TRANSFORMER MAINTENANCE AT SWAZILAND ELECTRICITY COMPANY (S.E.C.): A CRITICAL INVESTIGATION

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A treatise submitted in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (PROJECT MANAGEMENT)**

In the Faculty of Engineering, the Built Environment and Information Technology
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DECLARATION

I declare that this research is entirely my own, unaided work, except where otherwise stated. All sources referred to are adequately acknowledged in the text and listed.

I accept the rules of assessment of the University of Pretoria and the consequences of transgressing them.
This treatise is being submitted in partial fulfilment of the requirements for the degree of MSc (Project Management) at the University of Pretoria.

It has not been submitted before for any degree or examination at any other university.

Signed:

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Muziwandile Ayanda Dlamini

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ABSTRACT

Title of Treatise: Transformer Maintenance at Swaziland Electricity Company (SEC): A Critical Investigation

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SEC being an electricity utility within the context of a developing country, Swaziland is faced with the multi-faceted challenges of providing electricity to the poor in remote areas, comply with environmental and international standards and sustain industrial and economic growth. These challenges require that limited resources be allocated to the upkeep of existing network elements. Transformers form the most expensive single unit of these.

The critical investigation looks into the approach taken by the organisation towards transformer maintenance as well as the allocation of key resources for the effective carrying out of this function. Through structured interviews, network users and employees of the organisation provide vital information on the status quo of transformer maintenance as well as how it affects their work. Copper theft is a factor that could not be ignored as it compromises all efforts of network protection. The partial transformer maintenance policy of the company leaves a section of customers and network assets in complete neglect. This is an undesirable approach to looking after invested capital and customer service. The research recommends its amendment and the introduction of laws and technology to curb copper theft.

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1. Introduction

The research sets itself in Swaziland, Southern Africa. This country measures 17,394 sq. km. the country has a population of just over 1 million people. The country has an annual Gross Domestic Product of approximately US$ 1,400,000.00 (Source: Swaziland Statistics Office, 2011). The structure of the economy can be depicted in Chart 1 below:

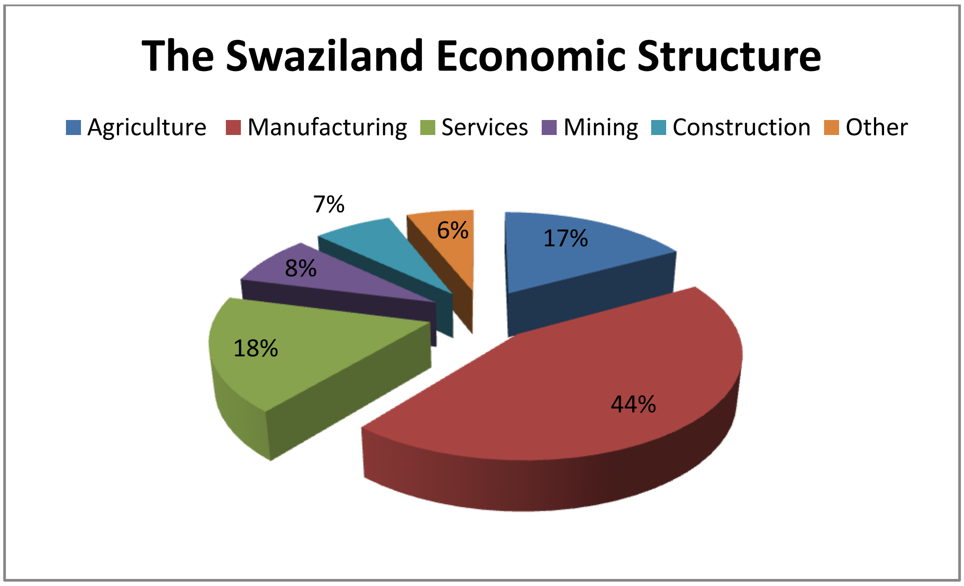

Figure1: The economic structure of Swaziland. (Source: Swaziland Statistics Office, 2011).

Swaziland is classified as a developing country and electricity is the main form of energy driving the economy of the country. In almost all the sectors of the economy indicated in the economic structure of the country, electrical energy is the basic form of energy for production.

The annual power requirement for the economy in the year 2010 was approximately 1 534 050.00 MWh. (Source: Swaziland Electricity Company, 2011).

Of this energy, 80% is imported from neighbouring countries, especially South Africa (Source: SEC, 2011). Transmission of electricity is typically at 66kV, 132kV and 400kV. Sub stations equipped with suitable power transformers are then used to step the voltage down to 11kV, which is the distribution voltage. 11kV/420V distribution transformers are used to step the voltage down to 420V/3 phase and 240V single phase. This is the voltage at which most customers obtain their supply.

Power transformers are an important node in any electrical network. In recent years, unprecedented levels of transformer failures have been experienced at SEC resulting indifferent kinds of problems for users of the network. The main problems that network users have had to deal with are outlined below:

1.1.1 Damage or Loss of Equipment Due to Poor Supply Quality

Some equipment in factories is sensitive to the quality voltage supply. When incoming voltage is outside of a permissible band e.g. 420V +- 10%, some of this equipment can be damaged or lost. Damaged equipment in some industrial processes could mean loss of valuable time in production. It could compromise the quality of the end product.

1.1.2 Shortened Life of Customers' Electrical Equipment Due to Poor Supply Quality.

Some equipment in industry does not fail instantaneously as a result poor supply quality. Instead the designed life expectancy of the equipment is compromised and useful life shortened as a result. Procuring such equipment often involves considerable investment and losing them before their expected life is a big financial loss to the owners.

1.1.3 Malfunctioning of voltage-sensitive equipment

Poor supply quality in some instances results in the equipment not performing their desired functions correctly.

1.1.4 Disruption of Business Due to Frequent Outages

Frequent outages cause business owners to invest resources in backup power (e.g. generators) because they were losing business due to unreliable supply.

1.1.5 Loss of Profit Due to Extra Investment in Backup Power

Frequent outages are compelling some companies whose operations are not tolerant to power outages to invest heavily in backup power solutions. These are in the form of:

- Uninterruptible Power Supply Systems (UPS)

- Standby Generator Systems
- DC Battery Systems with Inverters and Regulators

1.2 The Problem

The object of this treatise is to investigate the maintenance of power transformers within SEC.

1.3 Sub Problems

1.3.1 Sub Problem 1: Is a Structured Approach to Maintenance of Transformers Implemented within SEC?

Effective maintenance of transformers within an electrical grid requires that the company operating the network adopt a structured and organised approach. The maintenance department needs to be equipped with all skills, tools and resources to manage the maintenance function of transformers. The problem at SEC could be a result of the lack of this.

1.3.2Sub Problem 2: Are Allocated Financial Resources for Maintenance of Power Transformers Adequate?

As Swaziland is a developing country, the priority of the energy company (SEC) is to increase connectivity coverage for the population. This mandate influences the way available limited financial resources are allocated within the organisation. It could mean that even though the actions required for effective maintenance of transformers are known, they may not be carried out due to lack of finance.

The objective of the treatise is to investigate if effective maintenance of power transformers is not carried out due to inadequate financial resources.

1.3.3 Sub Problem 3: Does SEC have Trained and Experienced Personnel Capacity to Carry-Out Adequate Maintenance of Power Transformers?

Effective maintenance of power transformers requires a complement of trained and experienced staff. The carrying out of maintenance actions on power transformers requires specialised training and experience. The objective of the treatise is to investigate if there is adequate capacity within SEC to ensure that the maintenance of all transformers in their network are adequately maintained.

1.3.4 Sub Problem 4: Does Swaziland Have Facilities and the Technology Locally to Enable the Effective Maintenance of Power Transformers?

The effective maintenance of power transformers requires certain facilities to be available. These facilities are to be equipped with test equipment and control equipment to determine the internal condition of power transformers thereby providing information for effective maintenance.
SEC may be limited in that these facilities may be only present in neighbouring South Africa.

The treatise will investigate if this is not a limiting factor in the effective maintenance of power transformers.

1.4 The Hypothesis

The maintenance of transformers is not adequate to ensure optimum performance of the network.

1.4.1 Sub Problem 1: A Structured Approach to Maintenance Management of Transformers.

There is no structured approach to maintenance management of transformers within SEC.

1.4.2Sub Problem 2: Financial Resources for Transformer Maintenance.

There are not enough financial resources within SEC to ensure effective maintenance of transformers is carried out.

1.4.3 Sub Problem 3: Trained and Experienced Personnel for Transformer Maintenance

There aren't enough trained and experienced personnel to drive the transformer maintenance function within SEC.

1.4.4 Sub Problem 4: Facilities and Technology for Transformer Maintenance.

There are not adequate facilities and technology locally to support the effective maintenance of transformers at SEC.

1.5 Assumptions

The research will be working on the following assumptions:

a) The currency used is the Swazi Lilangeni (SZL) which is at par with the South African Rand (ZAR).
b) The rate of interest will be calculated as an average over the year.
c) Delivery of electricity is at 50Hz throughout.

1.6 Delimitations

The scope of this research will cover aspects of transformer maintenance but will not deal with the maintenance of single phase transformers. The research will only consider oil filled transformers. Dry chemical transformers will not be considered.

Transformers considered under this research will be Oil Natural, Air Natural (ONAN) Transformers. The research will only be limited to the maintenance of transformers in service, no new installations will be considered. Power transformers are the only elements of the SEC electricity network will be considered. Other elements, such as overhead lines will not be considered.

1.7 Importance of the Study

The following are primary considerations that make this study pertinent.

1.7.1 Transformers are the Most Expensive Elements of an Electrical Network

In an electrical network, the elements needing the biggest financial investment in procurement are power transformers (Source: Eskom, 2008). Therefore the failure of such an element of the network has serious consequences to the operator of the network.

1.7.2 Network Reliability is Largely Dependent on Transformers

The reliability of power supply in an electrical network is dependent on the sub stations or power transformers within that network. Network reliability also depends on other elements of the network, but transformers are crucial.

1.7.3 The Cost of Transformer Downtime

If there is a problem in a distribution line feeding an electricity user, there is often a switching arrangement to allow feeding via another ring leg. The failure of a power transformer invariably means that the user will be out of mains electricity until a replacement is done or the transformer repaired. If a customer is out of supply for an extended period, there is a direct loss of revenue for SEC. Over and above this, is the damage of consumer confidence. This can lead to loss of future revenue as customers will start exploring other supply options. In rare instances in Swaziland, claims are launched for loss of business during down time by customers.

1.7.4 The Rising Cost of Electricity

The study is pertinent because the cost of electricity has been on a constant increase in the last 10 years and the prediction is that this trend will continue at least for the next 5 years. If the end-user or the customer will be expected to pay a higher premium for electricity in the near future, a better quality end-product will be demanded. This study will provide crucial information to enhance the process of supply quality improvement. Eskom is one of the companies from which the SEC purchases electricity. Figure 1.1 shows the increases in electricity tariffs by Eskom, which affects SEC directly.

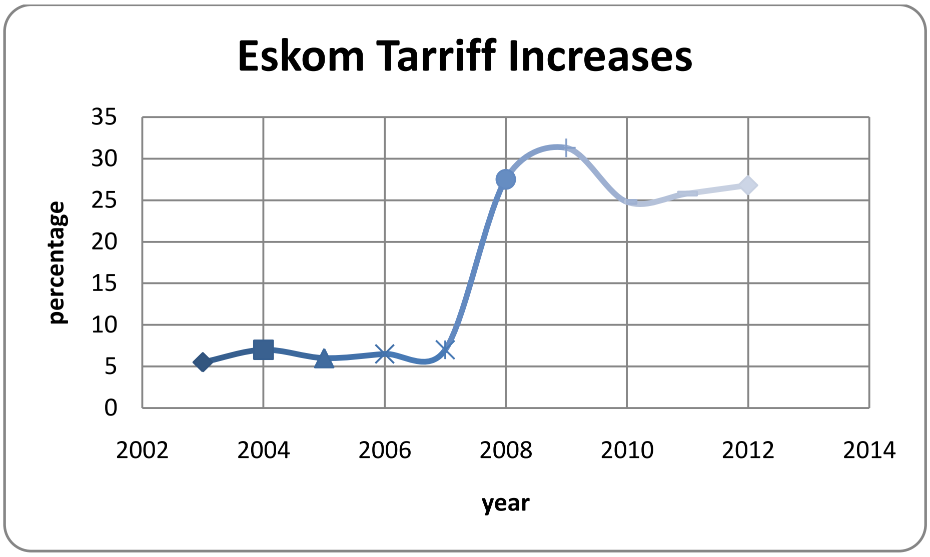

Figure 2: Eskom Tariff Increases Since 2000 (source: Eskom; 2012).

1.7.5 The Quality of Supply to the Customer is Largely Dependent on Transformers

The output voltage and current supplied to an electricity user is governed by the power transformer feeding his premises. Most industrial energy users have stringent conditions of supply quality to ensure smooth operation of their factories. Good performance of power transformers feeding their operations is key for this to be achieved.

1.7.6 The Role of Electricity in Development

There exists a direct relationship between electrical energy consumption and the rate of economic growth of a country. In most developing countries in

Southern Africa, electrical energy constitutes more than 60% of all energy used. This indicates that electrical energy is the basic fuel for:

1 Office Enterprises
2 Mining
3 Manufacturing
4 Industrial
5 Construction

Swaziland has a goal to promote economic development, which infers that good quality electricity delivery is also of primary importance. Without the availability of good quality supply of electricity, this goal is unattainable. As the study deals with issues surrounding the improvement of the quality of electricity supply, it is relevant.

1.7.7 The Need for Better Service Delivery

Electricity is one of the basic commodities the taxpayer wants delivered in better quality and with more coverage every year. It is one of the indicators used to measure the service delivery of a government. Government, through SEC thus has the obligation to meet that expectation.

1.7.8 The Introduction of the National Energy Regulator and the Possibility of Competition.

In 2007, the Swaziland Parliament passed a law which formed the Swaziland Energy Regulation Authority. This body was tasked among other things with overseeing the unbundling of the energy sector to a more competitive and open industry. Since its formation in 1963, the Swaziland Electricity Company (then Swaziland Electricity Board) was the sole licensed body to supply electricity in the Swazi economy. After 2008, any entity with enough skills and resources may apply to the Energy Regulator for a license to operate in the market. These changes mean that there will be increased focus on customer service and customer satisfaction among all players in the industry.

The results of this study will provide useful information for this to be achieved.

1.7.9 Environmental Compliance

The Swaziland Environmental Authority was formed in 2002 through an act of parliament. It was given the mandate to oversee the implementation of all national and international environmental requirements that the country had ratified. The electricity industry has been identified as one of the operations that cause pollution. Transformer oil has in observed cases contaminated both soil and water sources.

This study may assist in providing information to manage this problem better.

1.7.10 Standards

There exists a global trend that most providers of goods and services are striving to be compliant with international standards. These require the operations of these organisations to be carried out with a degree of excellence to enable the end product to be compliant. ISO 9001 is one such standard that is growing in use in the country and SEC aspires to achieve it. If this is to be achieved, then the area of transformers and their maintenance will be central in consideration.

1.7.11 Operational Safety Considerations

Safety is a central value in the operation of every modern energy company. SEC is not an exception in this regard. Adequate maintenance of transformers is also a key operation on the overall safety of operations within the organisation. Currently SEC has a 4-star rating with the National Organisation on Safety (NOSA).SEC aspires to achieve 5-star rating by 2015. The results of this study will also provide useful information to make this possible.

2. Review of Related Literature

2.1 Introduction

This chapter gives an overview of the available literature that was consulted for the research project.

Documented research material dealing with the subjects relevant to the research work will be covered in this chapter. The material used falls broadly under the following headings:

1. Overview of the SEC Electrical Network
2. Transformer Theory
3. The Physical Make Up of the Power Transformer
4. Principles of Maintenance Management
5. Transformer Maintenance
6. Life Cycle Management
7. Outsourcing

2.2 Overview of the SEC Electrical Network

2.2.1 Introduction

SEC was formed by an act of parliament in 1958. It was then called the Swaziland Electricity Board (SEB). Its primary mandate was to provide energy for economic growth and social upliftment (Source: Swaziland Parliament Archives; 2012).

The demand for electricity in the last twenty years between 1990 and 2010 has showing a steady increase. This is shown in Figure 3 below:

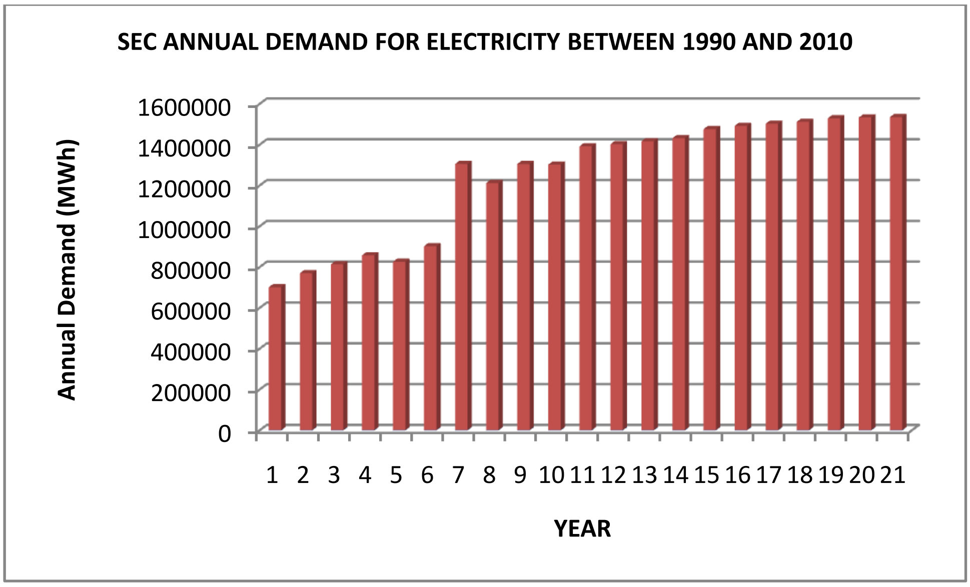

Figure 3: Annual Energy Demand from SEC between 1990 and 2000. (Source: Swaziland Electricity Company; 2012).

The delivery of electricity to the end user by SEC follows the following 5 stages as depicted in Figure 4.

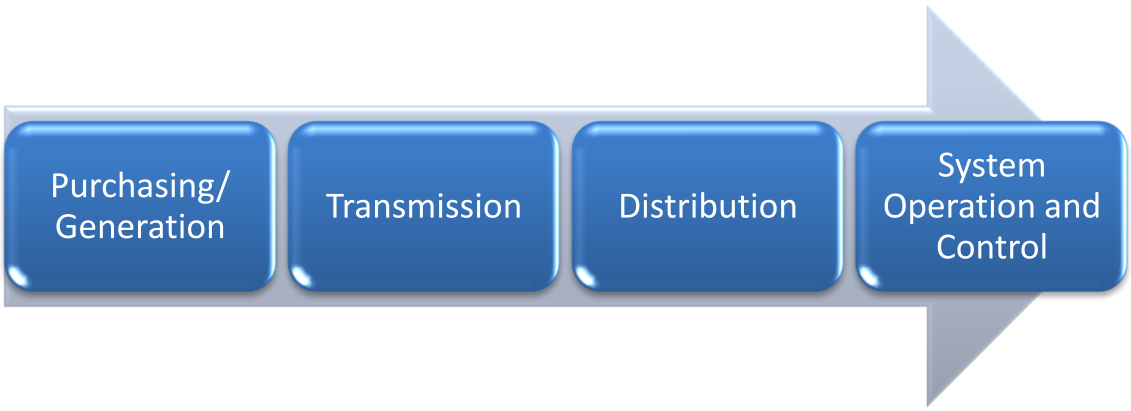

Figure 4: The energy delivery process at Swaziland Electricity Company.

2.1.2 Purchasing/Generation

2.1.2.1 Introduction

SEC generates approximately 21% of the required electricity demand of the country. The balance is purchased from either Eskom in South Africa, Mozambique and other energy pools in Southern Africa. This energy is transmitted at high voltages to sub stations which step it down to the distribution voltage of 11kV. Some heavy industrial users require the supply voltage of 11kV. Most users require the voltage further stepped down to 420V and 240V.

2.1.2.2 Purchasing

Purchasing is carried out within SEC by trained and experienced personnel. A process of ‘shopping’ for the most cost effective unit rate is carried out and orders are placed the previous day for required units. The system is such that the required units need not be supplied by one supplier. These are made available on the grid the following day by the respective supplier. The critical consideration is that the estimation of required units for the next day must be very accurate to avoid loss of income and waste. This is because the buyer pays for the full demand required the previous day, whether it has been used or not.

2.1.2.3 Generation

There are four power stations owned and operated by SEC in Swaziland. They are all Hydro Power stations. They are located at Maguduza, Edwaleni, Luphohlo and Maguga. These are used to feed peak time loads.

