Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Design and Simulation of Gas Insulated Substation (GIS) for Electrified Railway System: Case study of Shiro Meda

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A Thesis Submitted to Addis Ababa University

Addis Ababa Institute of technology

In Partial Fulfillment of the Requirement for the Degree of Master of Science in Electrical Engineering for Railway systems

June, 2016

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

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Declaration

I declare that, this thesis represents my own work, except where due acknowledgement is made, and that it has not been previously submitted to this university or to any other Institution for a degree or other qualification**.**

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Abstract

Nowadays the demand for Gas Insulated Substation (GIS) is increasing over the world for efficient utilization of electric power and space. In this thesis a gas insulated substations is investigated or studied since they are more advantageous though, they use same protective devices or equipment when compared to air insulated substations. They are compact, requiring little maintenance, more reliable, have longer service life (more than 50 years) and safer. The compactness is due to the use of SF6 gas, which has high dielectric strength at moderate pressure for phase to phase and phase to ground insulation.

Gas insulated substation system creates a vision of the future more efficient substations which includes various technical, economic and environmental criteria, such as reliability, cost, interoperability, re-configurability, security, controllability and flexibility need to be considered. In this one of Addis Ababa Light rail transit (LRT) gas insulated substation has been studied, analyzed and compared to conventional air insulated substation.

This thesis work presents the design and simulation of gas insulated substation for the case of Shiro Meda. For this purpose, all the necessary electrical parameters data are collected through literature survey and from Ethiopian electric utility at the same time major components of gas insulated substation such as bus bar is designed consequently volume of SF6 is calculated.

For designing a substation it is crucial to know the maximum value of short circuit current of substation and load flow analysis. For this purpose Electrical Transient Analyzer Program (ETAP) power 12.6.0 version has been used for numerous fault condition in 3 phase132kV gas insulated substation. The load flow analysis and short circuit for different bus have been done and the result is within limit according to the IEC 60909 and IEC 61363 standard. However, our design results 12.5 and 90 and 92% reduction the cost of maintenance, space and operation by 12.5 and 90 and 92% respectively compared to air insulated substation.

***Key words:* Gas Insulated Substation, design, simulation, SF6, Etaps, Air Insulated Substation, short circuit, standards**

Acknowledgement

First and foremost, as a firm believer in God, I would like to thank him who gave me his only Son to save me from eternal death, for the opportunity and the continuous endowment throughout my life.

I would like to express my extreme appreciation and sincere gratitude to my Advisor Dr. Mengesha Mamo, for his invaluable guidance, encouragement, readiness for consultation at all times, educative comments, concern and assistance advice in every phase of this thesis. It would have been an insurmountable task in completing the research without his advocacy.

A Special thank goes to Ethiopian Railway Corporation (ERC), for sponsoring me this MSc program in Electrical Railway Engineering and all the members of the academic and administrative staff of School of Electrical and Computer Engineering at AAiT.

I would like to take this opportunity to thank Melkamu Abebe and the people who have helped me directly and indirectly with my research, and influenced me to a better person and I wish everyone mentioned here the best of luck for their future endeavors.

At last but not least, I would like to thank my family, for the selfless patience and endless support which they have shown throughout the period of my studies.

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Abbreviations.

AALRT	Addis Ababa Light Rail transit
AC	Alternative Current
AIS	Air Insulated Substation
ANSI	American National Standard Institute
AU	African Union
BS	British Standard
CT	Current Transformer
DC	Direct Current
EN	European Standard
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
EMF	Electromotive Force
ERC	Ethiopian Railway Corporation
ETB	Ethiopian Birr
ETAP	Electrical Transient analyzer program
GIS	Gas Insulated Substation
GITL	Gas Insulated Transmission line
IEC	International Electro technical Commission

ISO	International Standard Organization
IEEE	Institute of Electrical and Electronics Engineers
LCC	Life Cycle cost
LRT	Light Rail Transit
OFAF	Oil Forced Air Forced
MVA	Mega Volt Ampere
PT	Potential Transformer

Symbols

q_{conv1}	Heat dissipated from busbars due to convection
q_{rad1}	Heat dissipated from busbars due to radiation
q_{cond}	Heat dissipated from busbars due to conduction
W_C	heat dissipated per square meter due to convection
W_r	heat dissipated per square meter due to radiation
A_c	surface area of conductor of convection
A_r	surface area of conductor of radiation
Ra	Rayleigh number
$\overline{N}_u$	Average Nusselt number
G	gravity constant,
β	volumetric thermal expansion coefficient
$\bar{T}_1$	Average temperature of busbar
H	height of the enclosure
G	gap between busbar and enclosure wall
V	kinematic viscosity
A	thermal diffusivity
Pr	Prandtl number
k	Thermal conductivity
σ	Stefan-Boltzmann constant

R	Resistance
R_o	Conductor Resistance at room temperature
R_{new}	Conductor Resistance at temperature T
L	Inductance
Π	Pi
ε	Emissivity
Z	Impedance
ω	Angular Frequency
I_{sc}	Short Circuit Current
Km	Kilometer
HZ	Hertz
D	Diameter
V	volume
SF6	sulfur hexafluoride
h_{v1}	Average vertical convection heat transfer coefficient
h_{t1}	Average top convection heat transfer coefficient
Δx	Enclosure wall thickness
P	power dissipated per unit length of bus bar
A_v	vertical surface area of enclosure, m^2
A_t	top surface area of enclosure

Lc	horizontal plane Nusselt correlation number
P	perimeter
A	Area
KV	kilo volt
KA	kilo Ampere
C_F	Cost of failure
C_M	Cost of maintenance
C_o	Cost of operation
C_{CR}	Cost of replacement
LL	Line to Line
LG	Line to Ground
LLG	Line, Line to Ground
CVT	Capacitive Voltage Transformer

CHAPTER ONE

INTRODUCTION

The knowledge of railway and steam engines has been around since the sixteenth century. Wagon roads for English coal mines using heavy planks were first designed and built in 1633. Mathew Murray of Leeds in England invented a steam locomotive that could run on timber rails in 1804 and this was probably the first railway engine [1]. Although railway and locomotive technologies were continually developed, the first electrified railway was introduced in the 1880s [2-4]. As a result of this revolution, the traction motor and the power supply system have become important parts of modern electrified railways [4].

As it`s already known, Ethiopia is in a take off stage for development, a lot of mega projects have launched in the first and the second growth and transformation plan. Extending the transportation facility is one among those projects. Under this, Ethiopian Rail Way Corporation has planned to construct 5,000km railway throughout the country in two phases. The first phase has started services like AALRT and sebeta – Adama – Miesso - Djibouti line, which are DC and AC electrified railway system respectively.

Electrified railway system is the latest railway system as compared to steam or diesel engine driven railway system. Railway transportation of passengers and goods has many advantages than other modes of land/air transportation. Among these advantages are better control on schedule and travel time, lower exposure to risk factors such as heavy traffic and road accidents, more comfortable seating, contribution to environment and economy. Another advantage of electrified railway system is that the needed energy is delivered to the train when needed, unlike the other modes of transportation (land, air, sea) where the source of energy must be carried by the vehicle for the duration of the journey [5].Any transportation system needs a source of power to drive its vehicles in order to carry their passengers or goods from place to place.

