaluated technical losses through a ratio of peak and off peak loads by not using load profiles, this dissertation proved to be the first as it used load profiles in evaluating the load factor through a ratio of average load and maximum load of the same period and battery storage system has been found being diverse in reducing technical losses when operating as a peak shaving source, while still not contradicting the literature of battery storage that of being diverse as a technology in distribution systems.

From this study and all case studies, important observations are concluded that, firstly the technical power loss of the distribution network can be mitigated by varying the load factor by synchronising the battery storage system, as fulfilling the objectives where technical loss is analysed by a load factor and secondly by implementing a battery storage system as a mitigation technique. This has proven to be new at the distribution literature, because of its level of varying the load factor of a distribution system when including a storage system as a technical loss mitigation effective tool in minimizing technical losses when peak shaving function.

5.2 Future work

At this level, work that is recommended here is that of using the technique of Artificial Intelligent (AI) in developing an intelligent distribution system that the data analysed at this level be analysed by developing an appropriate algorithm, which can contributes in distribution literature and innovation as the AI is growing. By intelligent here refers to the energy efficiency of the distribution system. This will be much interesting for AI of distribution systems for PhD research.
6 Reference


APPENDIX

DIgSILENT Modelling

1. Network parameters

Transformers, underground cable ratings and loads for John ware substation are shown in tables and figures below.

1.1 Transformers

The winding transformers found at John ware substation were modelled as type bus net basics with voltage rating and percentage impedance. Table A 1 below illustrates the specifications.

*Table A 1: Transformer qualifications*

<table>
<thead>
<tr>
<th>Power Rated MVA</th>
<th>HV Rtd.Volt. (kV)</th>
<th>LV Rtd.Volt. (kV)</th>
<th>Z (uk) (%)</th>
<th>Cu losses kW</th>
<th>Vec.Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>88</td>
<td>11</td>
<td>17.9</td>
<td>30</td>
<td>Yyn0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tap Side</th>
<th>Add.V/tap (%)</th>
<th>Phase of du (deg)</th>
<th>Neu.tap</th>
<th>Min Tap</th>
<th>Max Tap</th>
<th>No. Load cur. (%)</th>
<th>No Load loss (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV</td>
<td>1.5</td>
<td>0</td>
<td>10</td>
<td>1</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure A 1: Transformer demonstrating

Figure A 2: Transformer demonstrating general
1.2 Underground cable

Cross-linked polyethylene insulation cable is commonly known as XLPE cable and its specification for a copper cable were used. As 11kV XLPE copper cable are widely used in 11kV distribution networks, here Fox, Commissioner and Market distributors are of different length. The below table A 2 and A 3 stipulates the specifications applied.

**Table A 2: Underground cable qualifications**

<table>
<thead>
<tr>
<th>Name</th>
<th>Rated Voltage kV</th>
<th>Rated Current kA (in ground)</th>
<th>Cables/OHL</th>
<th>R’</th>
<th>X’</th>
<th>R0’</th>
<th>X0’</th>
<th>Conductor Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium voltage 185mm² XLPE cable</td>
<td>11</td>
<td>0.393</td>
<td>Cable</td>
<td>0.128</td>
<td>0.094</td>
<td>0.755</td>
<td>0.116</td>
<td>Copper</td>
</tr>
</tbody>
</table>

**Table A 3: Underground cable qualifications with corresponding lengths**

<table>
<thead>
<tr>
<th>Size (mm²)</th>
<th>Current (A) Rating (In ground)</th>
<th>Current (A) Rating (In air)</th>
<th>Resistance (Ω/km) @ 90°C</th>
<th>Impedance (Ω/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>185</td>
<td>393</td>
<td>465</td>
<td>0.128</td>
<td>0.159</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distributor</th>
<th>Length (Kilometre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commissioner</td>
<td>2,080</td>
</tr>
<tr>
<td>Fox</td>
<td>2,020</td>
</tr>
<tr>
<td>Market</td>
<td>2,180</td>
</tr>
</tbody>
</table>
Figure A 3: Cable demonstrating

1.3 Load

The loads of Fox, Commissioner and Market distributor are considered being general linear loads and represent residential, commercial and industrial respectively, therefore are demonstrated as static loads. Table A 4 below represents the specifications of the loads selected for John ware substation.

<table>
<thead>
<tr>
<th>Load</th>
<th>Voltage (kV)</th>
<th>Power factor (lag)</th>
<th>Current (kA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fox</td>
<td>11</td>
<td>0.98</td>
<td>5.25</td>
</tr>
<tr>
<td>Commissioner</td>
<td>11</td>
<td>0.98</td>
<td>9.93</td>
</tr>
<tr>
<td>Market</td>
<td>11</td>
<td>0.98</td>
<td>1257</td>
</tr>
</tbody>
</table>

The level that loads of the three distributors evaluated here being modelled as continuous impedance in DIgSILENT PowerFactory 15.1 is justifiable as (1996: M. N. Haque) substantiate that the simple continuous or constant impedance load model is better which gives more accurate results as compared to the constant power load model. In practical terms the power load
models are mostly questioned for distribution networks because of the nodes that are not voltage controllable.

Figure A 4: Load demonstrating

Figure A 5: Load demonstrating load flow