Please refer to Figure2-2 below for the brief discussion on generator theory that follows:

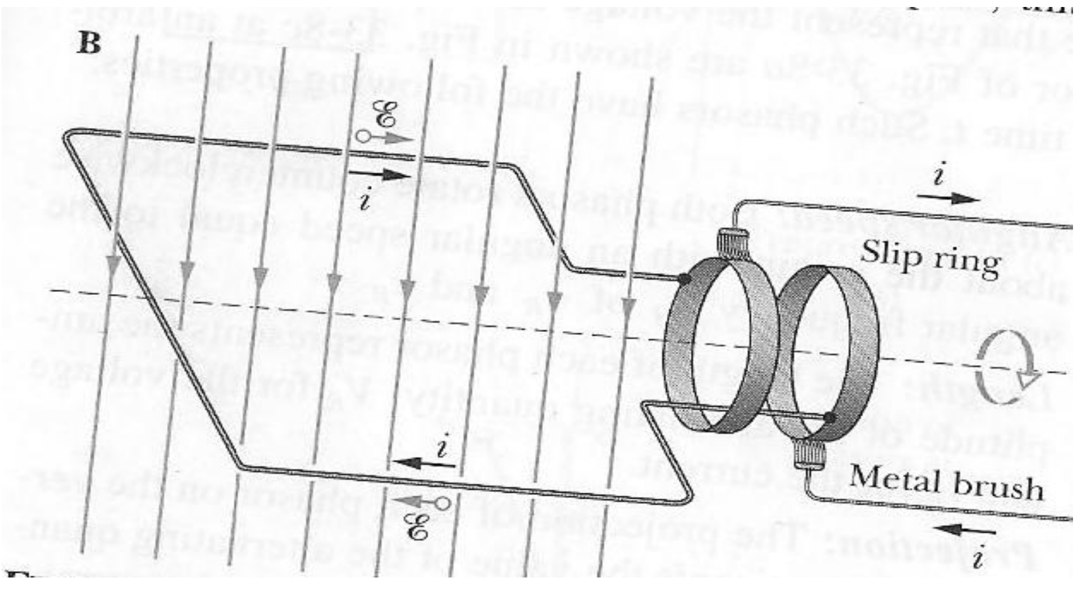

Figure 5: Basic generator arrangement. (Source: Halliday, Resnick and Walker, 1999:819).

Generation takes place at the power stations. The process of electricity generation utilises the basic principles of generator theory. The basis of electricity generation is Faraday's law of induction, which states that a changing magnetic flux in a conductor induces an electric field, which produces a current in that conductor.

Figure 6: A Hydro Turbine at Dwaleni Power Station (Source: SEC; 2012)

The mechanism providing the kinetic energy to rotate the coil is called a prime mover. This can be a water turbine, a gas turbine or a steam turbine. Most power stations boil water to produce steam to drive turbines to generate electricity. All of SEC's power stations are water driven, commonly called Hydro Power Stations. The advantage of this method of generating power is that it is renewable and clean. The downside is that it generates a limited amount of electricity compared to thermal or nuclear. There are four power stations supplying the SEC network as explained in Table 1 below.

Table 1: List of SEC Power Stations.

Power Station	Type	Capacity
Maguga Power Station	Hydro	2 X 9.9MW (19.8MW)
Dwaleni Power Station	Hydro	4 X 2.5MW + 1 X 5MW = (15MW)
Ezulwini Power Station	Hydro	2 X 10MW = (20MW)
Maguduza Power Station	Hydro	1 X 5.6MW = (5.6MW)

2.1.3 Power Transmission

For various reasons, power stations are located at places very remote from business centres and industrial areas. For hydro, it is the location of a suitable place in the dam or river to generate power that determines location. For thermal power stations it is the sheer size of them, the traffic of trucks ferrying the fuel and the exhaust gases produced that make them unsuitable in busy areas. Proximity to the fuel source, usually coal mines is also a consideration.

This usually means power stations are usually hundreds of kilometres from the load centre where the generated electricity will be required. From the generator to the substation close to the load centre, electricity is delivered through transmission lines. In Swaziland these are all overhead on either steel or wooden supports.

Figure 7: A steel supported 400kV transmission power line belonging to SEC.

2.1.3.1 Transmission Power Losses (Ohmic Losses)

The power dissipated by any resistive conductor with resistance R with current I flowing through it is governed by the equation:

$$P=I^2R.$$

To limit these losses, transmission voltages are very high while transmission currents are very low. The square relationship of current and Ohmic losses in a transmission line resulted in what became known as the General Transmission Rule: “Transmit at the highest possible voltage and the lowest possible current.”(Glover and Sarma, 1994: 28)

2.1.3.2 Voltage Drop Considerations

Various types of conductors are used in transmission. In the SEC network, invariably, ACSR conductors are used. This is a composite conductor consisting of an outer skin of aluminium cores with a few steel cores in the centre.

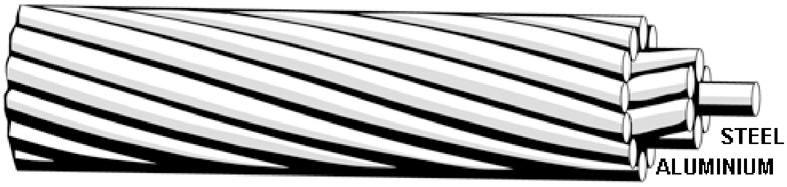

Figure 8: The basic make-up of an ACSR conductor.

ACSR conductors exploit the lightness and high conductivity of Aluminium and the strength of the steel for withstanding wind loads.

The voltage drop between two ends of a conductor is governed by the relationship:

V=IR,

This relationship is termed as Ohm's Law.

V being Voltage (Volts)
I being Current (Amps)
R being Resistance (Ohms).

The resistance of a material is directly related to a factor called 'Resistivity' depicted with the Greek symbol 'ρ' measured in Ω.m. (Halliday, Resnick and Walker, 1999:820). This is an electrical property of the material.

R = $\boldsymbol{\rho_t}$x (L/A), where L is the length of the conductor in metres and A is its cross sectional area, where $\boldsymbol{\rho_t}$is the resistivity at a certain temperature.

It follows thus then that for long distances of conductor encountered in transmission, resistance grows considerably and so does the voltage drop.

Other factors that contribute to resistance are:
Temperature – resistance increases with temperature.
Fequency – resistance increases with voltage frequency (A phenomenon known as the "Skin Effect")
Conductor Spiralling – a conductor is longer when stranded than when straight. This increases its resistance.

Data tables that give you the expected voltage drop of a conductor per kilometre for different types of conductors have been developed.

To overcome the voltage drop problem, transmission voltages are made to be very high. The attained voltage drop thus constitutes a small percentage of the transmission voltage at the delivery end.

Typically in Swaziland, the following voltages are used for transmission

Table 2: Transmission Voltages on the SEC network.

Transmission Voltage	**Support Structure**
66kV	Treated Wood
132kV	Steel
400kV	Steel

2.2.3 Distribution

This is the operation concerned with the delivery of electricity to the end user. In the SEC network, the distribution voltage is rated at 11kV. Power Transformers at sub stations step down the transmission voltage to 11kV. The end user voltage in Swaziland is rated at 420V/240V at 50Hz. (Source, Swaziland Electricity Company). Distribution transformers usually located within the premises of the end user step down the 11kV to this voltage. The distribution voltage is also selected for voltage drop considerations.

11kV supports in the SEC network are predominantly creosote treated wood. Steel supports are increasingly being utilised for critical industrial operations and facilities. E.g. Sikhuphe Airport.

2.2.4 System Operation and Control

This Operation is concerned with mainly the SCADA system. SCADA is an acronym for System Control and Data Acquisition. This is the system that allows the following operations to be done on the entire network:

- Acquiring of current system data, e.g. voltage at a point.
- Monitor system operation in real time
- Raising alarms on system faults

- Remote fault clearing
- Switching remotely
- Acquiring historical data on the system.

The SCADA system also plays a crucial role in the energy purchasing process. Current and historical data is readily available.

2.2.5 Transformers and Sub Stations.

Sub Stations are mainly concerned with stepping down the transmission voltage to the distribution voltage. They contain complex control systems but they are primarily made up of transformers. They form an integral part of the network and they are an important node in the delivery of electricity to the end user.

2.3 Overview of Transformer Theory

2.3.1 Introduction

In the electrical network, it is desirable to work with relatively low voltages at the generation end for safety, very high voltages at transmission to reduce power losses and low voltages again at the distribution end for user safety and efficient equipment design (refer to figure 4.2.1 below). Typically, generation voltages can be as low as 400V, transmission voltages as high as1000kV and distribution voltages as low as 110V.

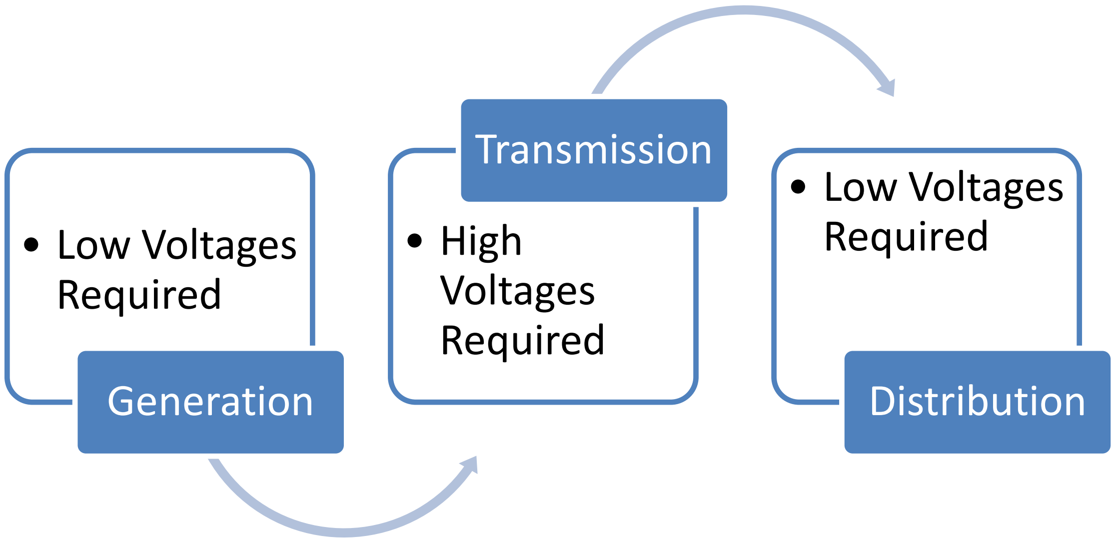

Figure 9: Desired voltages in an electrical network.

An instrument is thus required that will be able to step voltage up and down while leaving the total power in the network relatively constant. Such an instrument is the power transformer.

2.3.2 Basic Transformer Theory

The basic principle of operation of the power transformer is that of mutual flux between two or more coils linked by a common magnetic flux. Please refer to Figure 2-6 for the discussion following.

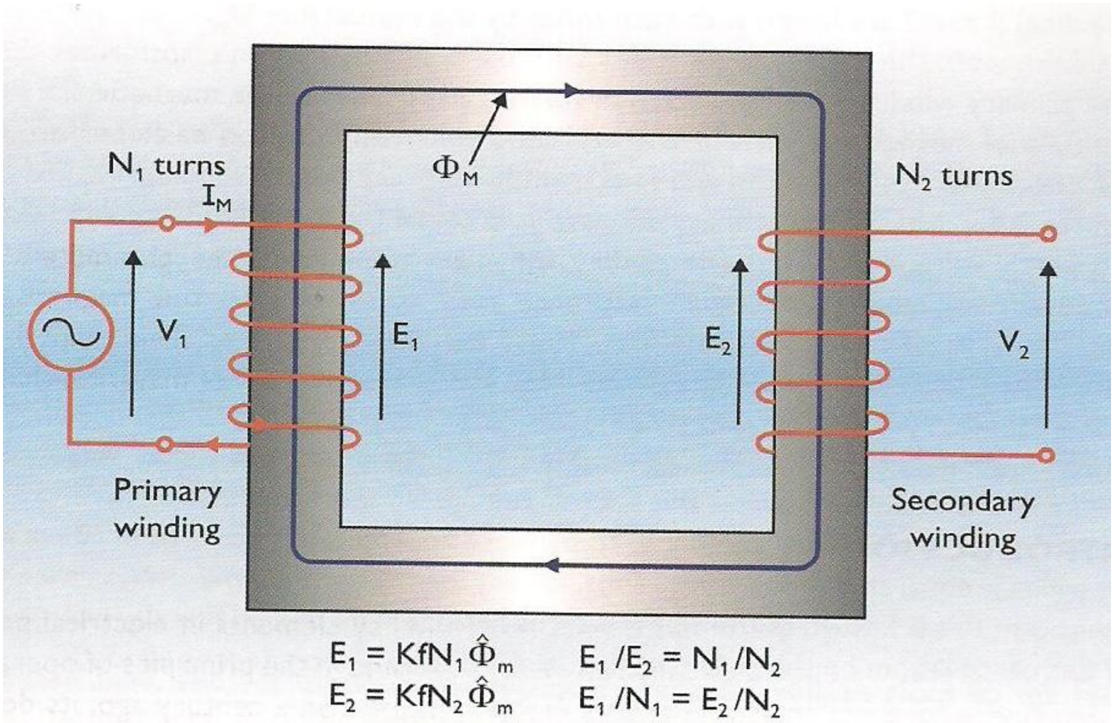

Figure 10: Transformer theory (Eskom; Power Transformers: 2008:13).

The secondary and the primary windings are coupled by the magnetic flux without actual electrical connection required. As earlier discussed, the transformer allows electrical energy to be supplied to the connected load at a predetermined voltage level. The voltage level is thus “transformed” from one voltage level to another.

Transformer efficiency is directly related to the degree to which the common magnetic flux links the primary and the secondary circuits. Reluctance, in magnetism is the quantity that measures a material’s resistance to flux permeability. A material commonly used in the construction of transformer cores, primarily for its high permeability is steel.

2.3.4 Transformer Operation

The primary winding is connected to the voltage source which initiates the flow of magnetising current and sets up the mutual flux $\Phi_{M.}$ this flux then induces an electromagnetic force (emf) in both primary and secondary windings. These are depicted by E_1 and E_2 in Figure 2-6. In the primary winding the induced emf opposed the supply voltage in its direction; hence it is commonly called the back emf. In the secondary circuit it is equivalent to the secondary voltage V_2.

The Basic Transformer Equation is the mathematical relationship that governs induced voltage and magnetic flux:

$$\boldsymbol{E = K\,\Phi_M fN}, \textbf{\textit{ where:}}$$

E= Induced voltage in the winding in Volts (V)
K = Constant
Φ_M = Peak Mutual Flux in Webbers (Wb)
F = Supply Frequency in Hertz (Hz)
N = Number of turns in the winding.

For a sinusoidal supply voltage (alternating current is sinusoidal), K = 4.44, hence the equation becomes:

$E = 4.44\ \Phi_M fN$

2.3.5 Relations of Primary and Secondary Quantities.

It is important in transformer calculations to determine the relationship between the primary and secondary induced voltages and turns ratio (primary to secondary).

As discussed earlier in this section, the same voltage is induced across each turn. The induced primary voltage and the induced secondary voltage are linked by the same flux. Hence the following equation develops from the basic transformer equation:

$$\boldsymbol{E_1/N_1 = Kf\Phi_M = E_2/N_2}$$

From this relationship we can derive the relationship between the induced voltages and the turns ratio:

$$E_1/N_1 = E_2/N_2$$

$$E_1/E_2 = N_1/N_2$$

Another relationship is developed from the concept of magnetic balance in a transformer circuit. This concept prescribes that for magnetic balance to be achieved, the ampere-turns of the primary must be equal to the ampere-turns of the secondary. This gives the following relationship:

$$N_1 I_1 = N_2 I_2$$

2.3.6 Power Losses and Efficiency in a Power Transformer

As earlier discussed, the power transformer is a device used to transform the voltage while conserving the same power level between the primary and the secondary. However, in reality, some input power is dissipated internally and not available as output power.

There are two main types of transformer losses:

1) Load-Loss

In a transformer equivalent circuit, this total power loss is determined by the total resistance of the windings (R) and the loss is determined by the relationship I^2R, where I is the current flowing in the windings.

2) No Load Losses

These are losses related to hysteresis losses in the core during the magnetisation and eddy current losses within the core. These losses are influenced by flux density, voltage frequency, material used for laminations and quality of lamination joints.

2.3.7 Transformer Efficiency

This is the measure of output voltage in a transformer as a fraction of input voltage. It is normally expressed as a percentage.

Efficiency = [P_{output}/($P_{outpput}$+P_{loss})]x 100

2.3.8 The Ideal Transformer

It is common for an ideal transformer to be assumed to simplify calculations in power

- The windings have zero resistance, hence the I^2R losses are zero.
- The core permeability is infinite, which means the core reluctance is zero.
- The entire flux in the magnetic circuit is confined to the core and links both windings.
- There are no core losses.

In some instances, the assumption of an ideal transformer is applicable as today transformers get produced with efficiencies as high as 99% (Ref: Glover and Sarma).

2.4 The Physical Construction of a Power Transformer

Having dealt with the theory of transformers, we would like to briefly discuss the physical construction of the power transformer, paying attention to the various components that constitute it.

Figure 11Picture of a physical power transformer.

2.4.1 The Tank

This is the physical enclosure or the transformer shell that encloses the electrical components of the transformer. The tank is to be air and water tight. It contains the core and windings and cooling oil.

2.4.2 The Core

This is the component that provides flux linkage between the primary and the secondary side of the transformer. It is normally manufactured from mild steel and laminated to reduce eddy current losses. This component was discussed in detail in Section 2.3.2.

2.4.3 Windings

These are conductors wound around the core in the primary and secondary side of the transformer. The turns ratio of the primary turns to the secondary turns of the transformer is directly related to the ratio of the primary to the secondary voltage.

2.4.4 Transformer Oil

In transformers under discussion in this research, oil is used as a coolant of the components inside the tank as well as an insulator. When a transformer is operational, the components within the tank (active components) warm up. The transformer oil dissipates this heat through convectional currents created in the oil and dissipation of the heat through fins.

2.4.4 Silica Gel Breather

This is a transparent container carrying silica gel. It works both as an oil preservation component by drying the air moving in and out of the tank during expansion and compression of the oil. It also acts as an indicator of how much moisture is in the tank and can be used during maintenance. The gel is normally blue, but turns pink to indicate the presence of moisture,

2.4.5 Conservator Tank

This is a tank containing insulation oil and positioned above the transformer tank. It is connected to the transformer tank. Its purpose is to 'top-up' the tank using gravity if the oil level drops due to sampling or leaks. It is also used to contain excess oil during thermal expansion of the oil in the tank.

2.4.6 Bushings

These are insulating components, normally of porcelain with a solid internal conductor allowing the live connection of the transformer windings to the outside of the tank. They carry the load current of the transformer. They are used both in the primary and the secondary side of the transformer.

2.4.7 Bucholz Relay

This is the gas collecting device that is used to warn of free gas generation in the transformer oil. It is also able to provide a transformer tripping function through internal relay contacts. It is connected between the conservator tank and the transformer tank and is normally filled with the transformer oil.

2.4.8 Tap Changer

These are mechanical winding connection point selectors that are used to regulate output voltage. It is effectively a large switch with between ten and twenty selection points. It is also able to determine the load current of the transformer through a current diverting technique.

2.4.8 Auxilliary Components

The following components are classified as auxiliary components:

- Oil Temperature indicators
- Oil Level Indicator
- Pressure Relief valve
- Shut off valve
- Drain Valve
- Filter Valve

2.5 Principles of Maintenance Management

2.5.1 Introduction to Maintenance

Maintenance has been given numerous definitions. They all carry the central theme but each is influenced by the activity in which it is applied. The following are some of the definitions used for maintenance:

a) Definition: Maintenance involves the actions of keeping a useful asset in its existing state or preserving it from failure or decline or keeping it in a certain condition or actions that cause the asset's continuity.

b) Definition: Maintenance is the function of keeping items or equipment in or restoring them to serviceable condition. It includes servicing, testing, inspection, adjustment, alignment, removal, replacement, reinstallation, troubleshooting, calibration, condition determination, repair, modification, overhaul, rebuilding, and reclamation.

c) Definition: Maintenance concerns the combination of technical administrative and managerial actions during the lifecycle of an item - physical asset (Building), work equipment, or means of transport – intended to retain it in or restore it to a state in which it can perform its intended function. (Source: CEN EN 13306 Maintenance Terminology, http://www.cen.eu/).

All the above definitions of maintenance have been applied in industry to describe maintenance.