The demand for railway transportation systems has considerably increased, by passengers' journey and goods delivery in both short and long distance services, ever since. To provide power propulsion and the need of higher-speed, more luxurious and more reliable services, electrification has been the first choice and widely applied to modernize most of the railway transport systems across the world for several decades. The modern society has come to depend heavily up on high quality of service, continuous and reliable electricity. Since the electric traction (railway) system depends upon continuous availability of traction power supply, sub-stations and switching stations have to be kept in proper working condition at all-time. Being one of the most important parts of the power system, substations play a key role in the generation, transmission and distribution of electricity.

The voltage is transformed from high to low, or reverse using transformers inside a substations or perform any of other several important functions between generating station and consumers. It also serves as a point of connection between various power system elements such as transmission lines, transformers, generators and loads [6]. Basically an electrical substation consists of a number of incoming circuits from generating station via incoming transmission and outgoing circuits connected to common bus bar system delivers electrical power via the outgoing transmission lines and distribution for customer end.

Substation can be categorized based on voltage level, structure and insulation system applied. We can classify substation based on their voltage level to transmit power from generation to consumer, like generation substation, transmission substation, distribution substation, switches substation and collector substation. Based on the structural system used substation can be classified as in door, outdoor and underground substation. Based on insulation system applied substations can be AIS or GIS [7].

GIS technology was originally invented in Japan, and then developed in various countries between 1968 and 1972[8]. The development and design of GIS and compressed Gas Insulated Transmission line (GITL) equipment have been progressed drastically for the last three decades throughout the world because of the excellent insulation properties of Sulfur hexafluoride (SF6) gas [9].

A GIS also has different voltage level of substation starting from 12 kV to 800 kV in which the major structures are contained in a sealed environment with sulfur Hexafluoride gas as the insulating medium. The GIS equipment such as compact substations and transmission lines is rapidly becoming an important part of high voltage transmission systems and they are used in key positions in the power transmission network, where there is insufficient space for an open air substation, or the land costs are prohibitive. Because GIS occupies less space compared to conventional AIS. In addition to this, it is very much required to establish an electrical substation at load center. Establishing a substation at load center is quite economical and profitable. As it reduces length of feeders which intern result in the voltage regulation improvement. However, space will be the main obstruction of establishing a substation at load center [10].

Also GIS uses a superior dielectric gas, SF6 which is an organic odorless gas consisting of sulphur atom surrounded by and tightly bonded to six fluorine atoms and five times more dense than air, SF6 shows several properties that make it suitable for equipment used in the transmission and distribution of electric power. Both at room temperature and at temperatures well above ambient, SF6 act as a strong electronegative (electron attaching) gas. This principally accounts for its relatively high dielectric strength and better arc-interruption properties [11]. The breakdown voltage of SF6 is higher i.e., at moderate pressure for phase-to phase and phase-to-ground insulation. The use of a gaseous medium with higher dielectric strength like SF6 instead of air helps in manifold reduction in the size of the sub-station components. The grounded metal encapsulation, on the other hand, makes the equipment safe, as the live components are no longer within the reach of the operator. The electric field intensity, at the enclosure surface, is reduced to zero as the enclosure is solidly grounded [12].

Considering the above advantage many developing countries are replacing the existing air insulated substation by GIS. This inspired the author to conduct the research on GIS which is safer, more reliable and cost effective with respect to long term maintenance.

Figure 1.1 132KV gas insulated substation

1.1 Overview of Substation under Study

This project is made to overcome the scarcity of land, electricity crises and to meet the power demand of Addis Ababa. As the Addis Ababa is upcoming with multi industrial, modern LRT, financial sectors, commercial and residential complexes, offices, clubs and an improved infrastructure, there is a huge demand of electricity in Addis Ababa which cannot be met by the existing structure of power supply. To meet the requirement a 132/15kV GIS project is planned by ERC for the second phase project.

The thesis entitled to design a 132/15 kV GIS. The author considered incoming power at 132 kV from Gefersa and North Addis Ababa, the feeder units are mounted inside the substation building and connected to the bushings outside the building through bus ducts and the power was transferred to main bus through isolator, circuit breaker, current transformer and voltage transformer-isolator combination. The power from main bus was fed into a 25MVA transformer which stepped the voltage down to 15kV. The power is then fed into a 15kV bus from which different loads will tap if necessary for the neighbor load.

1.2 Statement of the Problem

In Ethiopia road and air transport services are relatively well developed and more expensive than railways, despite their high costs. Development mode is imperative not only to optimize the use of existing modes but also more importantly to develop and operate cost effective, higher efficiency, increasing situational awareness, redundancy improvement, safety, client responsive, low level maintenance, easier operation and environment friendly railways that could meet the current and future transport demand that effectively satisfy the development needs of the country. A light rail transit system which is constructed for Addis Ababa to transport daily commuters is an example of a new situation.

So far an air AIS has been widely used in Ethiopia for the transmission and distribution of electric power can readily cause damage and has many drawbacks. For instance, high maintenance cost, safety (high risk on step and touch voltage) high clearance between phases and between phase and ground which is the major cause to take much space, though, in our capital city Addis Ababa the cost of a piece of land is very expensive, and less reliability. In addition to this power transfer problems have occurred frequently due to different weather conditions. Moreover, no longer line acceptable near to urban centers because of environmental and aesthetic.

Therefore, finding a solution for these kinds of problems is mandatory. This is the reason why the author inspired to design the latest GIS which makes the transportation system more advanced and cheaper by delivering reliable power for the train.

1.3 Objective

1.3.1 General Objectives

The main objective of this thesis is to design and simulate GIS for the case of Shiro Meda and presents methodology that optimize cost, time and space.

1.3.2 Specific Objectives

The following are the specific thesis objectives:

1. To collect the primary data required for the design of GIS for electrified railway system.
2. To design GIS
3. To simulate performance of the overall system through ETAP software and to make a cost comparison with other design of AIS

1.4 Scope of the Thesis

The scope of this thesis is to design and simulate GIS for Shiro Meda proposed by Ethiopian Railway Corporation for second phase projects. The performance analysis in this thesis work has been carried out based on the simulation of proposed techniques using ETAPS power software. In this thesis only single line diagram of GIS is performed.

1.5 Methodology

In order to achieve the main aim of the study there are various procedural tasks followed by the author. The first method towards processing the work is started with reviewing different literatures where all the theoretical information regarding the Gas Insulated Substation is gathered and a comparison of previous work of GIS and AIS research is studied. Alongside with literature reviewing, the collection data from EEU and EEP and verification of data at the site is performed. This is followed by studying the characteristic and modelling of the major components of gas insulated substation bus bar and picking the other from IEC standard based on the incoming line of current and voltage .Once the Model (single line diagram) is developed using ETAPs Power, the analysis of the system is performed. Then based on the analysis result proper rating value of major equipment is selected.