2.5.2 The Need for Maintenance Management

There are many reasons that have resulted in the growth of Maintenance Management as an essential function in industry. The increasing demand exerted by population and economic growth on assets coupled with ageing and neglect is one such reason. Maintenance then comes in as a solution in bringing these assets back to acceptable or serviceable condition.

2.5.3 Introduction to Maintenance Management

Maintenance management is widely considered as a subset of engineering management. It deals with the management and control of resources employed in the carrying out of maintenance within an organisation. Maintenance management is defined below:

a) Definition: Maintenance Management involves the planning, organising and controlling of all maintenance resources to adjust, repair, replace, and modify technical systems so that these systems can perform their intended functions for a specified period.

2.5.4 Maintenance Breakdown

The types of maintenance that exist can be broken down and classified. This will be presented diagrammatically as follows:

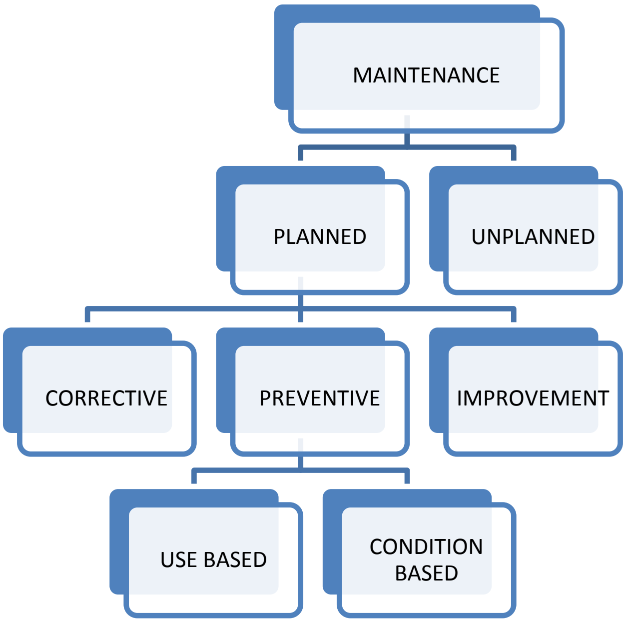

Figure 12 Maintenance Breakdown (1). (Source:Visser,2012)

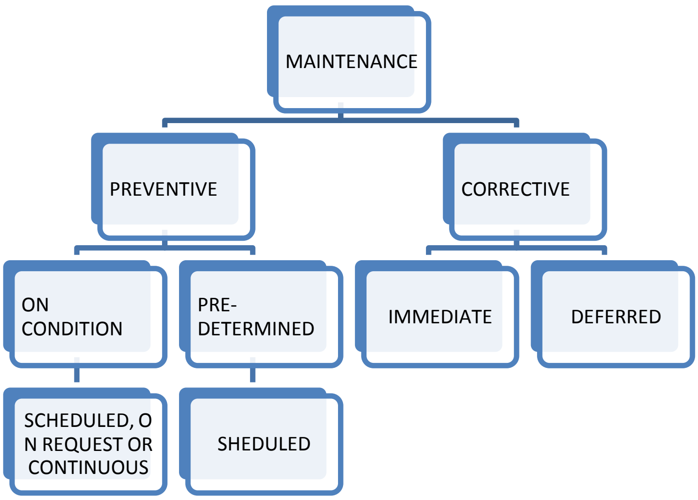

Figure 13:Maintenance Breakdown (2). (Source: BS EN 13306:2001)

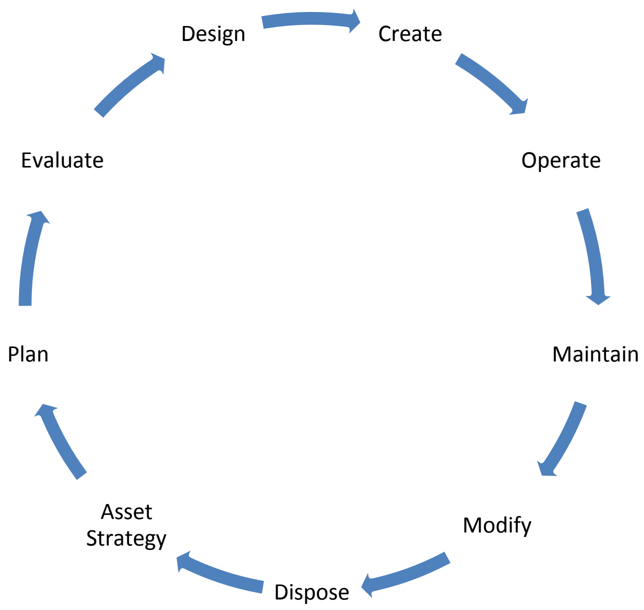

Figure 14: The Life Phases of Assets. (Source: Campbell, 1997).

2.5.5 Maintenance Tactics

Duffua defines maintenance tactics as follows:

- Corrective
- Preventive (time based and condition based
- Fault finding
- Opportunity
- Overhaul
- Design Modification
- Component Replacement

(Duffua, 1999, Ch1, Maintenance Tactics and Strategies)

2.5.6 Systems Approach to Maintenance Management

This is an approach to maintenance management aimed at reducing the disorder associated with a breakdown or problem situation. This approach has clearly defined objectives and for it to function, total system performance must be clearly defined. The system must be managed i.e. its goals set, resources allocated and system performance controlled. Each system is part of a hierarchy of systems. The system will have a boundary in which it functions and it is crucial for this to be defined. Anything outside the system boundary forms part of the system environment. There may also be sub systems under the system.

The maintenance system may also be viewed in the same approach as described through the figure below:

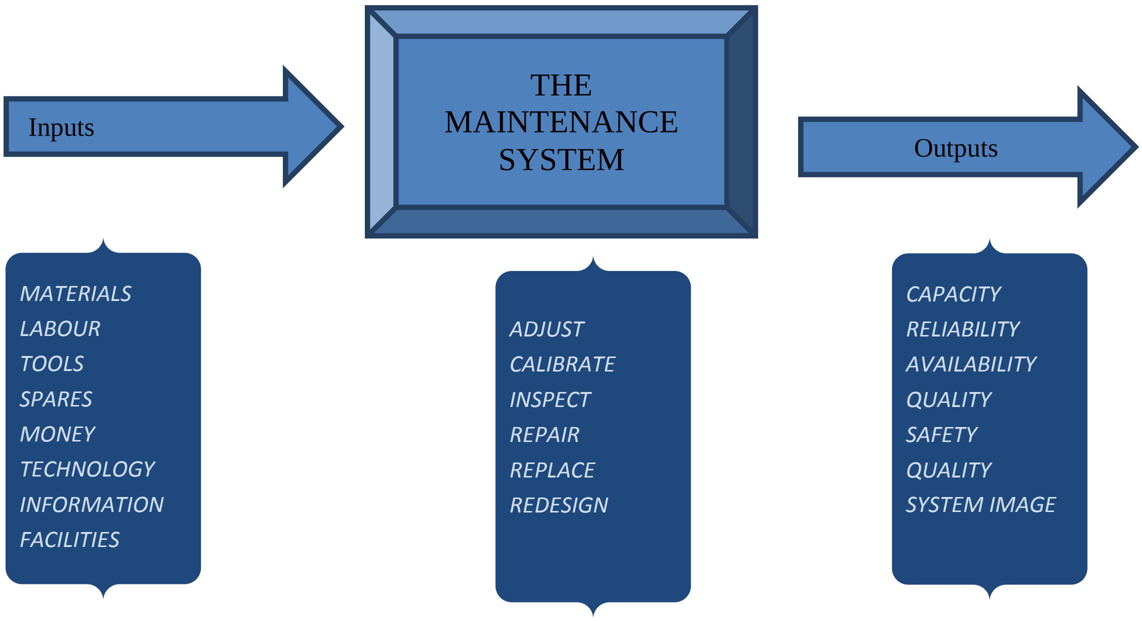

Figure15: A Systems Approach to Maintenance. (Source: Visser, 2012).

2.5.7 The Maintenance Management Process

Visser developed a maintenance management process model that defines the various activities in a maintenance management system. The management process can be depicted in the diagram below:

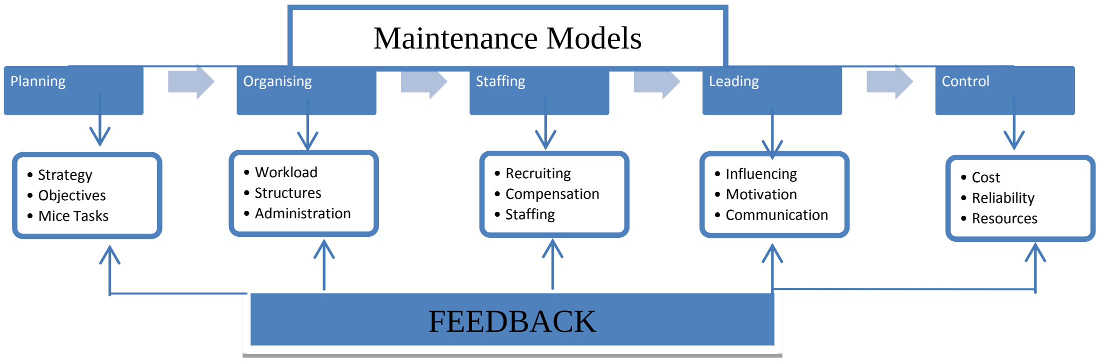

Figure 16: Maintenance Models. (Source: Visser, 1996).

2.5.8 The Maintenance Cycle

Coetzee developed a simplified model for a maintenance cycle as an integral approach to maintenance and maintenance management.

This model comprises two processes, namely;

- A strategic process (the outer cycle)
- An operational process (the inner cycle)

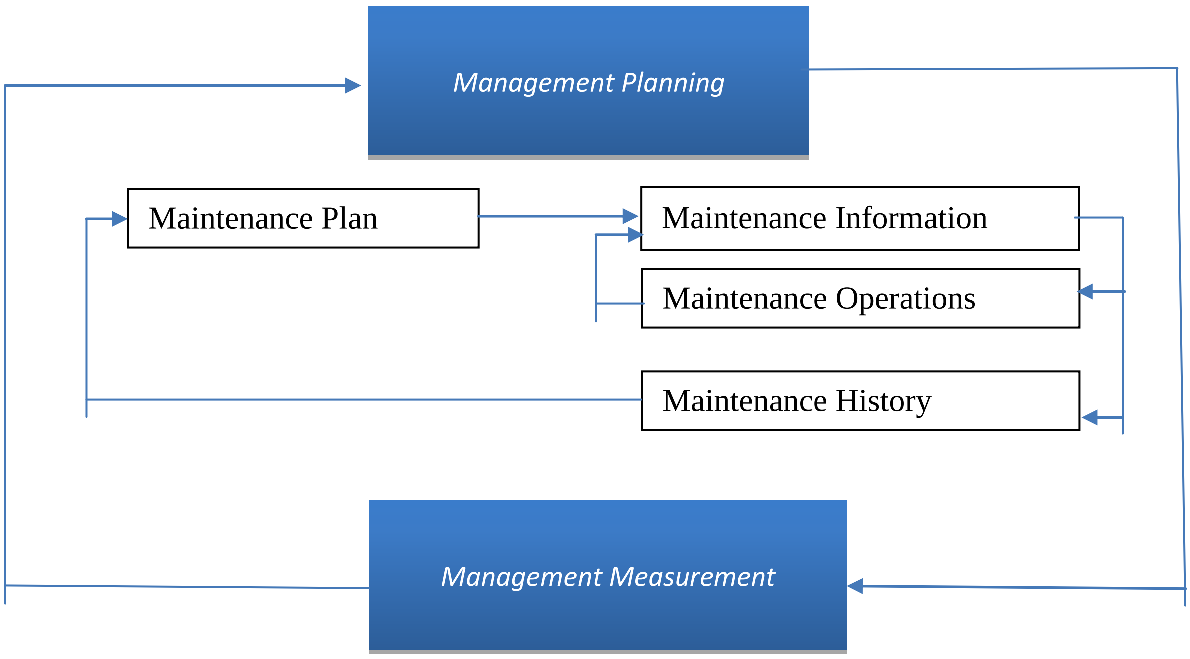

Figure 17: A Holistic Approach to the Maintenance Problem. (Coatzee, 1999).

2.5.9 Maintenance Management in the Context of the Enterprise

The maintenance system can be viewed as a sub system of the Enterprise system. The enterprise system may also be viewed as an input-output system. The primary goal for the enterprise system is to provide profits. Though this is not the sole objective, for most enterprises it is the primary one. Other objectives may include the following:

- Sustainability/Environmental responsibility
- Social responsibility
- Employee empowerment

The maintenance system should assist in achieving the enterprise goals by lowering costs and thus increasing profits. This is done through:

- Reducing failures
- Increasing availability
- Minimising system downtime
- Improving quality

2.5.10 The Importance of Maintenance

The following are some of the reasons why maintenance management is becoming an increasingly important function in organisations:

- An increase in the number and type of equipment used in production.
- An increase in the complexity of process and equipment.
- The increase of automation in the manufacturing process
- The rise in the cost of production and raw materials
- An increase in the specialisation of maintenance workers
- An increase in technological advancement and obsolescence of old equipment.
- Increase in the pressure from shareholders for more profits.
- The high cost of maintenance, up to 50% of total production cost (see table 2-3 below showing typical values in South Africa).
- ***Table 3: Maintenance Costs in South Africa (Source: South African Statistics, 2001.)***

Industry	Cost Ratio (%)
Agriculture and Forestry	20
Mining and Quarrying	45
Manufacturing	12
Electricity and Water	12
Construction	15
Transport and Communication	15

Cost Ratio = Total Maintenance Cost/Total production Cost

2.5.11 Introduction to Maintenance Planning

The execution of maintenance within the enterprise needs to be planned. Visser distinguished three levels of maintenance planning in maintenance management:

- Strategic Planning (encompassing long and medium term).
- Overall Maintenance Life Plan
- Detailed Task Planning and Scheduling.

The Maintenance Manager is mostly involved in strategic planning.

2.5.12 Strategic Planning for Maintenance

Campbell and Ryers-Picknell outline a business strategy as comprising the following elements:

- A description of the business involved and its products and services.
- A list of key customers and what factors keep them as customers
- A review of the regulatory, economic and financial environment
- Strengths, Weaknesses, Opportunities and Threats (SWOT Analysis).
- Description of the business vision for the next 3-5 years.
- Statement of the mission guiding principles and major objectives to be accomplished.

The strategy of the maintenance manager is concerned with future oriented plans for interacting with other departments to achieve the maintenance objectives. Maintenance strategy and objective must be derived from the company strategy and objectives. Strategic management is crucially important for the maintenance manager and should form part of his management task. The following flow diagram by Visser, 2012 outlines strategic planning for maintenance:

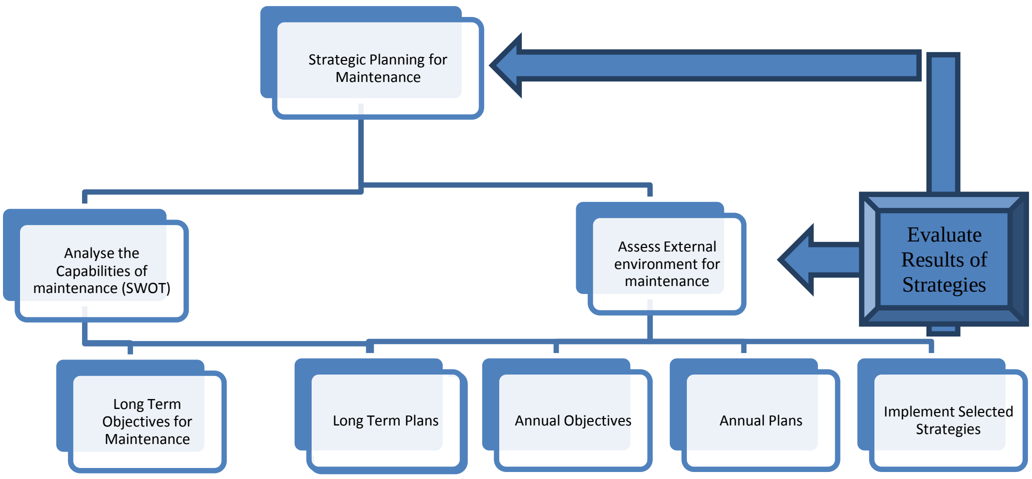

Figure 18: Strategic Planning for Maintenance

2.5.13 Maintenance Objective and Vision Statement

The function of maintenance within and organisation utilises resources to achieve a specific objective. The maintenance objective should support the overall company objective. Maintenance resources are used to:

- The system achieves its design life
- Safety regulations are adhered to
- Output quality and quantity is achieved
- The image of the system is satisfactory
- Energy usage is optimised
- Raw material consumption is optimised.

The maintenance department within the company may use a vision statement to summarise the maintenance ‘dream’ the department or the company wishes to pursue. This expressed ‘dream’ provides the energy and motivation for the employees to increase performance. An example of a maintenance vision statement could be:

“To minimise downtime and improve system availability to 90%”.

Audits, internal and external are then used to monitor performance against vision statement and provide feedback.

2.5.14 Selecting Maintenance Tactics

The primary goal of maintenance planning is to minimise the Total Cost of Maintenance. The total cost of maintenance has two major components namely:

- Direct Cost of Maintenance, e.g. labour, spares, materials, tools.
- Indirect Cost of Maintenance e.g. cost of lost production due to downtime (revenue loss), cost of damaged company reputation.
-

Maintenance tactics can therefore be classified broadly as preventive maintenance and corrective maintenance. The total maintenance cost curve has a minimum point. The maintenance manager has a primary task of determining the level of preventive maintenance that achieves the optimum level of total maintenance cost to achieve company objectives. This is not done mathematically. It is carried out through careful observation. The graph below shows these relationships.

The following maintenance tactics are available

- Operate to Failure (OTF) also known as Run to Failure (RTF)
- Failure Based Maintenance (FBM), same as OTF and RTF

- Fixed Time Maintenance (FTM), also known as Time Based Maintenance (TBM) or Use Based Maintenance (UBM).
- Condition Based Maintenance (CBM) also referred to as Predictive Maintenance.
- Failure Finding Tasks (FFT) also referred to as Proof Testing Tasks (PTT)
- Opportunity Maintenance (OM).

2.5.15 Organising Maintenance Resources

The primary task of the maintenance department is to match the maintenance resources to the workload. The aim is to achieve the desired system effectiveness at an acceptable resource cost.

Typical Maintenance resources include the following:

- People
- Spares
- Materials
- Tools
- Data and Information
- Technology
- Workshops
- Facilities

The maintenance department seeks to achieve lower resource costs through:

- Improved performance of maintenance workers
- Spares, tools and information availability
- Efficiency of work planning

2.5.16 Leading in Maintenance

Of all the maintenance resources available to the maintenance manager, people are the most important, yet also the most unpredictable and the most unstable.

Leading is to harmonise individual and company objectives. The leading function involves:

- Motivating
- Leadership
- Communication

Definition: Leading is the process of influencing people so that they will contribute to the goals of a group and of the total enterprise. (Visser, 2011).

The needs and objectives of the individuals of the enterprise are important and must be considered. Effective leadership aims to help workers to understand that they can satisfy their needs and utilise their potential while simultaneously contributing towards the aims of the enterprise. The maintenance manager must understand that every worker contributes towards the goals of the company and should therefore be treated with personal dignity and respect. He should also recognise that maintenance workers are different and that the management approach for each should differ. Maintenance errors have contributed towards several major accidents in industry. The avoidance of human and other errors is thus imperative. Maintenance managers can achieve this through effective motivation and communication techniques.

2.6 TRANSFORMER MAINTANANCE

2.6.1 Introduction

It is important to give a brief overview of the actions that constitute the maintenance of power transformers. Though the analysis discussions of transformer maintenance within an electrical grid will be at a higher level, an appreciation of the lower level concepts involved in transformer maintenance will be useful.

2.6.2 Life Limiting Factors of the Power Transformer in Operation

Life reducing events in transformer operation occur separately or in combination. The ability of the transformer to sustain such events depends on the following factors:

- Severity (amplitude and duration) of the event (particularly applicable to fault and surge conditions).
- Capability of the transformer design to withstand a certain event.
- Ability to control temperatures of various parts of the transformer.
- Concentration of oxygen and other gases in insulation and oil
- Deterioration of electrical insulation properties (Both in oil and insulation material separating laminations).
- Number, size and type of impurity particles in oil.

2.6.3 Common Causes for Condition Deterioration of Failure of Transformers

2.6.3.1 Moisture

Oil contamination by water compromises the insulation properties. It also causes the insulation material in the core laminations to lose effectiveness.

2.6.3.2 Gas Bubbles and Oxygen

The introduction of gas bubbles especially oxygen in transformer oil compromises its effectiveness as an insulator.

2.6.3.3Solid contamination

The introduction of solid particles on the inside of the transformer also a cause of deterioration and failure. Solidparticles deposited within the tank will move to various parts of the inside of the transformer as the oil heats up and generated convectional currents. This can cause deterioration of the transformer

2.6.3.4 Overcurrent and Overvoltage

Depending on the severity, overvoltage and overcurrent causes stress on the internal active components of the transformer causing insulation breakdown and subsequently transformer failure.

2.6.3.5 Over-temperature (Thermal Breakdown)

Two properties contribute to breakdown:

- Insulation has a high negative temperature coefficient of resistance. This means an increase in temperature means results in a decrease in the resistance of insulation materials (this is opposite for conductors).
- The dielectric strength of insulation in a transformer decreases rapidly with increase in temperature. This means, the higher the operating temperature, the less effective oil is as an insulator.

For example, from 32^0C to 60^0C, the resistance of oil decreases from 25 $X10^6$ to 1 $X10^6$ (Source: Doble Engineering Transformer Maintenance Training Notes)

2.6.3.6 Short circuit and fault Conditions

If a fault or a short circuit occurs in the circuit in which the transformer is connected, the effect of the fault current is the breakdown of insulation, in some severe cases physical stress on the core and the winding or even the explosion of the transformer tank.

2.6.4 Maintenance Approaches Employed in Power Transformers

2.6.4.1 Run to Failure – in this case,the transformer is operated until it ceases to function due to failure.

2.6.4.2Ordinary maintenance – repairs, adjustments and replacements of parts as found to be necessary by visual inspection at irregular intervals;

2.6.3 Preventive maintenance – this approach consists of regularly scheduled activities:

- Monthly ”hands off” inspection,
- Annual energised testing of equipment (oil testing, gas-in-oil analysis, infrared inspection)
- De-energised biennial or triennial dismantling or testing of equipment to check every detail likely to cause trouble (electrical insulation tests, switchgear, etc)

2.6.4Protective Maintenance

There are two broad classes of activities involved in protective maintenance in transformers.

2.6.4.1Predictive maintenance is a more frequent monitoring, inspection and testing of critical equipment. This begins with recognising the inevitable factors that contribute to equipment degradation and prevent eventual failure.

2.6.4.2Corrective maintenance is scheduled as soon as preventive or predictive maintenance has disclosed a serious problem.

2.6.5The Transformer Maintenance Program

- A proper maintenance starts with a proper maintenance programme.
- The first 3 years of a transformer are the most critical for long-term life of the unit.
- Life after 20 years depends on the quality of maintenance during the first 10 years.

2.6.5.1 Technical aspects

- Scheduled annual oil and gas-in-oil tests and regular checks, electrical tests and inspections.
- Regularly inspect, calibrate and maintain all protective devices.
- Eradicate life limiting conditions
- Respect all tolerances and recommendations
- Use undamaged parts and materials within set specifications
- Incorporate new technology as practical

- Parts must be lubricated, paintwork repaired, silicagel replaced & contacts changed as required.

2.6.5.2Organisational aspects

- Scheduled initial personnel training and periodic retraining inspections
- Build up-to-date reference library, including all relevant standards and specifications.
- Keep detailed record on each transformer
- Maintain daily log of units operating temperature, pressure, load and ambient temperature.
- Record the time and extent of any repair work, maintenance and tests done.
- Maintain history log on extraordinary occurrences and any adverse operating conditions.

2.6.5.3Field testing

- **Most commonly applied tests are:**
- Oil screening
- Moisture in oil test
- Gas-in-oil analysis
- Thermographic survey

Other reasons for performing field tests are:

- Establish a test reference point
- Determine the amount of insulation degradation
- Placing or removing a unit in or out from storage

2.6.5.4Measurement procedures

The following measurement procedures are very useful during maintenance:

- **Winding insulation resistance**
- **Voltage ratio & functionality test of tap changer**
- **No –load currents**
- **Winding resistance**

- **Polarity check of CTs built into TRFs**

2.6.5.5 Interpreting test data

A comprehensive test program can:

- Indicate the interior condition of the transformer, such as presence of sludge which can be removed before it precipitate out onto the windings or other parts of the transformer.
- Prevent an unscheduled outage by detecting problems early enough to scheduled a least disruptive outage.
- Reliably statistical data for plotting deterioration trends, which would be used globally.

2.6.6 Case Study: Eskom's Evolution of Transformer Maintenance Tactics.

Previously, the traditional maintenance strategy has been based on failure events, which have required corrective action to be taken. Although this was a low maintenance cost strategy, the consequences were costly from a plant availability point of view. Availability was low due to frequent and sometimes long supply restoration times.

A development on maintenance based on failure events was Time Based Maintenance (TBM). This strategy was higher in maintenance costs, yet realised a marginally small improvement in plant availability. A significant improvement in both cost and availability was witnessed with the introduction of maintenance based on the condition of the plant. This was termed Condition Based Maintenance (CBM).

A further improvement was the development o f a maintenance strategy based on risk and reliability, as embodied in Reliability Centred Maintenance (RCM). This strategy encompasses a probabilistic approach that relies on an effective transformer data management system and an adequate history for reliability and probability studies. The risk assessment process includes a multi-disciplinary study, including aspects such as design, protection, construction, commissioning, operation, maintenance, safety and environment.

Diagnostic methods have also enhanced the evolution of maintenance practices. Of particular importance to transformer maintenance is the regular and even on-line monitoring of key electrical, chemical and thermal parameters.

Source: Eskom; Power Transformers (Theory, Design, Maintenance and Life Management, 2008: 4)

2.6 Overview of Outsourcing Principles

2.6.1 Introduction to Outsourcing

Outsourcing is the act of transferring some of a company's recurring internal activities and decision rights to outside providers, as set forth in a contract. Because the activities are *recurring* and a contract is used, outsourcing goes beyond the use of consultants. As a matter of practice, not only are the activities transferred, but the factors of production and decision rights often are, too. (Griever, 1999:3)

Outsourcing is sometimes referred to as 'contracting out'.

Factors of production are the resources that make the activities occur and include people, facilities, equipment, technology, and other assets. *Decision rights* are the responsibilities for making decisions over certain elements of the activities transferred.

2.6.2 Justifications for Outsourcing

Because the objectives and needs of organisations differ, the option to outsource is taken for a variety of organisational reasons. The most common motivations will be discussed in this section:

2.6.2.1 Organizationally Driven Reasons

- Enhance effectiveness by focusing on what you do best.
- Increase flexibility to meet changing business conditions, demand for products and services, and technologies.

- Transform the organization.
- Increase product and service value, customer satisfaction, and shareholder value.

2.6.2.2Improvement- Driven Reasons

- Improve operating performance.
- Obtain expertise, skills, and technologies that would not otherwise be available.
- Improve management and control.
- Improve risk management.
- Acquire innovative ideas.
- Improve credibility and image by associating with superior providers.

2.6.2.3 Financially Driven Reasons

- Reduce investments in assets and free up these resources for other purposes.
- Generate cash by transferring assets to the provider.

2.6.2.4 Revenue- Driven Reasons

- Gain market access and business opportunities through the provider’s network.
- Accelerate expansion by tapping into the provider’s developed capacity. Processes and systems.
- Expand sales and production capacity during periods when such expansion could not be financed.
- Commercially exploit the existing skills.

2.6.2.5 Cost- Driven Reasons

- Reduce costs through superior provider performance and the provider’s lower cost structure.
- Turn fixed costs into variable costs.

2.6.2.6 Employee-Driven Reasons

- Give employees a stronger career path.
- Increase commitment and energy in noncore areas.

2.6.3 Potential Disadvantages of Outsourcing

2.6.3.1 Finding the Right Service Provider

In instances, the good service providers do not respond to the RFP for outsourcing. This can compromise the objectives of the outsourcing exercise and the anticipated gains be unrealised.

2.6.3.2 Loss of Core Competencies

The contracting out of certain functions from in house may result in the loss of core competencies as experienced personnel may have to be relocated.

2.6.3.3 Loss of Control

The relocation of the decision making centre to the contracted firm can result in the loss of control of certain areas of the organisation.

2.6.3.4 The Cost of Structural Adjustments

Declaring some functions within the firm redundant is costly. Paying off employees and getting rid of assets can be a costly exercise.

2.6.3.5 Uncertainty

Structural adjustments within the organisation can create uncertainty even in departments not affected by the outsourcing exercise. This has a bearing on the overall productivity of the workforce.

2.6.3.6 Risk of Failure

Not all outsourcing undertakings have n=been a succecess. Many factors come into play, including the strategy implemented when outsourcing and employee buy in and service provider delivery. The risk of ending up with a service level lower that what was being offered in house is ever present.

2.6.3.7 Difficulty in reversing

It is very difficult to reverse back to services being provided in house onv=ce the decision to outsource has been implemented.

2.7 LIFE-CYCLE MANAGEMENT

The organisation that operates an electrical network experiences constraints on operational resources. This includes financial and technical skills as well as human resource capacity. Asset management constraints are common to most international electricity utilities. In developing countries like Swaziland, the pressure experienced from the political front is for grid expansion, especially, domestic connections. These new customers typically do not provide enough return on investment for SEC. This exerts even more pressure on available resources.

There is thus a need to optimise and where possible, extend the operational life expectancy of primary grid assets. To address this trend, some electricity utilities have implemented a life cycle management approach in the management of assets. Life-Cycle Management Plans (LCMP's) for major grid assets are compiled. Transformers are an example of such assets. LCMP's are intended to optimise and sustain the functionality of transformers in both the short-and long term. This is achieved by employing engineers best practices aimed at avoiding, reducing and possibly eliminating failures. In addition, they serve to provide uniformity in the employment of maintenance and operational procedures, while ensuring minimal impact on the environment.

The primary focus of the LCMP's is towards customer and asset management. This includes integrated network planning, asset planning, management systems, and the management and disposal of assets. Decisions on transformer acquisition or replacement, the operation and maintenance, and disposal should be integrated within an organisation's strategic plans. The expected successes are measured by the following:

- Actual transformer performance achieves expected delivery and service standards.
- Transformer acquisition and replacement coincides with organisational financial management plans.

- Transformer acquisition and replacement aligns with organisational planning horizons.

What is crucial in the implementation of a transformer LCMP is its management. This includes the deployment of competent personnel. In addition, it is essential that there is consistency in transformer life cycle include the concept, planning, design, commercial process, construction, commissioning, operation, maintenance, decommissioning and disposal.

LCM requires that decisions made during the procurement or development phase of an asset, process be evaluated against the total life-cycle cost of the system. In the LCM approach, downstream costs of owning, operating and maintaining an asset are considered. For example, at the design phase of an asset, the maintenance cost may be ignored. This could later result in a higher cost of running the asset later. If LCM is employed, the maintenance and support costs may be substantially alternatives are explored during the design or procurement stage.

3 Research Methodology

3.1 The Sub Problem 1

The first sub problem was to ascertain is a structured maintenance management system was in place within SEC for transformers.

3.1.1 Research type

A non-experimental quantitative research approach was used to conduct part of the study. In addition a descriptive survey was conducted using questionnaires and structured interviews (Welman, Kruger and Mitchell, 2005: 92-93).

The aim of the questions was to:

- Identify the maintenance management approach taken by SEC to power transformers.
- Test the effectiveness of the maintenance approach
- Determine if transformer failures contribute substantially to overall outages experienced by network users
- To find out if Life cycle management is implemented for transformers
- To determine if the total cost of downtime was being seriously considered
- To determine if outsourcing some maintenance functions was being considered an option
- To determine if there are enough trained and experienced personnel within SEC for the maintenance of transformers
- To determine if SEC is remunerating maintenance technicians sufficiently to prevent skills migration.
- To determine if SEC is abreast with technology for transformer maintenance.

3.1.2 Selecting the population

The population sample for the full lift of interviewees was to be thirty (30) see Annexure 2, List of interviewees. The population groups were strategically selected to reflect a very wide spectrum of opinions on the questions presented.

3.1.3 Sample selection

The groups interviewed and their identified areas of research interest are listed below:

1. Officials from the utility SEC

These were identified as the group to give inside information. They were selected from the CEO down to the various area managers to give different viewpoints of the questions asked.

2. Senior Officials from the Ministry of Public Works Head Office

This is the group from the largest property owner and developer in the country. They were identified as the single group that paid the most for the procurement and maintenance of transformers in the country.

3. Electrical Engineering Consulting Engineers and Contractors

   This group is closely involved in the development of all new facilities requiring the supply of transformers. The members of this group are conversant with the day-to-day problems of transformers in service.

4. Large and Medium Industrial Users

   This group was identified as the group that is involved in mass production requiring maximum uptime of transformers. Transformer failures for them often mean loss of revenue.

5. Sensitive Users

   For security, health and other reasons, some energy users are least tolerant to power outages. This is the group selected as sensitive users.

6. Households

   This is the average man and woman needing electricity to run a home. Their opinion on the research was also considered pertinent.

3.1.4 Location of the Data

The data was obtained from the following sources:

1. **Work Knowledge of the Researcher**

Being a consulting electrical engineer, the researcher is involved daily with issues surrounding the research topic. Much knowledge was derived from this fact.

2. **SEC's Annual Reports**

The annual reports for the years 2009 and 2010 were made available and much research information was obtained from these documents for purposes of the research.

3. **Structured Interviews**

Responses to the research questions as presented in the questionnaires provided much of the required research information.

3.1.5 Data Collection Technique

Questionnaires were sent out by e-mail and by hand delivery in some instances. These were returned electronically and some had to be collected.

3.1.6 Treatment of Bias

As far as possible, the research attempted to eliminate bias in the following ways:-

1. Survey a broad population.
2. Within SEC, interview different levels of managers, which encompasses both makers and users of company policy.
3. Interview different interest groups in the use of electrical energy.
4. Make the interviews structured through questionnaires.
5. Make interviewees aware that the returned questionnaires are discreet or anonymous.

3.2 Subsequent Sub Problems

The research methodology followed in the other sub problems is the same as that of the first sub problem.

4. RESULTS AND FINDINGS

4.1 Introduction

The population was divided into specific interest groups covering a broad spectrum of SEC network users. SEC staff also formed part of the population. The responses of each sample group shall be presented in the findings. The full set of interview results are included as Annexure B. these were considered to be too detailed for purposes of this research. They have been summarized into specific sub problem question responses and presented in this chapter. The presented results are a summary of the interview responses.

Table4 : Groups in the sample population.

GROUP	**Description**	
A	SEC Staff Member	
B	Ministry of Public Works & Transport Official	
C	Electrical Engineering Consultant or Contractor	
D	Large SEC Customer	
E	Sensitive SEC Customer	
F	Domestic & Small Commercial SEC customer	

4.2 Sub Problem 1 Results

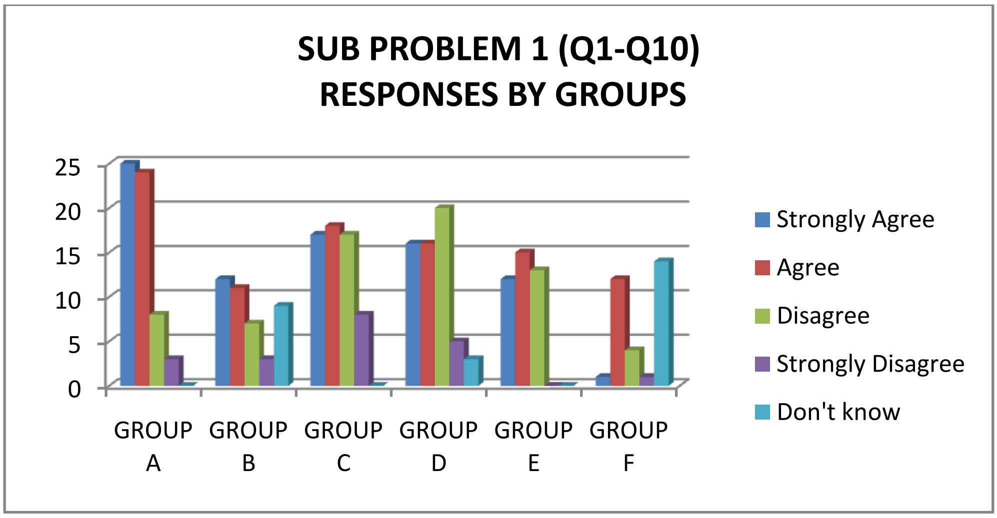

Figure 19: Graphical Results showing population responses relating to sub problem 1 questions.

Table5: Tabulated results showing population responses to relating to sub problem 1 questions.

	GROUP A	**GROUP B**	**GROUP C**	**GROUP D**	**GROUP E**	**GROUP F**
Strongly Agree	25	12	17	16	12	1
Agree	24	11	18	16	15	12
Disagree	8	7	17	20	13	4
Strongly Disagree	3	3	8	5	0	1
Don't know	0	9	0	3	0	14

4.2.1 Group A: SEC Employees

The responses from this sample group show that 82% of SEC employees believe that maintenance management of transformers is being implemented within the organization. 18% feel that this is not happening.

4.2.2 Group B: Ministry of Public Works

This sample group involves engineers and officials who deal with SEC quite frequently. 56% of them agree that SEC implements maintenance management. 15% of them disagree.

4.2.3 Group C: Large Contractors and Consultants

This sample group involves electrical engineering contractors of the large scale and consultants who typically deal with large projects involving SEC. some consultants get involved with smaller projects. 58% of this group feels that SEC does implement maintenance management of transformers. Approximately 42% of this group feels that SEC does not implement maintenance management of transformers.

4.2.4 Group D: Large SEC Customers

53% respondents in this sample group agree that SEC implements transformer maintenance management. 42% disagree. 3% did not know.

4.2.5 Group E: Sensitive Customers

68% of this group feels that SEC does implement a maintenance management system for transformers. 32 % feel this is not happening.

4.2.6 Group F: Small Commercial Customers and Households

45% of this sample group responded as not knowing whether SEC implements maintenance management of transformers. About 13% disagree and 42% agree

4.2.7 Summary of Sub Problem 1 Findings

SEC operates a partial transformer maintenance program. Transformers smaller than 800kVA are tested upon procurement and then operated to failure. Transformers larger than 800kVA are maintained.

Copper theft is very rife within the SEC network and the softest targets are the earth protection installation for transformers.

There is no maintenance department within SEC. Maintenance of various network elements is carried out within the larger Operations Department.

4.3 Sub Problem 2 Results

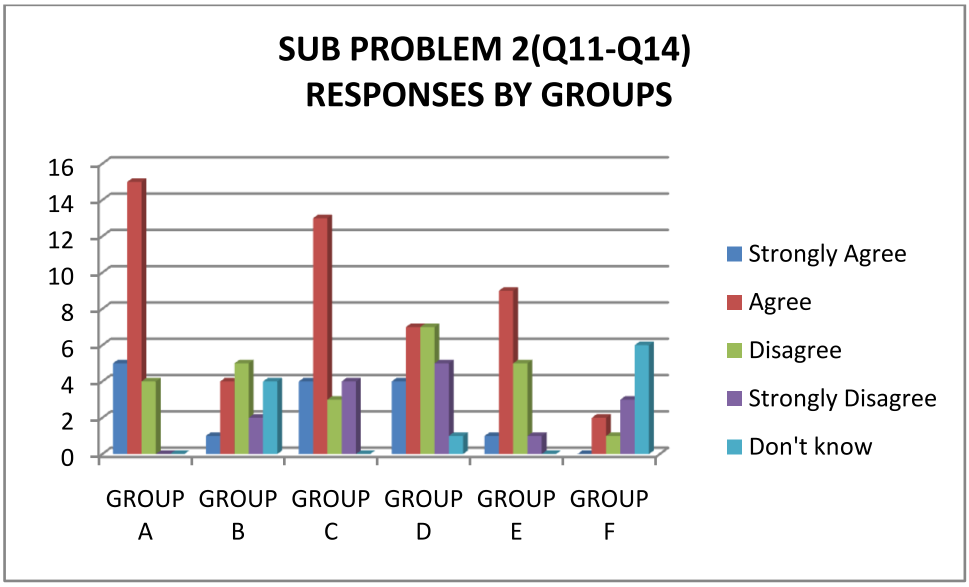

Figure 20: Graphical Results showing population responses relating to sub problem 2 questions.

Table6: Tabulated results showing population responses to relating to sub problem 2 questions.

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	5	1	4	4	1	0
Agree	15	4	13	7	9	2
Disagree	4	5	3	7	5	1
Strongly Disagree	0	2	4	5	1	3
Don't know	0	4	0	1	0	6

4.3.1 Group A: SEC Employees

The responses from this sample group show that 83% of SEC employees believe that adequate financial resources are being allocated within SEC for maintenance of power transformers. 17% feel that this is not happening.

4.3.2 Group B: Ministry of Public Works

This sample group involves engineers and officials who deal with SEC quite frequently. 31% of them agree that adequate financial resources are being allocated within SEC for maintenance of power transformers.44% of them disagree. 25% did not know.