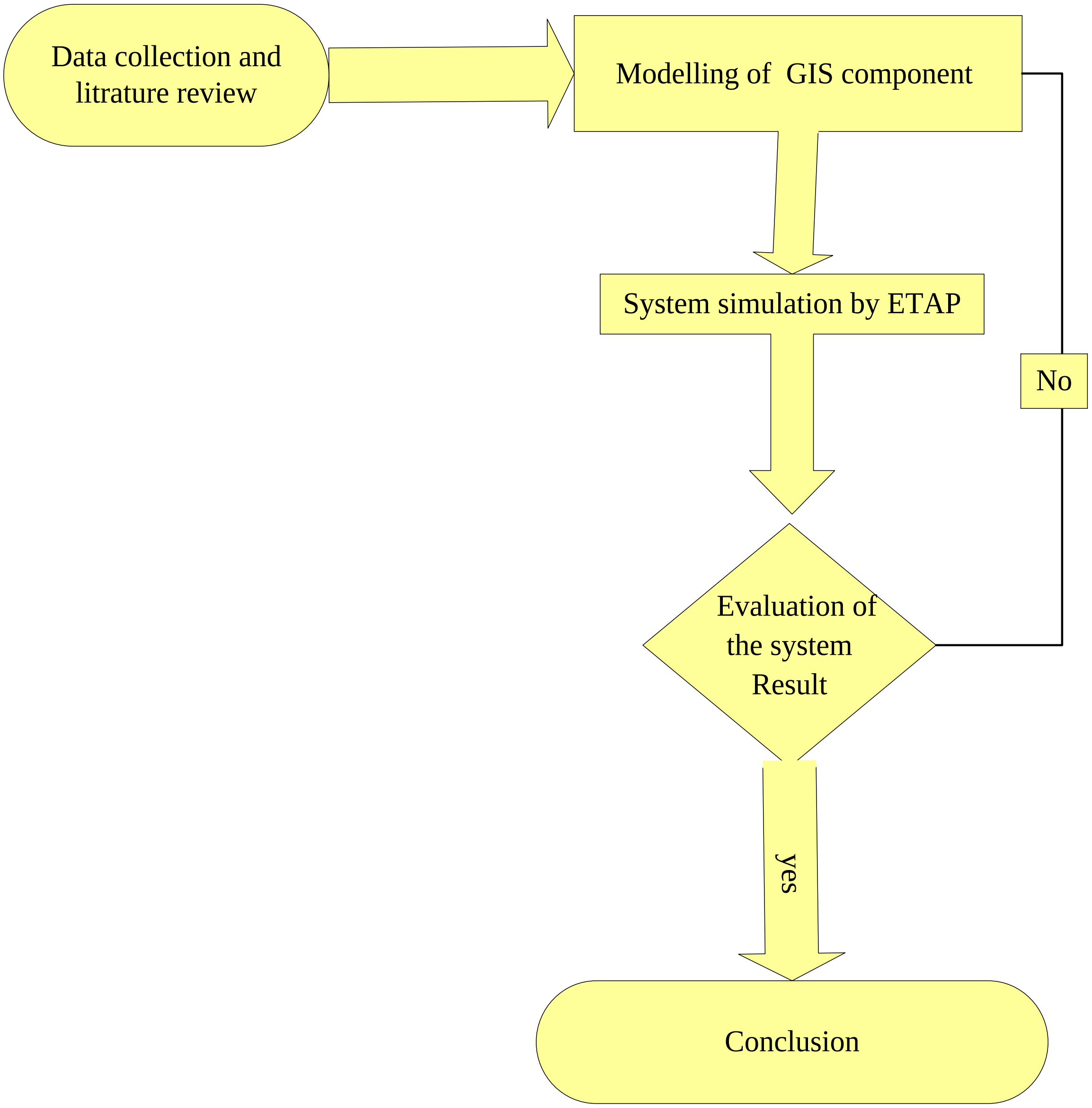

Figure 1.2 summary of methodology

1.6 Organization of Thesis

This thesis is organized under five chapters which are briefly summarized as shown below.

In the first chapter introduction of gas insulated substation has been discussed and also describes objective, statement of the problem, scope and methodology of the research.

Chapter 2 Presents definition and description on theoretical background of major components of gas insulated substation and literature review of various other works that has been done on GIS and related topics on the main component of the GIS.

Chapter 3 Provides the details of methodology, mathematical calculation of busbars related to temperatures, calculation for the volume of SF6and cost comparison for conventional substation and gas insulated substation.

Chapter 4 This chapters describes the single line diagram of 132 kV GIS, load flow analysis and short circuit analysis for purpose of carrying out a steady state power flow study for different voltage and current value. It also explore the summary of finding.

Chapter 5 Explains the conclusion of the thesis by comparing the life cycle cost (LCC), space taken, aesthetics of city of GIS and AIS and also recommendation and future work.

CHAPTER TWO

2 THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 THEORETICAL BACKGROUND

The purpose of this chapter is to provide the necessary background and literature survey required to understand the concepts that relate to GIS, recent standardization developments and the use of sulfur hexafluoride and GIS component architectures in substations. When designing any type of GIS component, it is important to learn from past research experience, which has resulted in many contrasting gas insulated substation technologies with different strengths and weaknesses.

Over the last couple of years, GIS have been used increasingly in transmission systems due to their many advantages over conventional substations which include space saving and flexible design, less field construction work resulting in shorter installation time, reduced maintenance, higher reliability and safety, and excellent seismic tolerance characteristics. Aesthetics of a GIS are far superior to that of a conventional substation due to its substantially smaller size [13]. Therefore, GIS has become an indispensable part of transmission networks for many years in most of continents. Now in Ethiopia, we might use for railway project which has vital role in the development of the country especially in capital city Addis Ababa due to scarcity of land.

The increasing in electricity demand along with the difficulty to find a new space for building a substation are the two important reasons why the development of GIS keeps on growing. Even though the use of SF6 in GIS has been considered having a potential drawback to the environment, by carefully handling the gas during the GIS operation and maintenance, or, by mixing the SF6 with less harmful electronegative gasses, the risk can be reduced.

2.2 Definition, Description of GIS Components and Power Transformer

2.2.1 Definition, Description of GIS Components

Here describe the main component of GIS [14] which are SF6, Circuit breaker, current transformer voltage transformer, bus bars, surge arresters, disconnectors and earthing switches.

2.2.1.1 Sulfur Hexafluoride (SF6)

The introduction of SF6 gas has revolutionized not only the technology of circuit breakers but also the layout of substations. **SF_6** gas molecules are combined by one sulfur and six fluorine atoms. This gas was first realized in the year of 1900 in the laboratories of the Faculte de Pharmacie de, Paris and became commercially available in 1947.Since 1960, SF6 has been used as arc quenching and insulating medium for high and medium voltage switchgear systems [11].

The favorable electro technical, chemical and physical characteristics of the gas have considerably influenced the development of the switchgear technology. SF6 is an alternative to other conventional insulating and quenching media such as e.g. oil, and air. The use of SF6 gas considerably increases, in some applications, the efficient utilization of resources in energy transmission and distribution with respect to technology, finances and personnel. At the same time SF6 in comparison to oil reduces the risk of hazard (e.g. fire, explosion) to personnel and environment. An overall evaluation considering all ecological, economic, safety and technological aspects has proven that SF6 is still an excellent choice as insulating medium.

Table 2.1 Physical properties of SF6.