4.3.3 Group C: Large Contractors and Consultants

This sample group involves electrical engineering contractors of the large scale and consultants who typically deal with large projects involving SEC. Some consultants get involved with smaller projects. 71% of this group feels that adequate financial resources are being allocated within SEC for maintenance of power transformers. Approximately 29% of this group feels that inadequate financial resources are not being allocated within SEC for maintenance of power transformers.

4.3.4 Group D: Large SEC Customers

42% respondents in this sample group agree that adequate financial resources are being allocated within SEC for maintenance of power transformers.50% disagree. 8% did not know.

4.3.5 Group E: Sensitive Customers

63% of this group feels that adequate financial resources are being allocated within SEC for maintenance of power transformers. 27 % feel this is not happening.

4.3.6 Group F: Small Commercial Customers and Households

18% respondents in this sample group agree that adequate financial resources are being allocated within SEC for maintenance of power transformers. About 36% disagree and 46% did not know.

4.3.7 Summary of Findings

Limited resources are largely allocated to the extension of network coverage to rural areas.

4.4 Sub Problem 3 Results

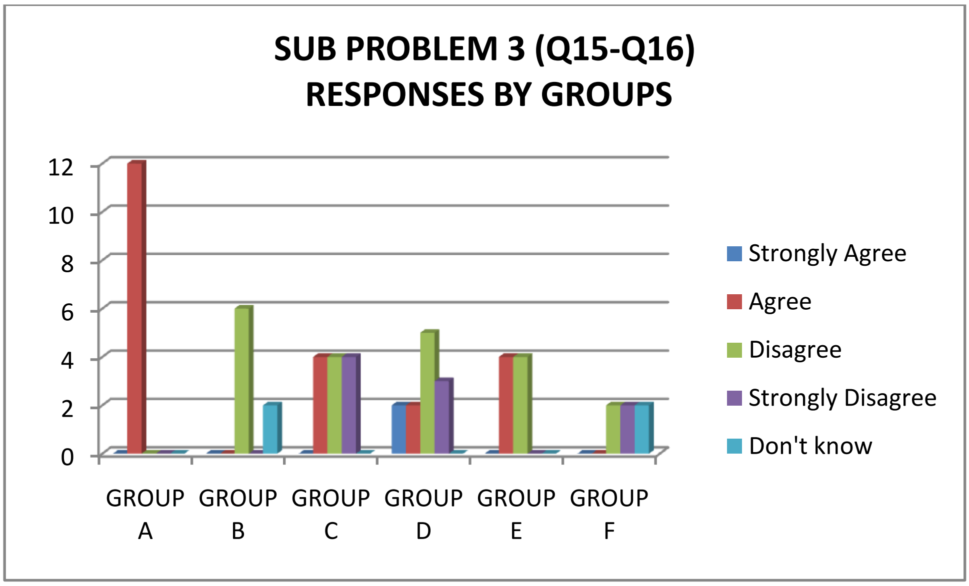

Figure 21: Graphical Results showing population responses relating to sub problem 3 questions.

Table7: Tabulated results showing population responses to relating to sub problem 3 questions.

	GROUP A	**GROUP B**	**GROUP C**	**GROUP D**	**GROUP E**	**GROUP F**
Strongly Agree	0	0	0	2	0	0
Agree	12	0	4	2	4	0
Disagree	0	6	4	5	4	2
Strongly Disagree	0	0	4	3	0	2
Don't know	0	2	0	0	0	2

4.4.1 Group A: SEC Employees

The responses from this sample group show that 100% of SEC employees believe that SEC have trained and experienced personnel capacity to carry-out adequate maintenance of power transformers.

4.4.2 Group B: Ministry of Public Works

This sample group involves engineers and officials who deal with SEC quite frequently. 0% of them agree that SEC have trained and experienced personnel capacity to carry-out adequate maintenance of power transformers. 75% of them disagree. 25% did not know.

4.4.3 Group C: Large Contractors and Consultants

This sample group involves electrical engineering contractors of the large scale and consultants who typically deal with large projects involving SEC. Some consultants get involved with smaller projects. 33% of this group feels that SEC have trained and experienced personnel capacity to carry-out adequate maintenance of power transformers. Approximately 67% of this group feels that SEC does not have trained and experienced personnel capacity to carry-out adequate maintenance of power transformers.

4.4.4 Group D: Large SEC Customers

33% respondents in this sample group agree that SEC have trained and experienced personnel capacity to carry-out adequate maintenance of power transformers. 67% disagree.

4.4.5 Group E: Sensitive Customers

50% of this group feels that SEC have trained and experienced personnel capacity to carry-out adequate maintenance of power transformers. 50 %disagree.

4.4.6 Group F: Small Commercial Customers and Households

0% respondents in this sample group agree that SEC have trained and experienced personnel capacity to carry-out adequate maintenance of power transformers. About 66% disagree and 34% did not know.

4.4.7 Summary of Sub Problem 3 Findings

The technicians tasked to carry out transformer maintenance are actually trained to carry out condition monitoring. The captured data is then sent to various South African companies for processing and action.

4.5 Sub Problem 4 Results

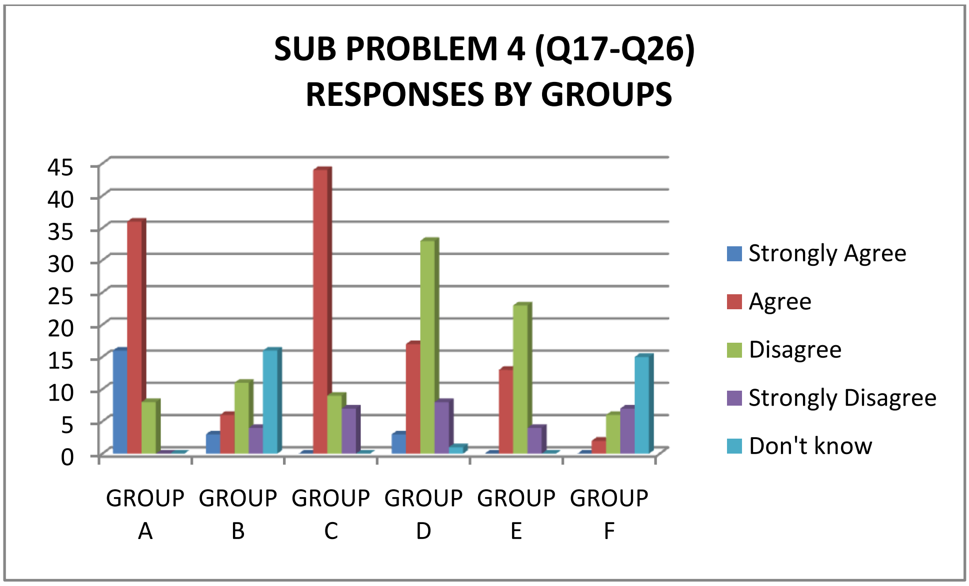

Figure 22: Graphical Results showing population responses relating to sub problem 1 questions.

Table 8: Tabulated results showing population responses to relating to sub problem 1 questions.

	GROUP A	**GROUP B**	**GROUP C**	**GROUP D**	**GROUP E**	**GROUP F**
Strongly Agree	16	3	0	3	0	0
Agree	36	6	44	17	13	2
Disagree	8	11	9	33	23	6
Strongly Disagree	0	4	7	8	4	7
Don't know	0	16	0	1	0	15

4.5.1 Group A: SEC Employees

The responses from this sample group show that87% of SEC employees believe that SEC have facilities and technology locally to enable the effective maintenance of power transformers. 13%disagree.

4.5.2 Group B: Ministry of Public Works

This sample group involves engineers and officials who deal with SEC quite frequently. 23% of them agree that SEC have facilities and technology locally to enable the effective maintenance of power transformers.37% of them disagree. 40% did not know.

4.5.3 Group C: Large Contractors and Consultants

This sample group involves electrical engineering contractors of the large scale and consultants who typically deal with large projects involving SEC. Some consultants get involved with smaller projects. 73% of this group feels that SEC has facilities and technology locally to enable the effective maintenance of power transformers. Approximately 27% of this group disagrees.

4.5.4 Group D: Large SEC Customers

32% respondents in this sample group agree that SEC have facilities and technology locally to enable the effective maintenance of power transformers.66% disagree and 2% did not know.

4.5.5 Group E: Sensitive Customers

32% of this group feels that SEC has facilities and technology locally to enable the effective maintenance of power transformers. 68 %disagree.

4.5.6 Group F: Small Commercial Customers and Households

7% respondents in this sample group agree that SEC have facilities and technology locally to enable the effective maintenance of power transformers. About 43% disagree and 50% did not know.

4.6.7 Sub Problem 4 Summary of Findings

Technology available locally is only for collecting transformer maintenance data and sending it to South Africa. Processing and interpretation of data and samples is done by the South African contracted companies.

5. CONCLUSIONS

5.1 RESOURCE CONSTRAINTS ARE THE MOTIVATION BEHIND THE IMPLEMENTATION OF THE PARTIAL TRANSFORMER MAINTENANCE APPROACH

The limitation of resources available to the utility resulted in the implementation of the partial transformer maintenance policy. Other commitments that the utility had took priority over having a maintenance policy that covered all transformers. Expanding network coverage has been high on the commitment of SEC for example. The inherent robustness of the power transformer makes the partial maintenance policy justifiable in some circles within SEC.

5.2 THE ABSENCE OF A MAINTENANCE DEPARTMENT MAKES THE MAINTENANCE FUNCTION OF THE UTILITY TO BE UNDERDEVELOPED.

From the findings, it was discovered that SEC as a utility does not have a maintenance department. This makes maintenance to be constantly overlooked in its importance and always overshadowed by other functions when it comes to prioritisation. The absence of a 'maintenance' representative' at the highest management level makes area managers to live with whatever resources have been allocated for maintenance.

5.2 THE PARTIAL TRANSFORMER MAINTENANCE APPROACH RESULTS IN NETWORK PERFORMANCE GETTING COMPROMISED

The approach taken by SEC to maintain only transformers above 800kVA has resulted in the transformers below 800kVA to be neglected in their upkeep. The reality is that they are still connected to the network and their neglect results in weak points in the network. Unfortunately they also form part of the interface with a large percentage of customers.

5.3 THE PARTIAL MAITNENANCE APPPROACH TO TRANSFORMERS RESULTS IN POOR CUSTOMER SATISFACTION.

Transformers falling below the 800kVA boarder constitute 62% of all distribution network transformers. The neglect of their maintenance is a source of much customer dissatisfaction. That is why a good percentage of medium to small SEC customers responses are seen to be critical or negative towards SEC practices.

5.4 THE LACK OF RESOURCES RESULTS IN MUCH FRUSTRATION FOR SOME MANAGERS WITHIN SEC

From the findings, it can be extrapolated that although most employees within the utility responded positively towards the transformer maintenance practices in place, there were some negative responses that were consistently given. This emanates mainly from the officers who have to deal with the customer problems of poor supply quality resulting from non-maintenance of transformers.

5.5 HEAVY RELIANCE ON OUTSOURCED SERVICES FROM SOUTH AFRICA RESULTS IN LACK OF GROWTH OF IN HOUSE TECHNOLOGICAL CAPACITY

Currently, the in house transformer maintenance staffs are only trained to collect samples and maintenance raw data, which are sent to South Africa for processing. This approach results in in-house technology capacity not getting developed.

5.6 COPPER THEFT COMPROMISES TRANSFORMER MAINTENANCE EFFORTS

The prevalence of copper theft in the country compromises the very vital elements of transformer installation, which is protection. Many transformer failures would have been avoided had this problem not occurred.

6. RECOMMENDATIONS

6.1 THE PARTIAL TRANSFORMER MAINTENANCE POLOCY NEEDS TO BE REVIEWED

The partial maintenance policy needs review. The commercial and business landscape has changed significantly since it was first implemented in 1972. Customer needs have changed significantly since then and the composition of network users has changed. Business has become much more intolerant to power outages than forty years ago. The recommendation is not to remove it entirely but to modify it in the way it is implemented. The way it is currently implemented is tantamount to neglect and no utility can afford to neglect any asset connected to its network. Basic maintenance of smaller transformer involving basic maintenance such as bush clearing, visual inspections and taking earth protection readings can be done. These basic actions would not constitute a large capital requirement but would eliminate the most common causes of smaller transformer failures.

6.2 SEC SHOULD INTRODUCE A MAINTENANCE DEPARTMENT IN ITS STRUCTURE

Just like any other organisational function, be it safety, the environment or staff welfare, if it does not have representation at the higher management level, its interests are ignored in the struggle for limited resources. Transformer maintenance is just one aspect of maintenance as was considered under this research, but the maintenance of other network elements could be neglected and causing loss of revenue for the utility. The introduction of a maintenance department will give maintenance a voice in all organisational decisions being considered.

6.3 SOME TECHNOLOGICAL CAPACITY MUST BE BUILT IN HOUSE AND OUTSOURCING MUST BE IMPLEMENTED WITH DISCRETION

Entire reliance on outside technology and facilities for transformer maintenance is undesirable as the objectives of outside service providers sometimes are not in harmony with internal organisational objectives. Though this research does not recommend the elimination of outsourcing, it does recommend that SEC build in house facilities and invest in technology and personnel to carry out transformer functions in house.

6.4 TECHNOLOGY AND LEGISLATION TO CURB COPPER THEFT MUST BE INTRODUCED

Currently, copper theft is treated as a generic theft crime and the country does not have legislation in place for punishing offenders in a manner that reflects the cost and damage done by copper theft to both electrical and telephone networks. The introduction of legislation that will address this is needed in the country. There are also available various technologies that monitor networks in real time and provide alarms for copper theft. SEC must invest in these.

6.5 AREAS OF FURTHER RESEARCH WORK

The current operation and maintenance of other elements of the SEC network, which were not considered in this research can form part of future research work. The current operation and maintenance of the overhead distribution lines for example would form part of this research. Research into technologies to curb copper theft can also be an area of future research.

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ANNEXURE 1: THE QUESTIONNAIRE

(Please mark your group with an 'x' in the table below before answering)

GROUP	Description	
A	SEC Staff Member	
B	Ministry of Public Works & Transport Official	
C	Electrical Engineering Consultant or Contractor	
D	Large & Medium SEC Customer	
E	Sensitive SEC Customer	
F	Domestic & Small Commercial SEC customer	

General Maintenance Management Questions

(Please mark selected answer with an 'X')

1. **Does SEC have a maintenance Department?**

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

1 **Is the transformer maintenance department effective ?**

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

2 **Is maintenance considered essential in the organizational structure?**

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

3 Transformer failures contribution is substantial to overall outages?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

4 Is SEC spending too much on replacing failed transformers?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

5 Most transformer failure problems are maintenance related?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

6 Is a maintenance program in place for power transformers?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

7 Is Strategic maintenance Planning Implemented?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

8 **Is Life Cycle Management implemented for transformers?**

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

9 **Would Outsourcing of transformer maintenance improve network performance?**

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

10 **At SEC, the cost of down time is calculated and documented?**

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

Questions for Financial Resource Allocation for Transformer Maintenance

11 **Does transformer maintenance get a sufficient budget allocation?**

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

12 **Do maintenance workers get a good remuneration from the company?**

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

13 Could the remuneration of transformer maintenance technicians attract young professionals to train in the field?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

14 Does SEC have enough top managers with a maintenance background?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

Questions for Human Resource Allocation for Transformer Maintenance at SEC.

15 Does SEC have enough experienced technicians to carry out transformer maintenance?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

16 Does SEC have enough trained technicians to carry out transformer maintenance?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

Questions for Technology Availability for Transformer Maintenance at SEC.

17 Does SEC possess equipment to allow for condition monitoring of transformers?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don’t Know**	

18 Does the company have in house capacity for oil sampling?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don’t Know**	

19 Does SEC possess the technology for performing Gas analysis in oil?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don’t Know**	

20 Does SEC possess the technology for performing moisture analysis in oil?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don’t Know**	

21 Do technicians have access to equipment for analyzing input voltage?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don’t Know**	

22 Do technicians have equipment to test the resistance of the earth installation for transformers?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don’t Know**	

23 Is a library in place for references, standards and specifications for transformer maintenance?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

24 Is a history log in place for transformer maintenance?

1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

25 Is Technology in place for taking oil and operating temperature readings?

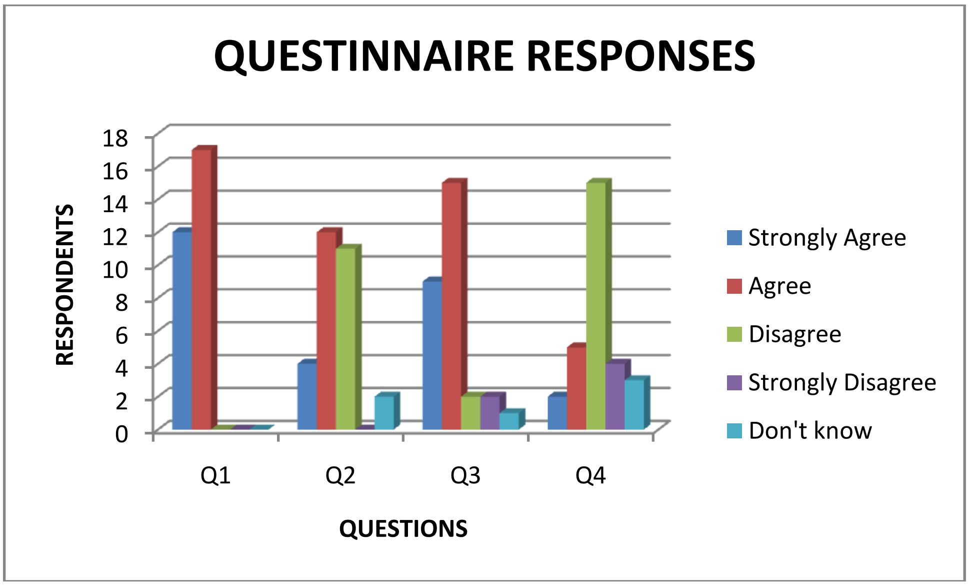
1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

26 Generally, is SEC abreast with global transformer maintenance technologies?

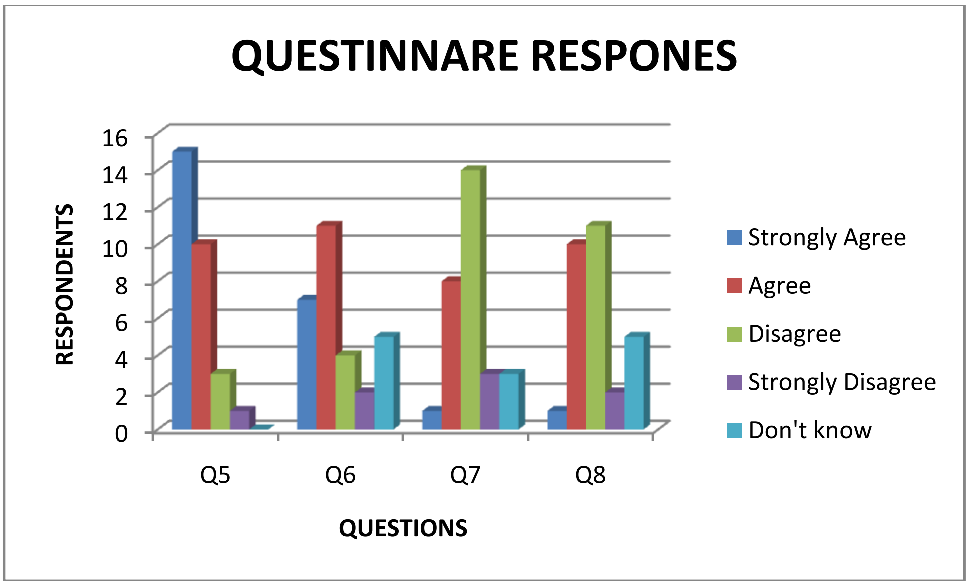
1 Strongly Agree		**2Agree**		**3Disagree**		**4 Strongly Disagree**		**5Don't Know**	

ANNEXURE 2: QUESTIONNAIRE RESULTS

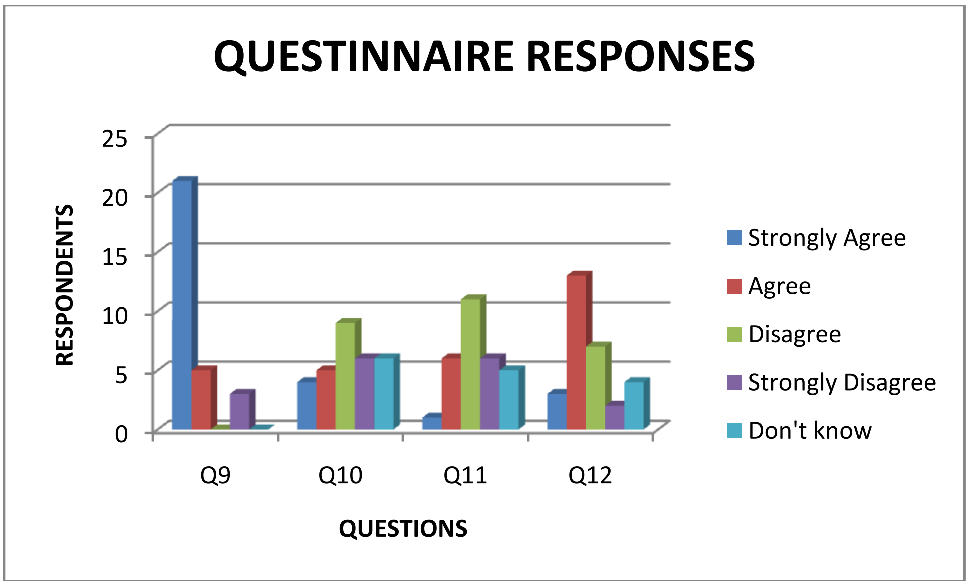
RESPONSES BY THE WHOLE POPULATION



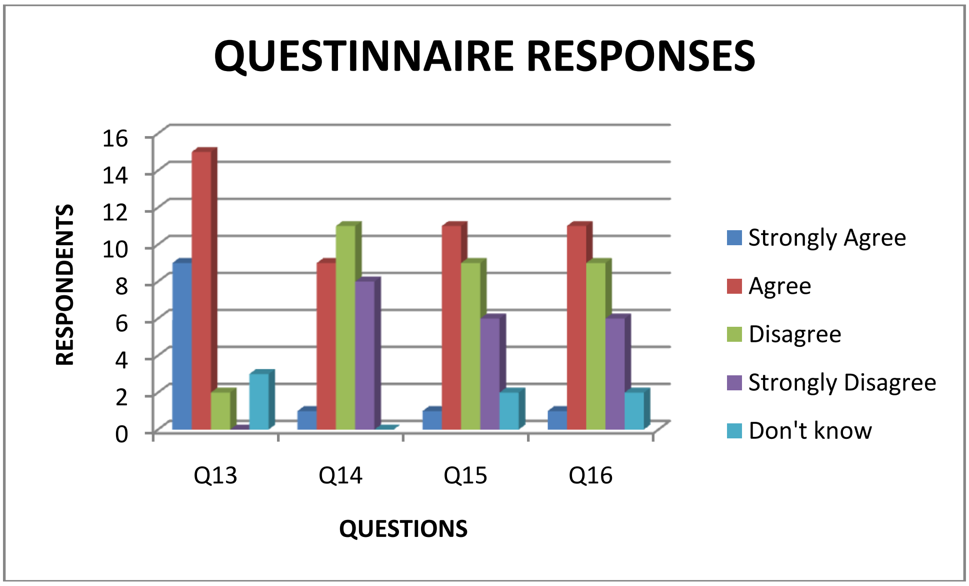
	Strongly Agree	Agree	Disagree	Strongly Disagree	Don't know
Q1	12	17	0	0	0
Q2	4	12	11	0	2
Q3	9	15	2	2	1
Q4	2	5	15	4	3



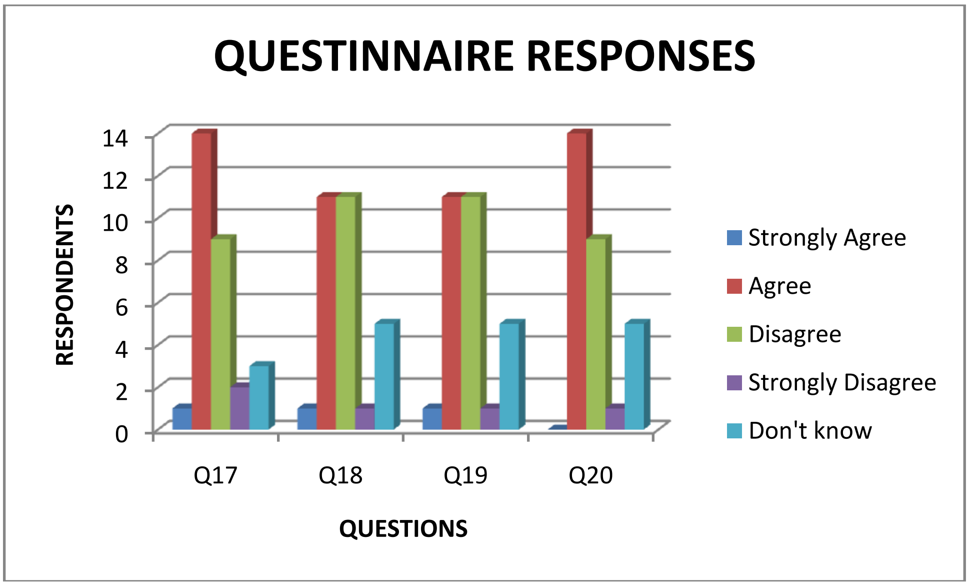
	Strongly Agree	Agree	Disagree	Strongly Disagree	Don't know
Q5	15	10	3	1	0
Q6	7	11	4	2	5
Q7	1	8	14	3	3
Q8	1	10	11	2	5



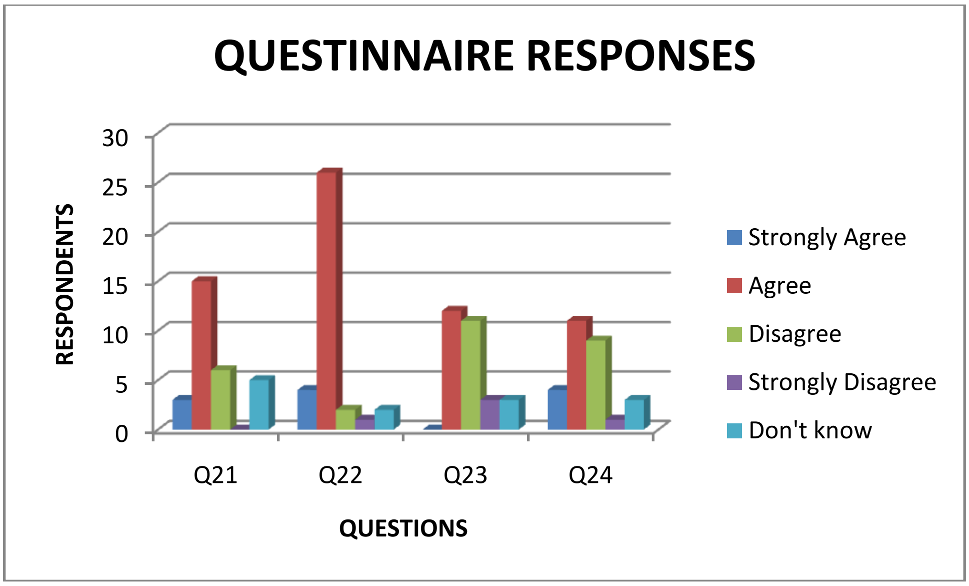
	Strongly Agree	Agree	Disagree	Strongly Disagree	Don't know
Q9	21	5	0	3	0
Q10	4	5	9	6	6
Q11	1	6	11	6	5
Q12	3	13	7	2	4



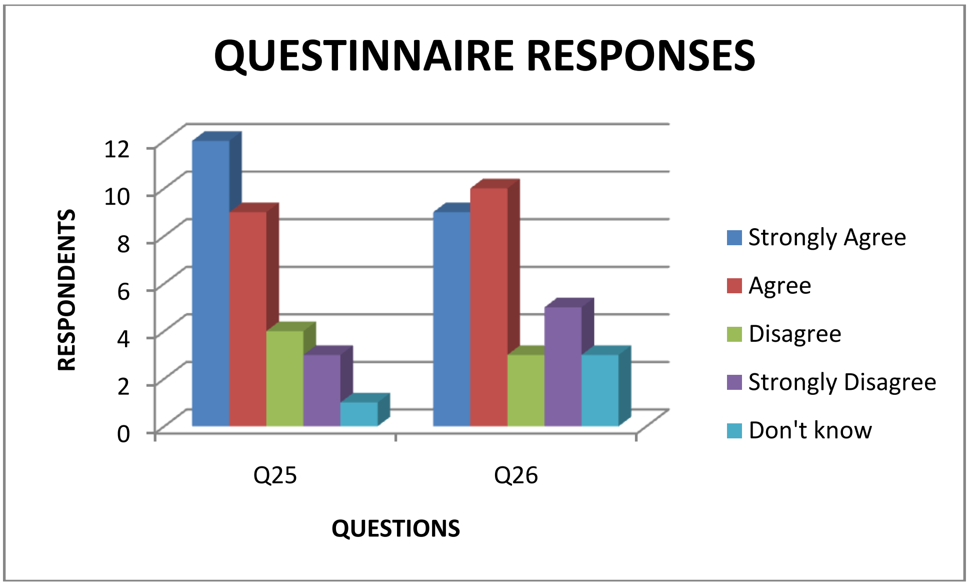
	Strongly Agree	Agree	Disagree	Strongly Disagree	Don't know
Q13	9	15	2	0	3
Q14	1	9	11	8	0
Q15	1	11	9	6	2
Q16	1	11	9	6	2



	Strongly Agree	Agree	Disagree	Strongly Disagree	Don't know
Q17	1	14	9	2	3
Q18	1	11	11	1	5
Q19	1	11	11	1	5
Q20	0	14	9	1	5

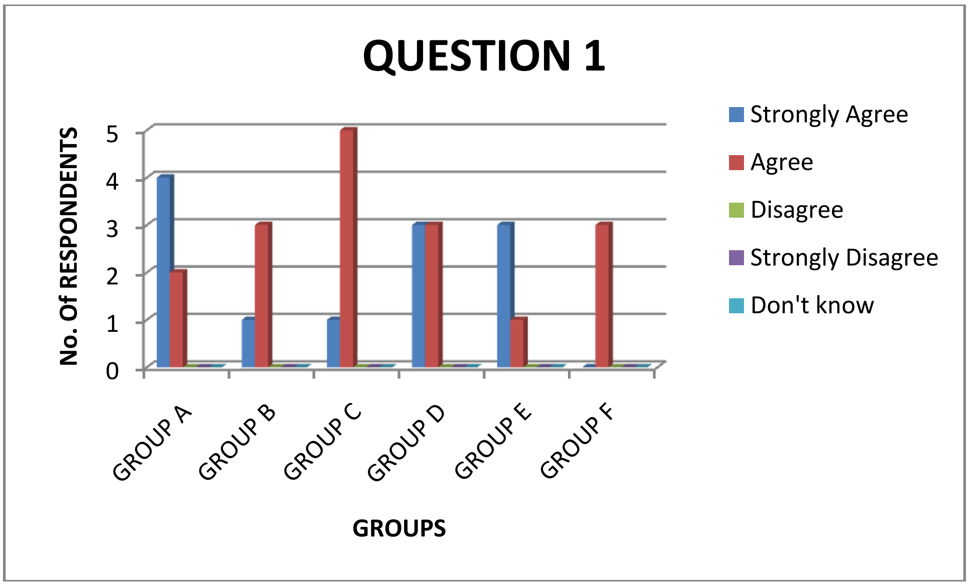


	Strongly Agree	Agree	Disagree	Strongly Disagree	Don't know
Q21	3	15	6	0	5
Q22	4	26	2	1	2
Q23	0	12	11	3	3
Q24	4	11	9	1	3



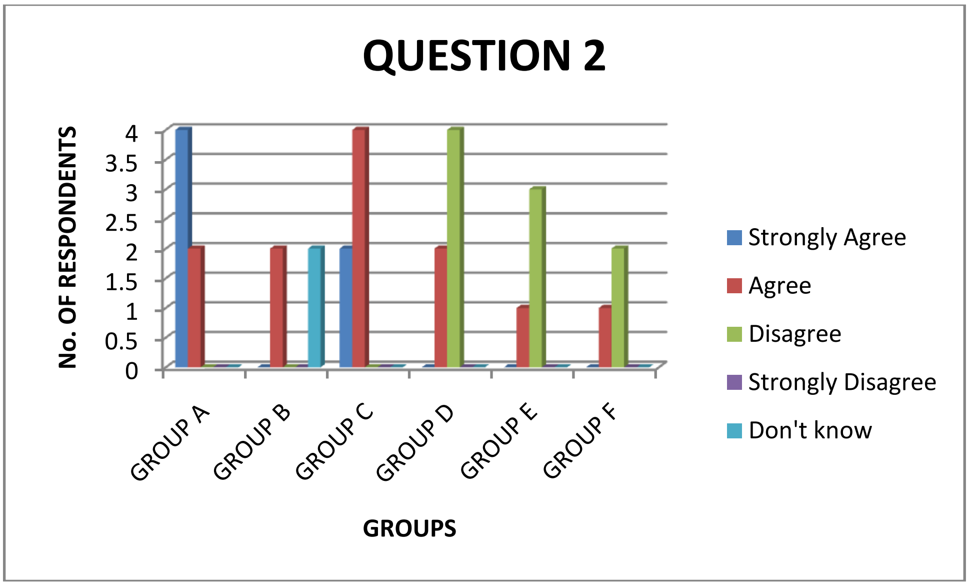
	Strongly Agree	Agree	Disagree	Strongly Disagree	Don't know
Q25	12	9	4	3	1
Q26	9	10	3	5	3

RESPONSES TO ALL QUESTIONS BY GROUPS



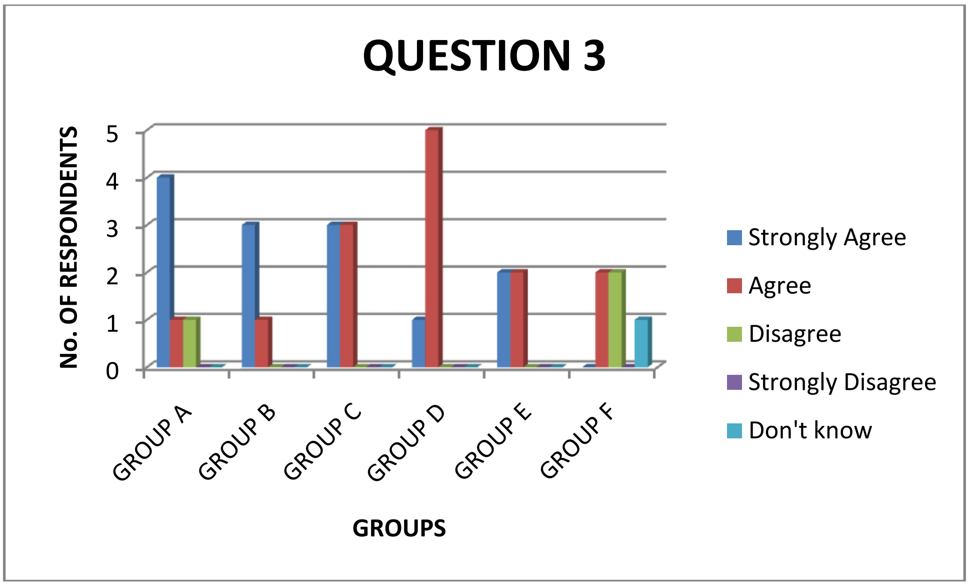
QUESTION 1

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	4	1	1	3	3	0
Agree	2	3	5	3	1	3
Disagree	0	0	0	0	0	0
Strongly Disagree	0	0	0	0	0	0
Don't know	0	0	0	0	0	0



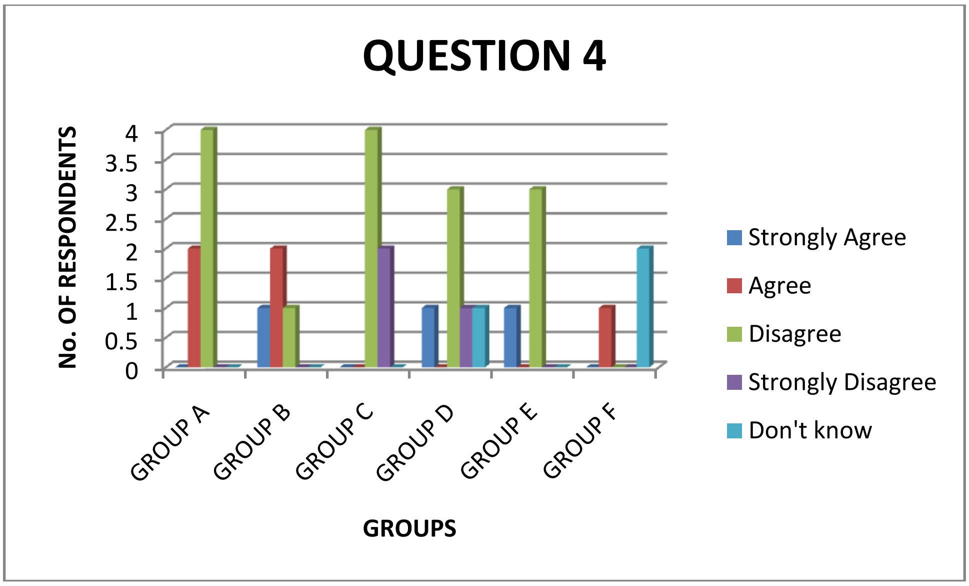
QUESTION 2

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	4	0	2	0	0	0
Agree	2	2	4	2	1	1
Disagree	0	0	0	4	3	2
Strongly Disagree	0	0	0	0	0	0
Don't know	0	2	0	0	0	0



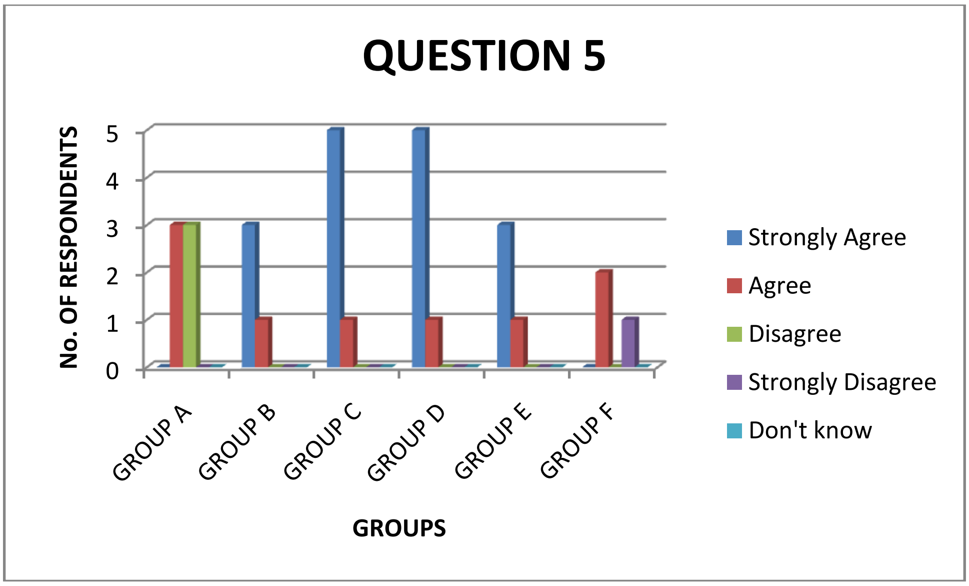
QUESTION 3

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	4	3	3	1	2	0
Agree	1	1	3	5	2	2
Disagree	1	0	0	0	0	2
Strongly Disagree	0	0	0	0	0	0
Don't know	0	0	0	0	0	1



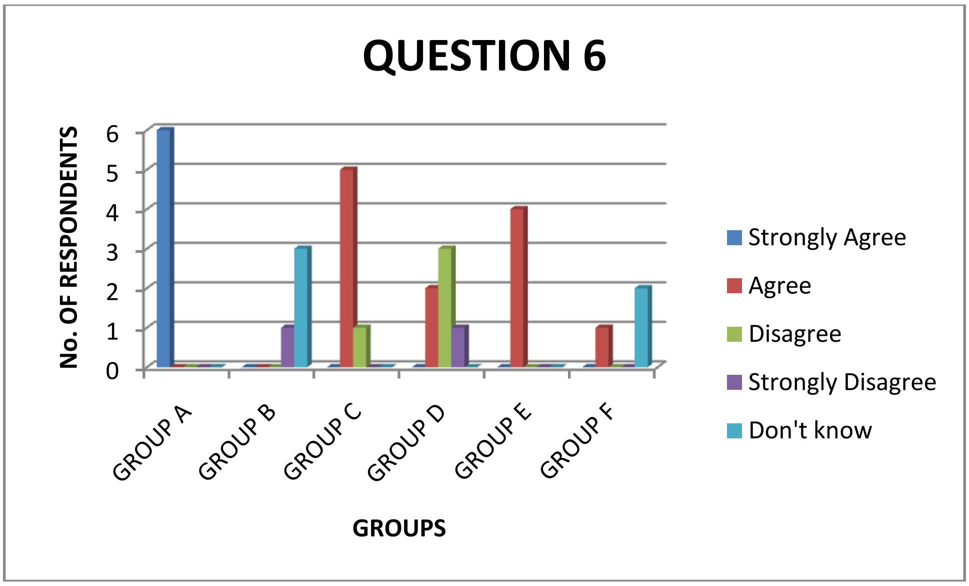
QUESTION 4

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	0	1	0	1	1	0
Agree	2	2	0	0	0	1
Disagree	4	1	4	3	3	0
Strongly Disagree	0	0	2	1	0	0
Don't know	0	0	0	1	0	2