Name of properties	Values
Molecular weight	146.06
Melting point	-50.8
Sublimation temperature(℃)	-63.8
Boiling point (℃)	-63
Density (solid) at 50 ℃	2.5 g/ml
Density (liquid) 50 ℃	1.98g/ml
Density (liquid) 20℃	1.39g/ml
Density (gas at 1 bar and 20 ℃)	6.164g/l
Relative density (air =1)	5.10
Critical temperature (℃)	45.6
Critical pressure (bar)	36.557
Critical density	0.755g/ml
Specific heat (25℃ $-cp$)	7.0g cal/ ml℃
Coefficient of expansion (-18℃)	0.027
Expansion on melting	30 %
Thermal conductivity (x 10^4)	3.36 cal/ sec/ cm^2/℃/cm
Viscosity (gas at 25℃ x 10^4)	1.61 poise
Vapor pressure (at 20℃)	10.62 bar
Dielectric strength	2.3* air =7.5kV/mm

2.2.1.1.1 Chemical Properties of SF6

SF6 has the following chemical properties:

- Stable up to 500℃.
- Does not react with structural material up to 500℃.

- This is inert gas. The inertness of this gas is advantageous in switchgear. The life of metallic parts, contacts is longer in SF6 gas.

2.2.1.1.2 Electrical Properties of SF6

SF6 gas is highly electronegative. Due to high electro negativity, it absorbs free electrons which produced due to arcing between contacts of circuit breaker. Combination of free electrons with molecules produces heavy and big ions, which have very low mobility. Because of absorption of free electrons and low mobility of ions. SF6 has very excellent dielectric property.

Now a days, it is one of the most extensively and comprehensively studied molecular gases largely because of its many commercial and research applications. In its normal state it is, thermally stable, chemically inert non-flammable, non-ignitable, non-explosive and non-toxic [12]. Because of its relative inertness and nontoxic characteristics, it is generally assumed to be an environmentally safe and acceptable material in the sense that it does not interact unfavorably with the biomass. The usefulness of SF6 gas is mainly due to its high dielectric strength, unique arc quenching ability and good thermal stability and conductivity. In addition, SF6 gas has good heat transfer and insulating properties. When contained has a relatively high pressure at room temperature. This principally accounts for its relatively high dielectric strength and better arc-interruption properties. The breakdown voltage of SF6 is higher i.e., at moderate pressure for phase-to phase and phase-to-ground insulation. In GIS, high voltage conductors, circuit breaker interrupters, switches, current transformers and voltage transformers are in SF6 gas inside grounded metal enclosures. SF6 doesn’t contribute ozone depletion layer because it doesn’t contain chlorine elements. Pure SF6 is physiologically completely harmless for humans and animals; it’s even used in medical diagnostic [15]. Due to its weight it might displace the oxygen in the air, if large quantities are concentrating in deeper and non-ventilated places. Legislation for chemicals does not categories SF6 as a hazardous material.in addition to this SF6 can be used in different areas for different applications. for instance For sound insulation in windows, in vehicle tires, for magnesium casting in the automotive industry, as insulating and arc extinguishing medium in electric power equipment, for manufacturing of semi-conductors, in tandem-particle accelerators, in electron microscopes, as tracer-gas in mining, in x-ray material examination equipment, as purification and protection gas for Aluminium and Magnesium casting, in sport shoes, medical examinations, in military aircraft radar systems and other military applications.

2.2.1.2 Busbars

Busbar is a low impedance conductor to which several electric circuits can be separately connected. In electrical power substations, busbars connect a number of incoming circuit connections to a number of outgoing circuit connections [34].

The bus bar is one of the most elementary components of the GIS system. Co-axial bus bars are common in isolated-phase GIS as this configuration results in an optimal stress distribution. Two sections of bus are joined by using plug-in connecting elements. Various sizes of the bus enclosures are shown in Figure: 2.1.

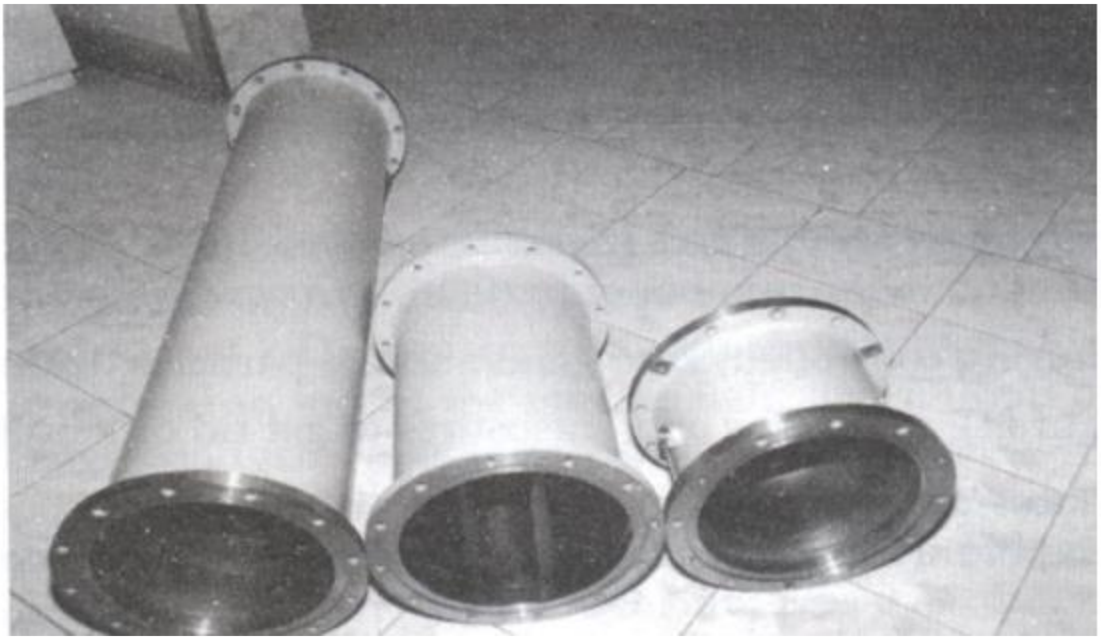

Figure 2.1 Metal enclosure for GIS busbar

Figure 2.2 Gas Insulated tube busbar with its metal enclosure

Energy can be transferred by interactions of a system and its surroundings, which is the case with the bus bar system. Electrical energy enters the system, however, not all of the electrical energy leaves the system due to the resistance of the bus bar conductors and Ohms Law. The remainder of the energy is dissipated as heat from the busbars into its surroundings [16].

In any electrical circuit some electrical energy is lost as heat which, if not kept within safe limits, may impair the long term performance or the safety of the system. For bus bar systems, the maximum working current is determined primarily by the maximum tolerable working temperature, which is, in turn, determined by considerations such as safety, the retention of mechanical properties of the conductor, compatibility with mounting structures and cable connections. A higher working temperature means that energy is being wasted. Designing for lower energy loss requires the use of more conductor material but results in more reliable operation due to the lower working temperature and, because the cost of lifetime energy losses is far greater than the cost of first installation, lower lifetime costs. Because of the large currents involved, short circuit protection of bus bar systems needs careful consideration [17].

2.2.1.3 Circuit Breakers

The circuit breaker is an automatic and manual switching device [35].it is used for the controlling and protection of the power system, when the large amount of current flow in the circuit then the arc will be produced between the contacts of the circuit breaker, thus circuit quench this arc in safe manner with the help SF6 gas.