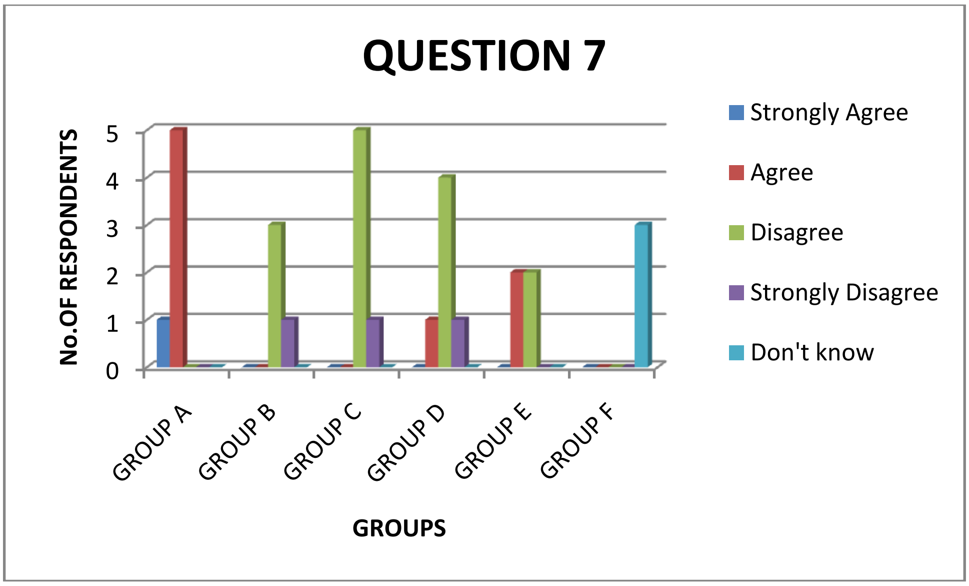
QUESTION 5

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	0	3	5	5	3	0
Agree	3	1	1	1	1	2
Disagree	3	0	0	0	0	0
Strongly Disagree	0	0	0	0	0	1
Don't know	0	0	0	0	0	0



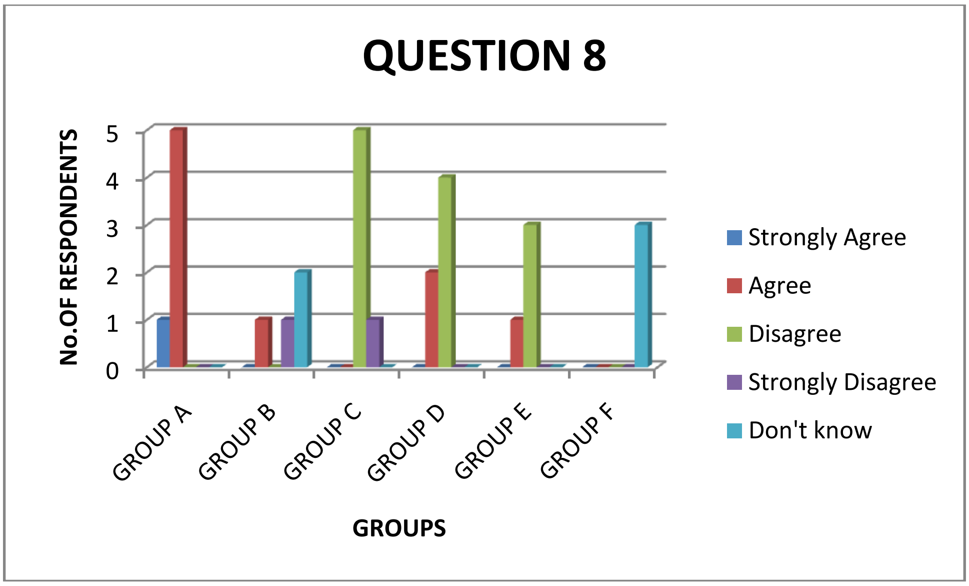
QUESTION 6

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	6	0	0	0	0	0
Agree	0	0	5	2	4	1
Disagree	0	0	1	3	0	0
Strongly Disagree	0	1	0	1	0	0
Don't know	0	3	0	0	0	2



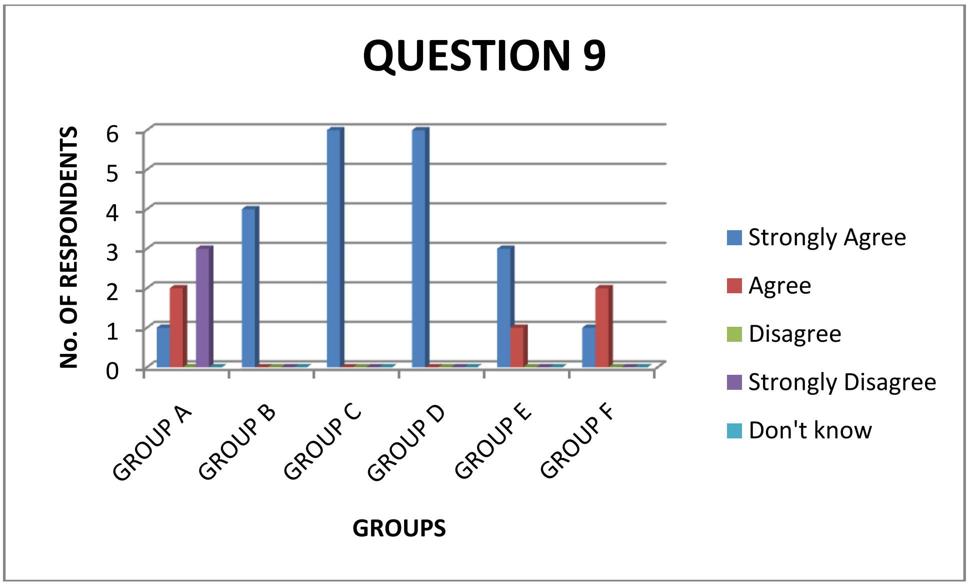
QUESTION 7

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	1	0	0	0	0	0
Agree	5	0	0	1	2	0
Disagree	0	3	5	4	2	0
Strongly Disagree	0	1	1	1	0	0
Don't know	0	0	0	0	0	3



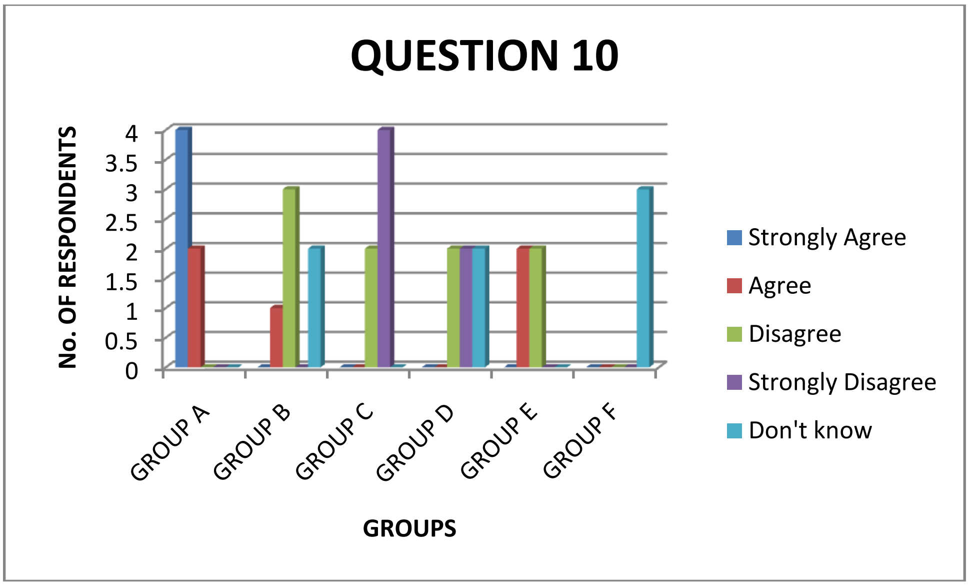
QUESTION 8

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	1	0	0	0	0	0
Agree	5	1	0	2	1	0
Disagree	0	0	5	4	3	0
Strongly Disagree	0	1	1	0	0	0
Don't know	0	2	0	0	0	3



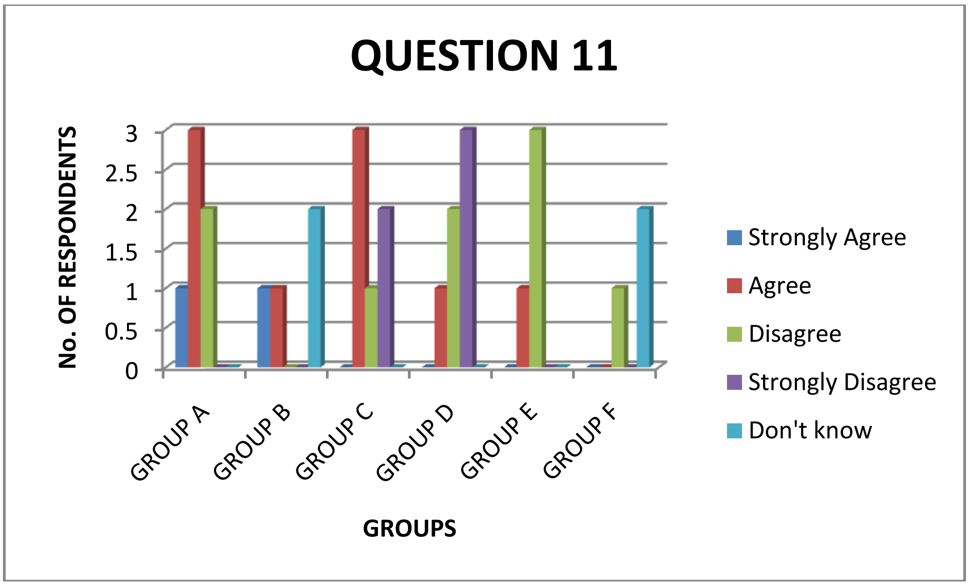
QUESTION 9

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	1	4	6	6	3	1
Agree	2	0	0	0	1	2
Disagree	0	0	0	0	0	0
Strongly Disagree	3	0	0	0	0	0
Don't know	0	0	0	0	0	0



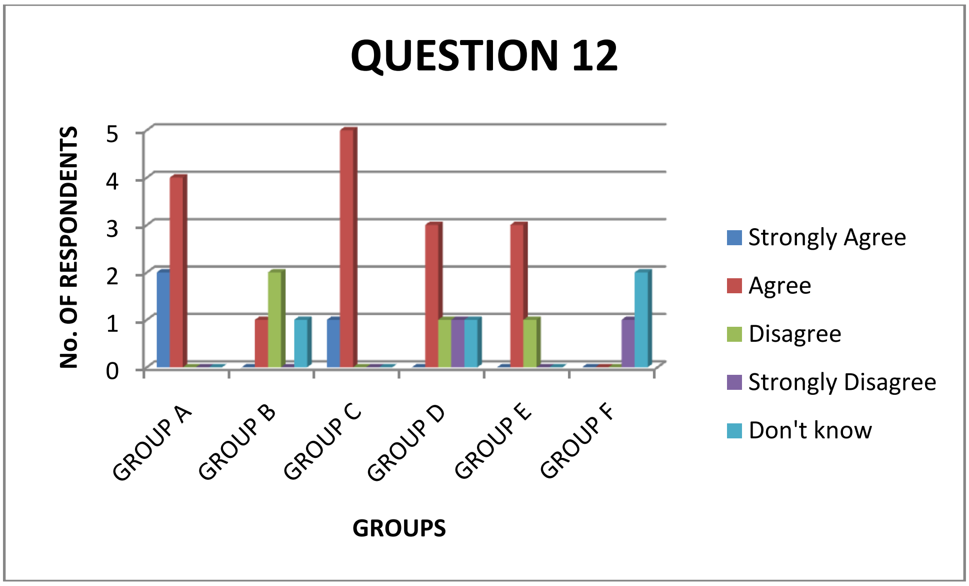
QUESTION 10

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	4	0	0	0	0	0
Agree	2	1	0	0	2	0
Disagree	0	3	2	2	2	0
Strongly Disagree	0	0	4	2	0	0
Don't know	0	2	0	2	0	3



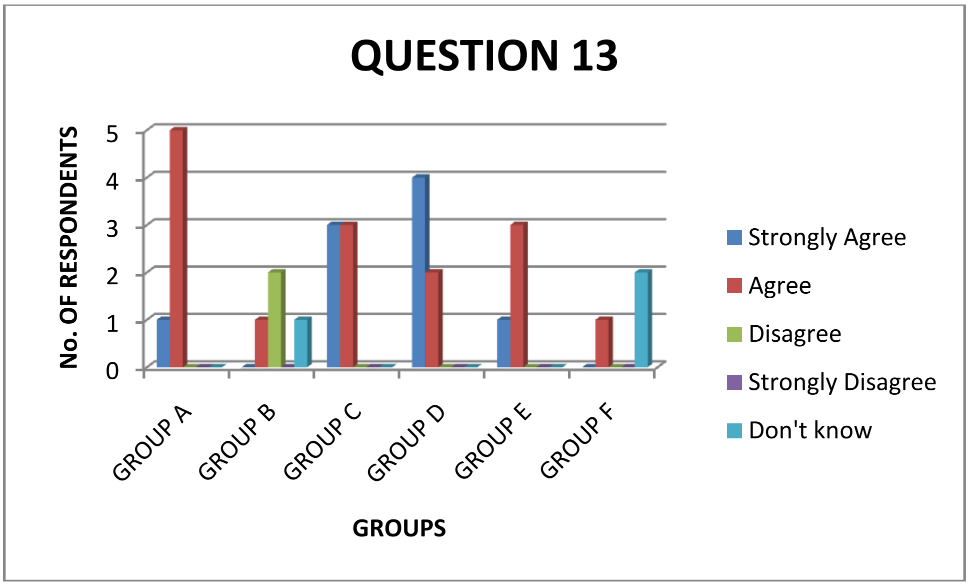
QUESTION 11

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	1	1	0	0	0	0
Agree	3	1	3	1	1	0
Disagree	2	0	1	2	3	1
Strongly Disagree	0	0	2	3	0	0
Don't know	0	2	0	0	0	2



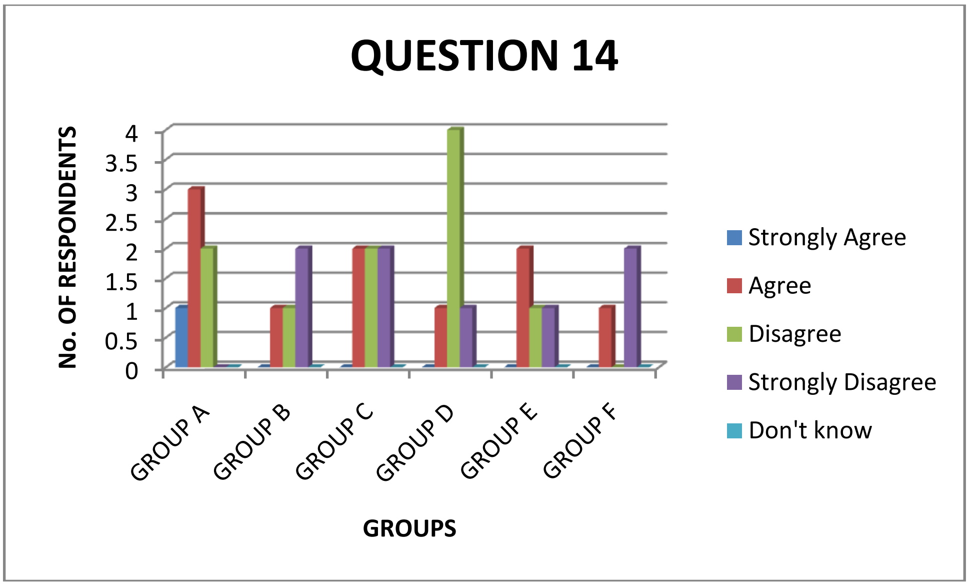
QUESTION 12

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	2	0	1	0	0	0
Agree	4	1	5	3	3	0
Disagree	0	2	0	1	1	0
Strongly Disagree	0	0	0	1	0	1
Don't know	0	1	0	1	0	2



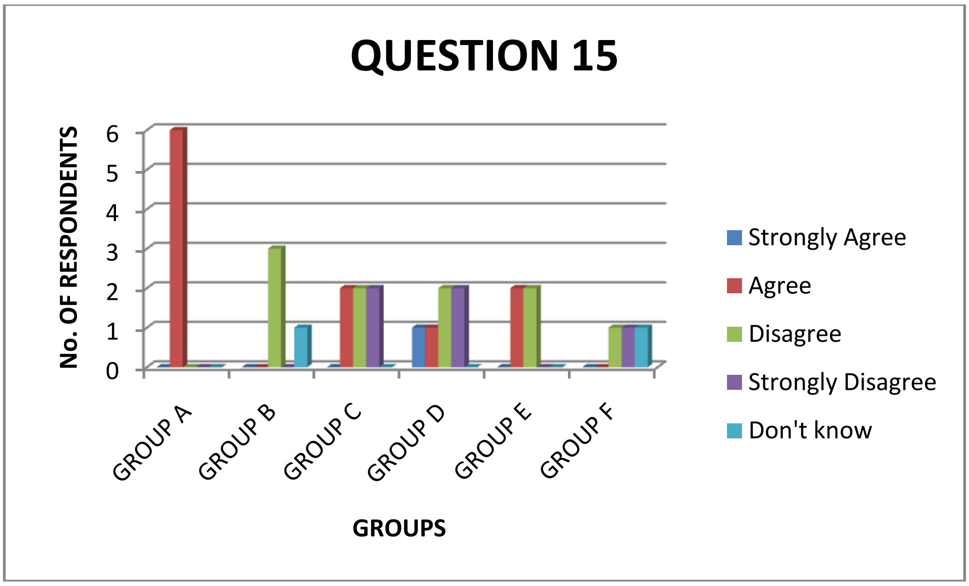
QUESTION 13

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	1	0	3	4	1	0
Agree	5	1	3	2	3	1
Disagree	0	2	0	0	0	0
Strongly Disagree	0	0	0	0	0	0
Don't know	0	1	0	0	0	2



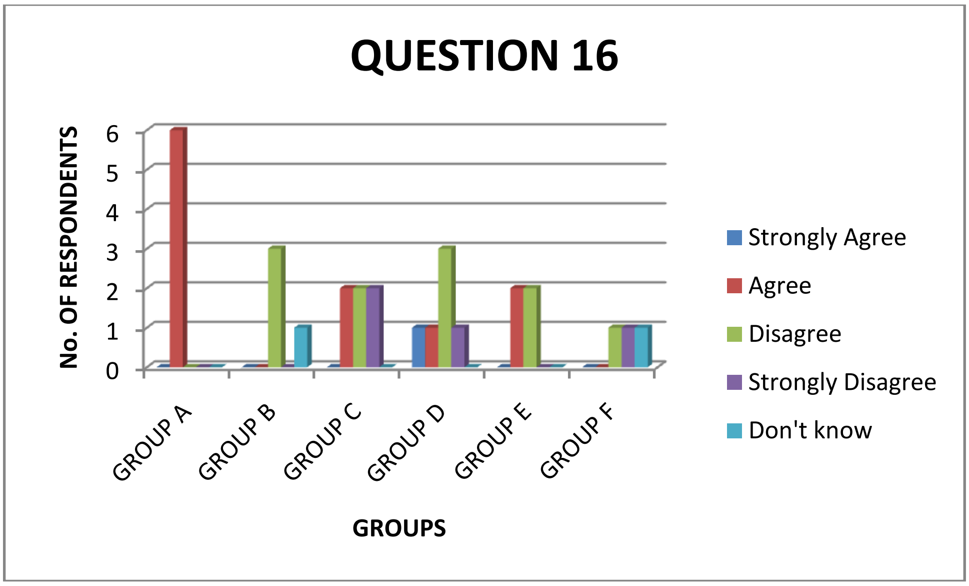
QUESTION 14

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	1	0	0	0	0	0
Agree	3	1	2	1	2	1
Disagree	2	1	2	4	1	0
Strongly Disagree	0	2	2	1	1	2
Don't know	0	0	0	0	0	0