A circuit breaker is a mechanical switching device that is capable of breaking or connecting currents under normal or abnormal conditions, such as a short circuit. The circuit breaker is an important component of the switchgear. Whenever there is a fault, the circuit breaker helps in disconnecting the circuit on load and breaking the fault current. Circuit breakers have a medium for arc extinction and this is what distinguishes them from isolators. In the simplest model, the circuit breaker is assumed to be an ideal switch whose impedance changes instantaneously from an infinite value for the open switch condition to a zero value at the closing switch condition. This performance can be represented at any point of a power cycle. A closing operation can produce transient over voltages whose maximum peaks depend on several factors, such as the closing instant, the network representation on the source side of the breaker, or the trapped charge on transmission lines in a reclosing operation. The closing instant, which can be different for every pole of a three-phase breaker, has more influence on the maximum peak of the over voltages subjected to the power system.

The SF6 circuit breaker is the most critical part of a GIS system. It is a switching device built ruggedly to enable it to interrupt or make the load current but also break the much larger fault current, which may occur on a circuit.it contains both fixed contacts and moving contacts and their major purpose is to eliminate a short circuit that occurs on the line. The circuit breaker in a gas-insulated system is metal-clad and utilizes SF6 gas, both for insulation and fault interruption The SF6 breakers used in GIS have a high capacity for carrying the full rated and short circuit currents with short interrupting times. They have separate contact system for carrying continuous current and for current interruption.

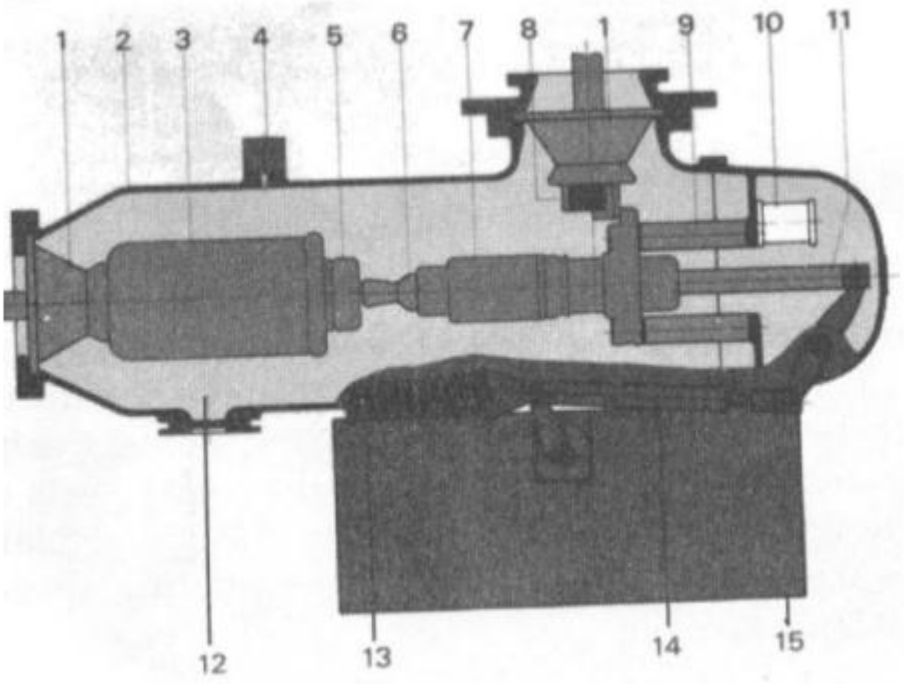

Figure 2.3 Circuit breaker Cross section of Gas insulated substation

The overall size of circuit breakers in GIS is considerably reduced due to the absence of porcelain insulators and the use of short terminal connection. Additionally they are used to isolate faulted sections of a network Interrupt fault currents (up to the MVA rating of the breaker), interrupt abnormal currents: due to nonlinear loads (arc furnace), and other load variations which are supported by insulating spacers. It is used to disconnect any section or unit from all live parts of a substation. It is normally a knife switch designed to open a circuit under no load. Isolators are placed in series with the circuit breaker to provide additional protection and physical isolation. The main purpose of using isolator is to isolate one portion of a circuit from the other. It should never be opened until the circuit breaker in the same circuit has been opened and should always be closed before the circuit breaker is closed. Isolators are usually placed on either side of the circuit breakers for safety during maintenance and troubleshooting.

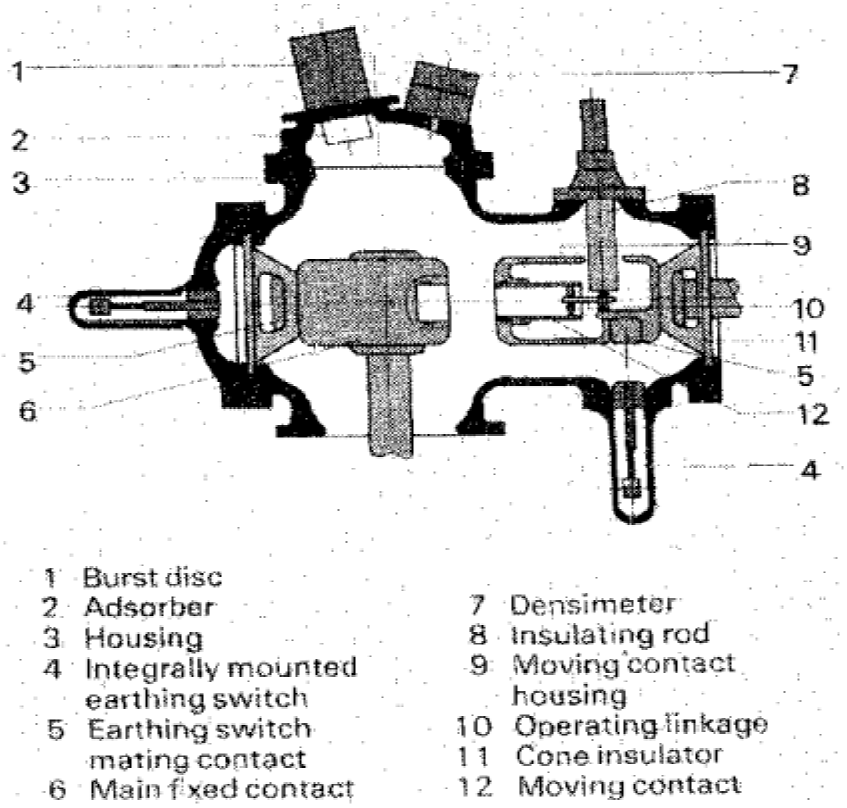

Figure 2.4 cross section of an isolated phase GIS isolator

2.2.1.4 Earthing Switch

In GIS, earthing switch is used to facilitate the grounding of conducting parts during maintenance which are rarely occur. They are generally slow acting device that are operated during the off state of the GIS equipment's. Operation of these device (switch) can be done either by an electric motor or manually and also used to protect the circuit-connected instrument voltage transformer from core saturation caused by direct current flowing through its primary as a consequence of remnant charge (stored online during isolation/switching off of the line). The earth switch is the smallest module of a GIS system. Furthermore, easy access is provided to active parts to facilitate easy inspection and maintenance.