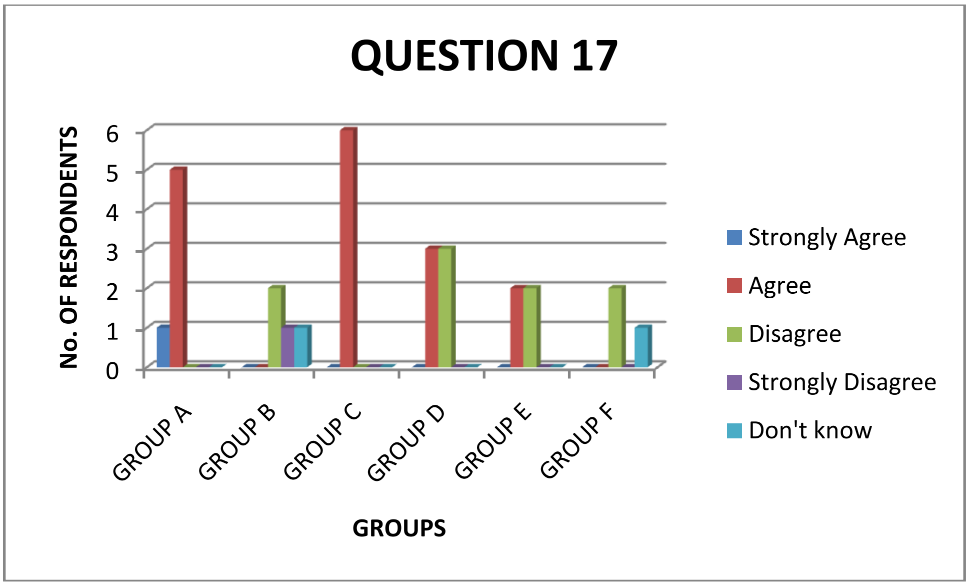
QUESTION 15

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	0	0	0	1	0	0
Agree	6	0	2	1	2	0
Disagree	0	3	2	2	2	1
Strongly Disagree	0	0	2	2	0	1
Don't know	0	1	0	0	0	1



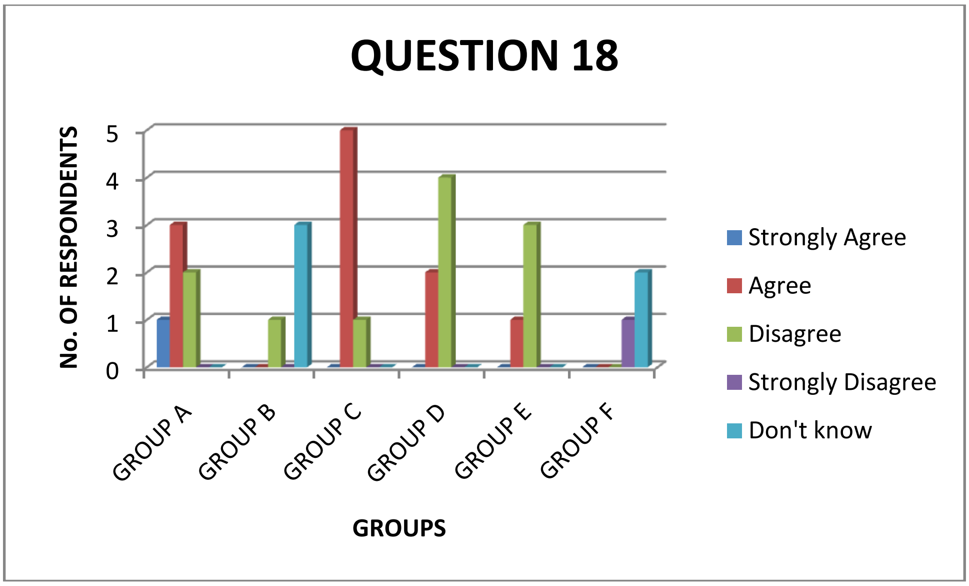
QUESTION 16

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	0	0	0	1	0	0
Agree	6	0	2	1	2	0
Disagree	0	3	2	3	2	1
Strongly Disagree	0	0	2	1	0	1
Don't know	0	1	0	0	0	1



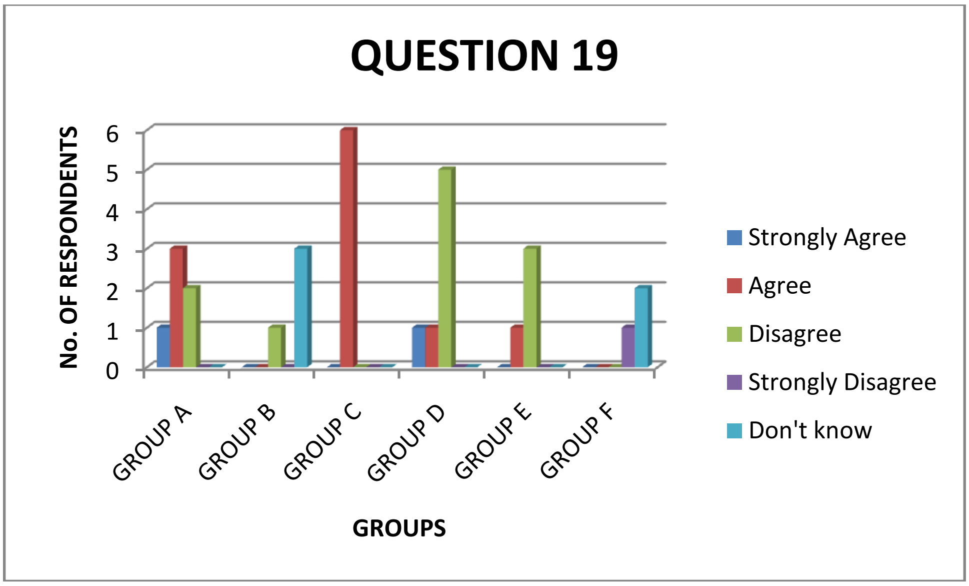
QUESTION 17

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	1	0	0	0	0	0
Agree	5	0	6	3	2	0
Disagree	0	2	0	3	2	2
Strongly Disagree	0	1	0	0	0	0
Don't know	0	1	0	0	0	1



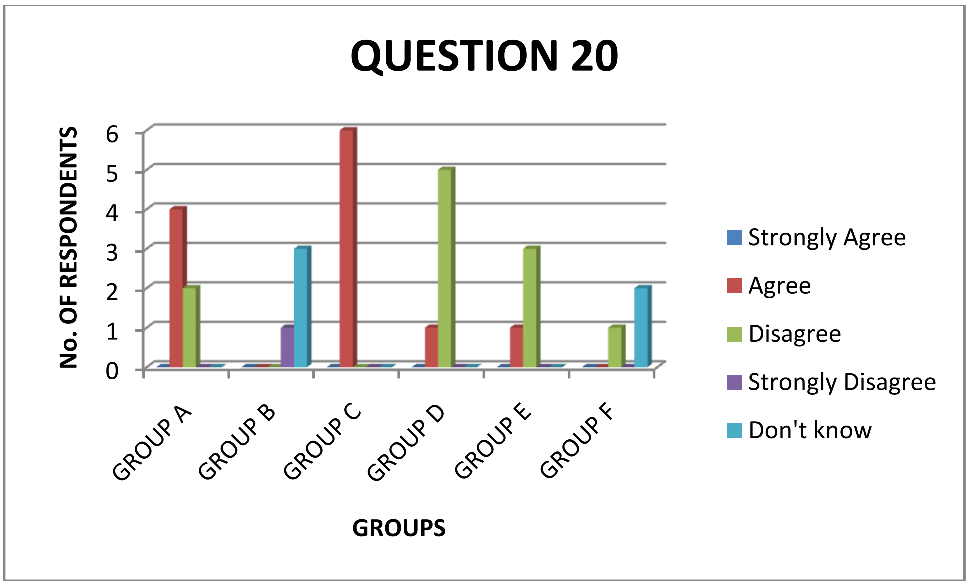
QUESTION 18

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	1	0	0	0	0	0
Agree	3	0	5	2	1	0
Disagree	2	1	1	4	3	0
Strongly Disagree	0	0	0	0	0	1
Don't know	0	3	0	0	0	2



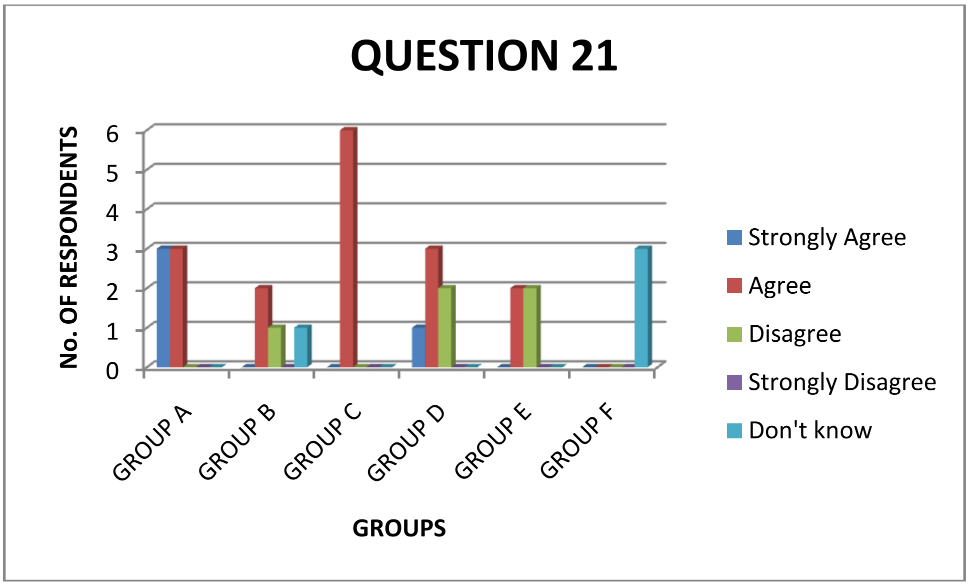
QUESTION 19

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	1	0	0	1	0	0
Agree	3	0	6	1	1	0
Disagree	2	1	0	5	3	0
Strongly Disagree	0	0	0	0	0	1
Don't know	0	3	0	0	0	2



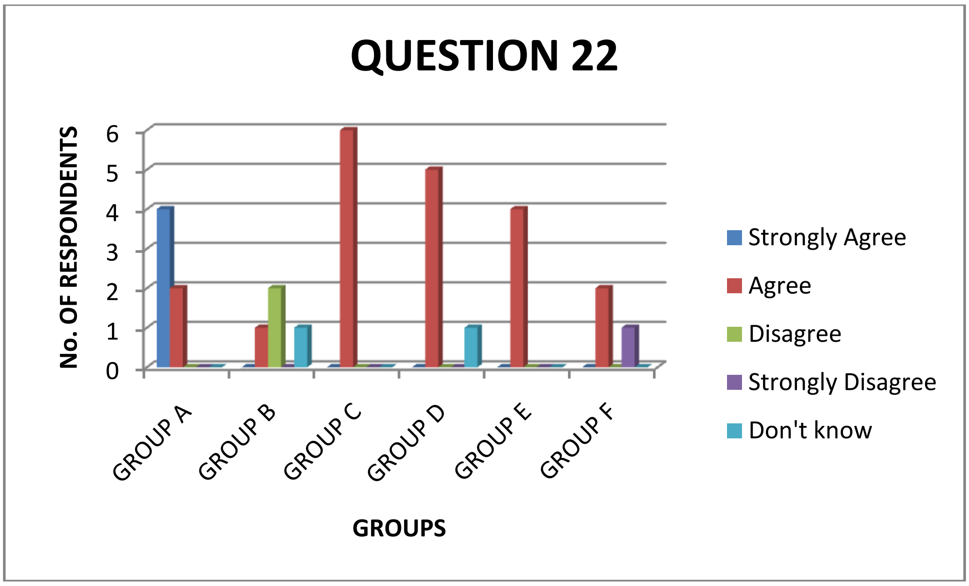
QUESTION 20

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	0	0	0	0	0	0
Agree	4	0	6	1	1	0
Disagree	2	0	0	5	3	1
Strongly Disagree	0	1	0	0	0	0
Don't know	0	3	0	0	0	2



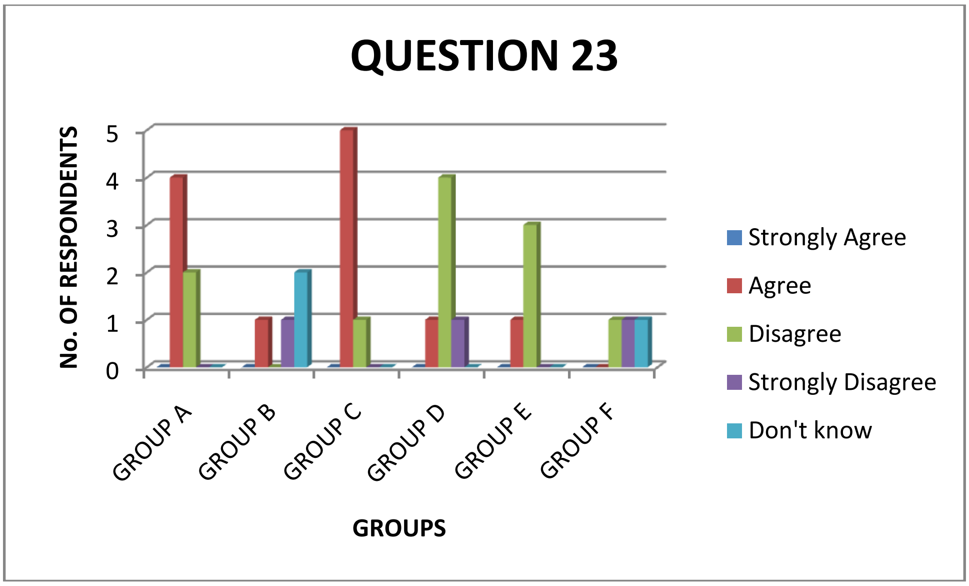
QUESTION 21

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	3	0	0	1	0	0
Agree	3	2	6	3	2	0
Disagree	0	1	0	2	2	0
Strongly Disagree	0	0	0	0	0	0
Don't know	0	1	0	0	0	3



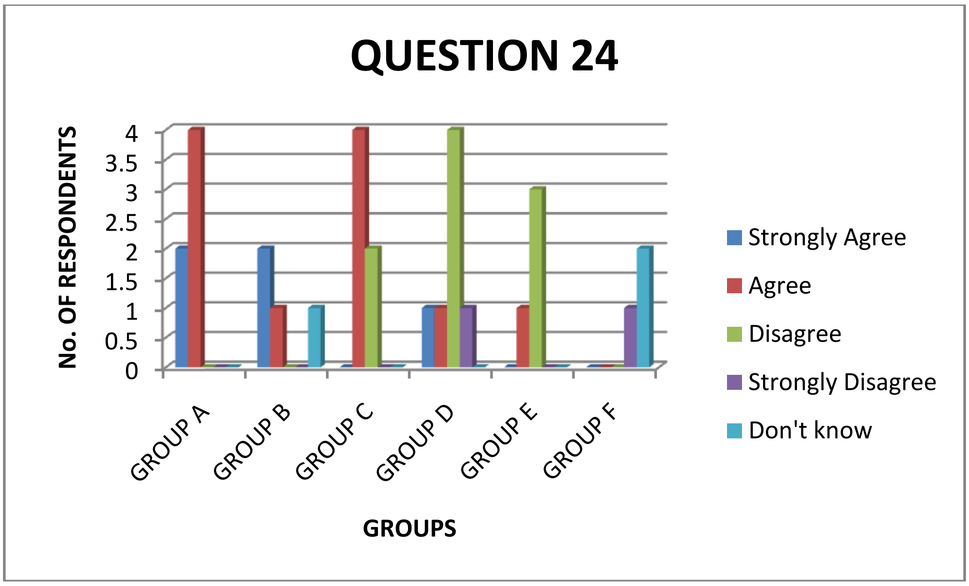
QUESTION 22

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	4	0	0	0	0	0
Agree	2	1	6	5	4	2
Disagree	0	2	0	0	0	0
Strongly Disagree	0	0	0	0	0	1
Don't know	0	1	0	1	0	0



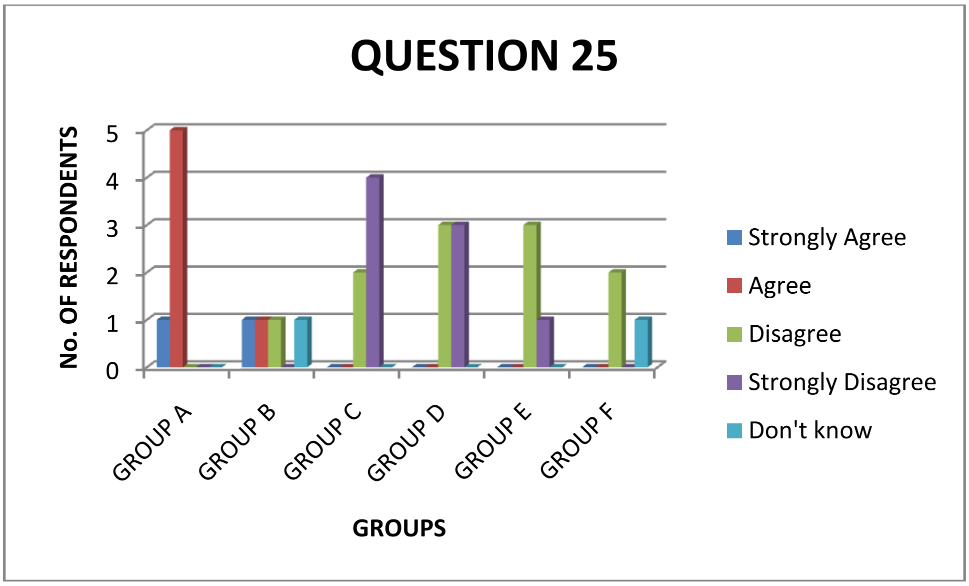
QUESTION 23

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	0	0	0	0	0	0
Agree	4	1	5	1	1	0
Disagree	2	0	1	4	3	1
Strongly Disagree	0	1	0	1	0	1
Don't know	0	2	0	0	0	1



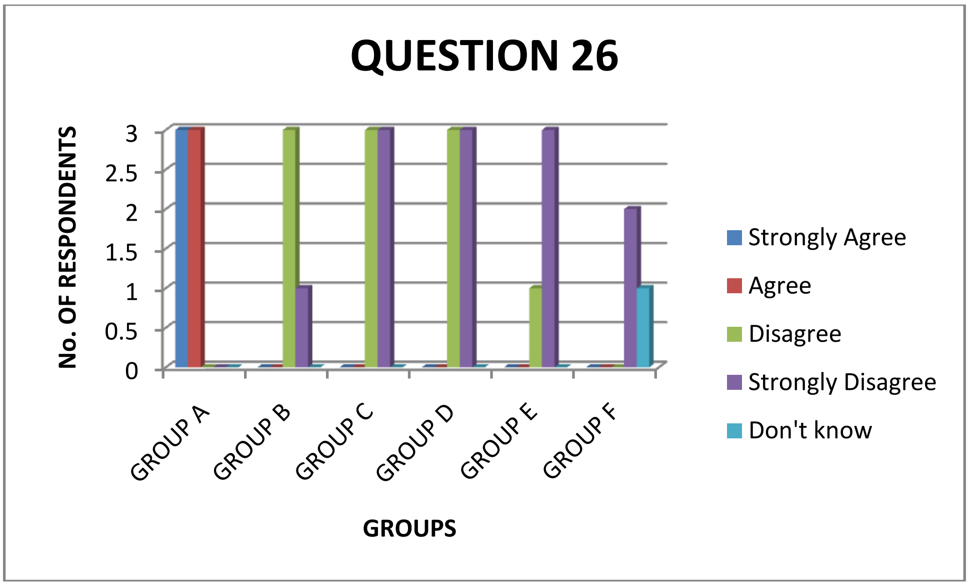
QUESTION 24

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	2	2	0	1	0	0
Agree	4	1	4	1	1	0
Disagree	0	0	2	4	3	0
Strongly Disagree	0	0	0	1	0	1
Don't know	0	1	0	0	0	2



QUESTION 25

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	1	1	0	0	0	0
Agree	5	1	0	0	0	0
Disagree	0	1	2	3	3	2
Strongly Disagree	0	0	4	3	1	0
Don't know	0	1	0	0	0	1



QUESTION 26

	GROUP A	GROUP B	GROUP C	GROUP D	GROUP E	GROUP F
Strongly Agree	3	0	0	0	0	0
Agree	3	0	0	0	0	0
Disagree	0	3	3	3	1	0
Strongly Disagree	0	1	3	3	3	2
Don't know	0	0	0	0	0	1