2.2.1.5 Surge Arrestor/ Lightning Arrestor

Surge arrestor is a device used on electrical power system and telecommunication system to protect the insulation and conductor of the system from damaging. The effect of lightning Surge arrestors are employed to protect GIS units, connecting cables, transformers etc., against all types of over voltages. The main characteristics features of these SF6 insulated lightning arrestors are absence of spark gaps, high degree of protection, high energy absorption and flexibility in mounting. The electrically active parts of surge arrestor is column of ZnO resistor discs, which is mounted in a high pressure metal enclosure that ensure uniform voltage distribution across arrestor blocks. Surge arrester can be connected directly if it is required its function is to limit over voltages. Surge arresters are flange joint to the switch gear through a gas tight bushing. In a tank of arrester module, it has an inspection hole in which a conductor inspected and at the bottom there are the connection for monitoring, arrester testing and operation counter.

Surge arresters are connected in parallel with the equipment to be protected, typically between phase and earth for three phase installations. Lightning arresters are the most effective means of protecting an electrical apparatus against traveling voltage waves caused by lightning and switching. Lightning arrestors are connected across and apparatus to provide a Low resistance path to ground, thus limiting the transient voltages below the Basic Impulse Level of the apparatus.

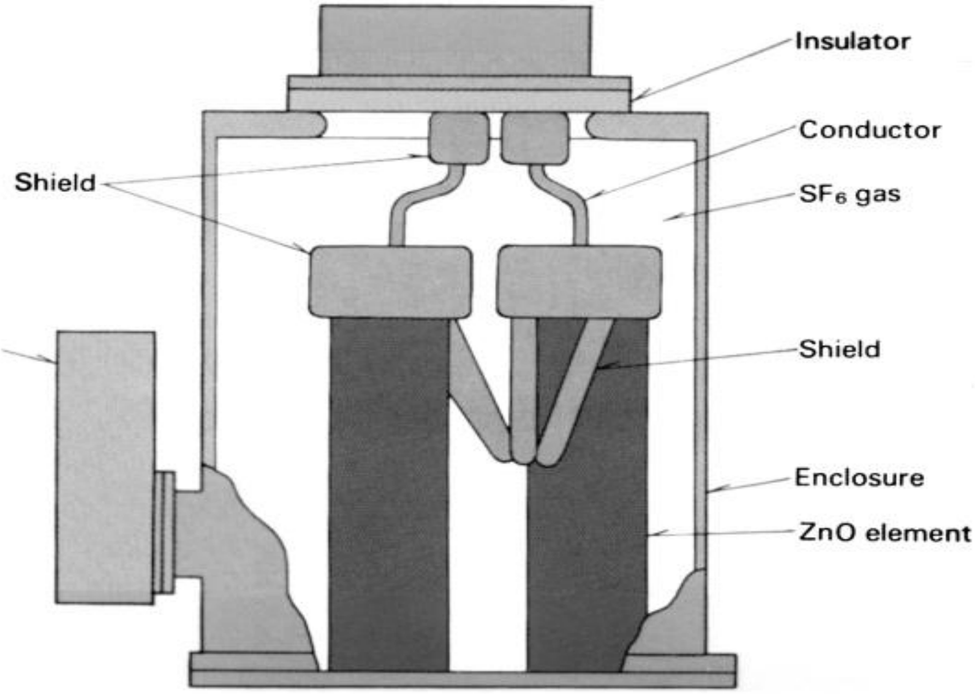

Figure 2.5 lightning structure inside gas insulated substation.

2.2.1.6 Instrumental Transformers

One of the crucial components of protection, measuring and controlling system are instrument transformers [18]. Instrumental transformers are high accuracy class electrical devices used to transform voltage or current levels. The most common usage of instrument transformers is to operate instruments or metering from high voltage or high current or vice versa circuits control circuitry from the high voltages or currents. The primary winding of the transformer is connected to the high voltage or high current circuit, and the meter and protection relay are connected to the secondary circuit. Instrument transformers may also be used as an isolation transformer so that secondary quantities may be used in phase shifting without affecting other primary connected devices. Instrumental transformers can be used for metering, for protection, controlling and for network purpose.

Electrical instrument transformers transform high currents and voltages to standardized low and easily measurable values that are isolated from the high voltage. Instrument transformers are used to proportionally step down the values to lower ranges to enable measuring instruments to monitor them carefully. In this case, a very high level of precision is required to be maintained as relays are connected to the secondary side of the instrument transformer and in case of any abnormal condition; it sends a signal or command to the circuit breakers to trip. It’s used for metering purposes, instrument transformers provide step down voltage or current signals that are very accurate representations of the transmission line values in both magnitude and phase [19].

These measurable value of current and voltage command allow accurate determination of revenue billing. When used for protection purposes, the instrument transformer outputs must accurately represent the transmission line values during both steady-state and transient conditions. These critical commands provide the basis for circuit-breaker operation under fault conditions, and as such are fundamental to network reliability and security. Instrument transformers used for network control supply important information for determining the state of the operating conditions of the network. Instrumental transformers can be Current Transformer and Voltage Transformer. Each instrumental Transformer are explained here after.

2.2.1.6.1 Current Transformers (CT)

CT are a series connected to the circuit type of instrument transformer. They are designed to present negligible load to the supply being measured and have an accurate current ratio and phase relationship to enable accurate secondary connected metering. CTs are inductive ring types installed either inside the GIS enclosure or outside the GIS enclosure. The GIS conductor is the single turn primary for the CT. CTs inside the enclosure must be shielded from the electric field produced by the high voltage conductor or high transient voltages can appear on the secondary through capacitive coupling.

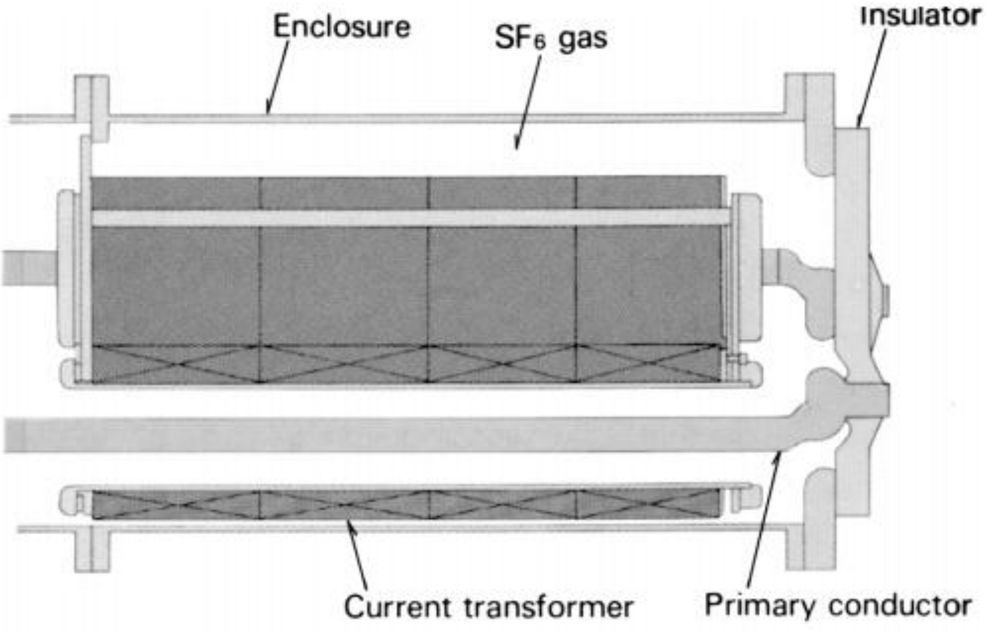

Figure 2.6 Current Transformer for GIS.

For CTs outside the enclosure, the enclosure itself must be provided with an insulating joint, and enclosure currents shunted around the CT.

2.2.1.6.2 Voltage (Potential) Transformers (VT)

VTs are inductive types with an iron core. The primary winding is supported on an insulating plastic film immersed in SF6. The VT should have an electric field shield between the primary and secondary windings to prevent capacitive coupling of transient voltages. The VT is usually a sealed unit with a gas barrier insulator.

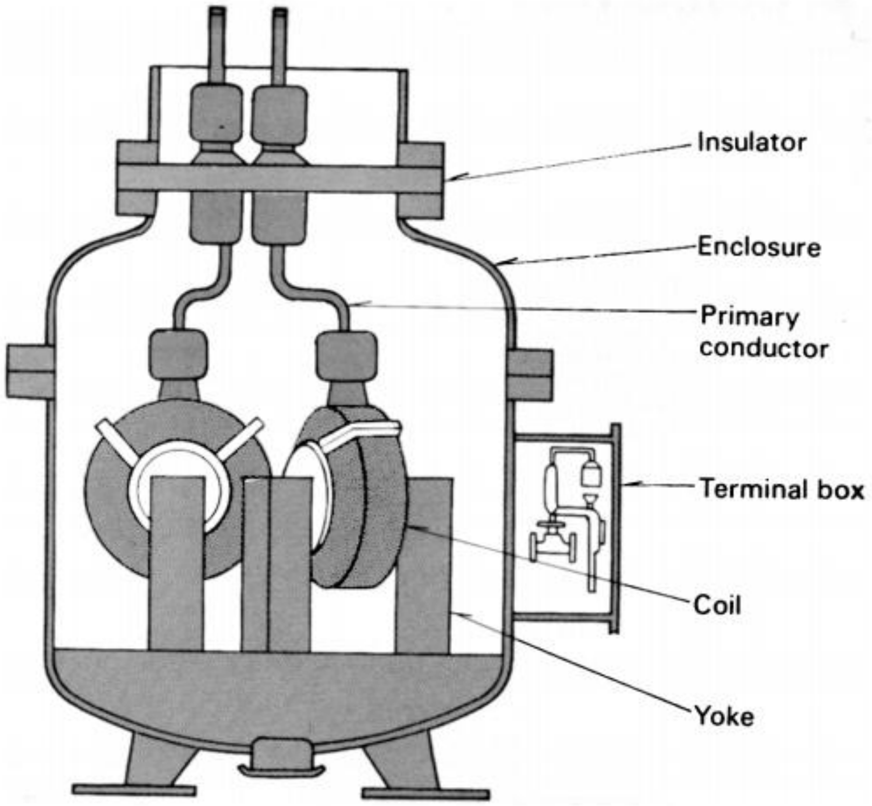

Figure 2.7 Voltage Transformer for GIS.

2.2.2 Power Transformer

The invention of the power transformer towards the end of the nineteenth century made possible the development of the modern constant voltage AC supply system, with power stations often located many miles from centers of electrical load. The first transformer was installed 1883 in London, by Gaillard and Gibbs. ASEA manufactured their first transformer 1893, a three phase transformer [20-22].

One of the most important components as well as cost-intensive components in a power network is the power transformer. Efficient transmission and distribution of electricity through different voltage levels are made possible by using power transformers. Any outage of this component may affect the reliability of the entire network and has considerable economic impact on the system [17].

A power transformer is static peace of apparatus with two or more windings which, by electromagnetic induction, transform a system of alternating voltage and current in to another system of alternating voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power. It can change high voltage to low voltage and the other way around. And also Transformer is a device that transforms step up or down voltage & current reversely by keeping the power constant. A varying Current in the primary winding creates a self-inductance in the primary winding which causes a voltage to be created on the secondary windings, varying magnetic field through the secondary winding i.e. mutual inductance.

A transformer has one primary and one or two secondary windings. In this session the author is going to study highlights of two winding power transformers. With their unique ability, the power transformers are able to change the voltage to different requirements. Efficient transmission and distribution of electricity through different voltage levels is made possible only by using power transformers.

The power transformer is a key component of the electrical network as it links the generators, the transmission lines and the distribution networks. It also ensures that the electrical power system is operating in an efficient, reliable and effective manner. The main uses of electrical transformers are for changing the magnitude of an AC voltage and current by making constant power with the same frequency.

In general power transformers are either auto-transformer or two or three winding three phase transformer. However, the three-phase Power transformer which steps down 132 kV/15 kV High voltage to medium voltage respectively has been studied. The selection of the rating of power transformer i.e. 25 MVA relies on the data collected from EEP.

2.2.2.1 Construction of Power Transformer

The transformer consists of core, primary winding, secondary winding, pole shoe, tanker, bushing, on load tap changer and conservator tank, breather, Buchholz Relay and etc.

Core: - many pieces of sheets laminated with each other and stuck together in order to hold the winding and to transfer full flux induction on the secondary winding and also to reduce eddy current loss and Hysteresis loss.

Core is used to support the windings in the transformer. It also provides a low reluctance path to the flow of magnetic flux. The composition of a transformer core depends on such factors as voltage, current, and frequency.

Primary winding: - a thin wire, which has many number of turns, and forming a coil. As an alternating a current passes through this coil it becomes electro magnetized and produces flux (Self-inductance).

Secondary winding: - a thick winding bar or sheet which has small number of turns, placed inside the primary winding, but do not have electrical contact (there is no any electrical linkage between primary and secondary windings)with each other. As the flux produces by the primary winding it induces on the secondary winding.

Pole shoe: - it is a wooden/ Bakelite material to hold the core tight and to support the poles.

Tap changer: -The output voltage may vary according to the input voltage and the load. During loaded conditions the voltage on the output terminal fall and during off load conditions the output voltage increases. In order to balance the voltage variations tap changers are used. Tap changers can be either on load tap changer or off load tap changer. In on load tap changers the tapping can be changed without isolating the transformer from the supply and in off load tap changers it is done after disconnecting the transformer. Automatic tap changers are also available.

Conservator: -conserves the transformer oil. It is an airtight metallic cylindrical drum which is fitted above the transformer. The conservator tank is vented to the atmosphere at the top and the natural oil which is cooled in the system of OFAF. Oil level is approximately in the middle of the conservator to allow expansion and contraction of oil during the temperature variations. It is connected to the main tank inside the transformer which is completely filled with transformer oil pass through a Buchholz Relay by a pipeline. The function of conservator is to take up construction & expansion of oil without allowing it to come in contact with outside air. Transformer oil will expand due to the heat generated because of losses.

Breather: - is a device used for absorb the moisture content of an oil and sucked air. When the temperature changes, expansion of contacts & there is a displacement of air. When the transformer cools the oil level goes down the air is drawn in. The oil should not be allowed to come in contact with the atmospheric air as it may take moisture, which may spoil its insulating properties. Air may cause acidity or sledging of oil, so, the air coming in is passed through an apparatus called breather for extracting moisture. The breather consists of a small vessel, which contains a drying agent like Silica gel crystal.

Silica gel: -it is a chemical material these are the only one main component inside the breather. Basically silica gel is a blue colored one after the absorption silica gel become pink.

Bushing: - is an insulated device that allows an electrical conductor to pass safely through an (usually) earthed conducting barrier. It found on the primary or input voltage and secondary output voltage. It is fixed on the transformer tank and these connections is made to the external circuits.

Buchholz Relay: -It is a protective device container housed over the connecting pipe from main tank to conservator tank. It is used to sense the faults occurring inside the transformer. It is a simple relay which is operated by the gases emitted due to the high pressure of transformer oil during internal faults, this relay is used to give an alarm in case of incipient (slow developing) faults in transformer and to disconnect the transformer from the supply in the event of sever e internal faults. It helps in sensing and protecting the transformer from internal faults

2.3 LITERATURE REVIEW

This study has been focused on finding similar and comparable studies of the research problems for the thesis. Literature has been searched and different articles, books and previous master thesis have been revised, especially the literatures mentioned below have been in great favor.

Since the invention of GIS by Japanese Engineers which was invented before thirty years ago, different types of Gas Insulated Substations have been designed by different scholars over the world among which, indoor and outdoor are more widely used in different continents where there is a problem of land due to high population density or high mountains availability which makes AIS installation impossible.

Despite the invention of GIS by Japanese, highly experienced ALSTOM Grid has many years of experience in the design of gas-insulated, high voltage switchgear rated up to 800 KV. ALSTOM has been actively involved in SF6 technology for several decades and their GIS have been in operation worldwide since1965 with proven success. Excellent field experience confirms the soundness of their technical concepts [24].

GIS equipment have been developed and improved drastically over the last three decades. Several Authors have studied and surveyed them. Considering the growing necessity of electrical power for developing countries and also in view of the relatively low per capital power consumption, there is a constant need for additional power capacity and technological up gradation, even though non-conventional energy systems have proved to be good alternative sources for energy. Some of the developing countries, which are quenching the need of additional power by conventional electric sources, have shifted the emphasis towards improving the reliability of transmission and distribution systems, ensuring that the innovations are not harmful to the environment. It is felt that brief survey of the work done by several Authors and Researchers in the field is in place here, before going into the details of the present study.

L.G.Christoporou [14]. Mentioned that the conventional AIS have many problems such as pollution by salt or dust, meteorological difficulties, safety etc. Hence, there is a need to replace the conventional transmission lines and substations with underground cable and GIS to overcome the above problems. Due to its many advantages, most of the utilities and industrial units are opting for GIS.

Sharif Ahmed [23]. Has mentioned the problems with air insulated substation like environmental problems like dust, corrosive gases rats, cat, snakes and altitude on his presentation of Senior Member IEEE.

Mr. ChetanRedasani, Prof.Dr.P.D.Patil, Prof. H. G.Patil [31] Discussed that Gas insulated switchgear is the device, which bridges the gap between protection system and space requirements of substation. In current scenario the urbanization taking place at glance. There is increasing demand of land in city areas to cope up this, GIS is best fit. those scholars also mentioned that Gas insulated switchgear is the heart of protection system, the basic need of GIS is to protect the power transformers Every GIS is having various electrical components starting from Circuit Breaker, Disconnector, Ear thing switch, CT, VT, and many more and configured in various arrangement, which generates large mechanical and electrical stresses in GIS due normal and abnormal service conditions, This stresses generates reactions and moments on GIS, which needs to transfer to foundations for proper operation of GIS.

ALSTOM [24] company described his motto word like the increasing demand for electrical power in cities and industrial centers requires the installation of compact and efficient distribution and transmission networks. High voltage GIS are ideal for such applications.

K.Chakrabarti [40]. Discussed that SF6 gas is extensively used in compressed gas insulated power apparatus, such as gas insulated transmission line (GITL), GIS and switchgear (GIS). SF6, besides being dielectrically superior to air, is non-toxic, environmentally safe, and chemically stable. However, in such equipment the SF6 gas, goes an insulating medium, is used well below its ideal dielectric capabilities (88.4$MVmm^{-1}MPa^{-1}$).

Sayed.A.Ward [52] discussed that the use of compressed gas as insulated media has made possible compact equipment compared to that air insulation. However, the compact construction increases the operating field intensity. SF6 insulation is extremely sensitive to local increases in electric field which results from protrusions on electrode. Triple junction (The region where the electrode, insulator and SF6 gas meet) in compressed gas, the presence of conducting particles in gas insulation and the shape of spacers supporting the conductor system typically results in a reduction in the insulation in the strength of SF6 to about half the theoretical field strength. Metallic particle initiated breakdown can occur at fields considerably lower than this, reducing the insulation level by as much as 90% of the surface roughness.

CHAPTER THREE

3 DESIGN OF THE GIS

3.1 Introduction

The goal of this thesis is to design and simulate a GIS in a traction power system. The results are useful for evaluating the merits and demerits of GIS and to make comparisons with the AIS. The GIS studies can also determine the power loss of the busbar and verify compliance with the international standards. The need for a gas insulated substation study may be indicated by excessive land use and maintenance costs in existing systems.

The following steps has been considered while designing the GIS:

1) Definition of various components of the GIS and determination of models for their representations.
2) Identifying range of solutions.
3) Evaluation of solutions.
4) Introducing optimum solution.

3.2 Design Assumptions and Requirements

When designing the busbar of GIS the following assumptions have been made to calculate the operating temperature of current carrying of copper busbars.

a. The substation is operating at 132kV/15KV.
b. The earthing switches and surge arrestors inside the substation are neglected in this chapter.
c. The generators are not considered in this substation.
d. Assume the average SF6 temperature within the enclosure is distributed equally and the busbars conductors have the same temperature and all heat produced by the busbars is absorbed by SF6 inside the enclosure.
e. The temperature of a busbar is 95℃ , SF6 is 75℃, enclosure surrounding is 24℃, outer surface of enclosure is 45℃ and inner surface of enclosure 50℃.

f. Assume the width, thickness and diameter of bus bar is 50mm and 6.3 mm and 200mm respectively for 1600A [25].
g. Assume the substation installed in zero years.

3.3 GIS Site Considerations

The conventional AIS design uses a large number of disconnectors in order to allow for maintenance and repair with a minimum of interruption. The occupied area of AIS is typically large and the maintenance demand of the open-air apparatus is relatively high, particularly in case of severe environmental conditions. Besides, switchgear, its subsystems and components are exposed to aging and wearing during the years of exploitation that leads to the increase in fault events over the years of service and also they are prone to electromagnetic interference. The attempt in the new substation designs is to make them more compact and somewhat protected from the environmental impacts. 132kV Shiro Meda GIS is free from the environmental impact and non-electromagnetic interference. The housing of the substation and the incoming high voltage transmission line should almost exist on the same straight line.

3.4 Utilities Coordination

Disturbances in the electrical distribution substation contribute most to the majority of equipment outages per year compared to the generation and transmission systems. A way to reduce the duration of the customer outages is to increase the reliability and reserve capacity within the distribution network. An increase in reliability can be achieved by increased maintenance of the components within the system and thereby lowering the probability of failure. The duration of outages for the customer can be reduced by adding redundancy and reserve capacity for the supply of electricity. Similarly for the 132kV Shiro Meda GIS, two EEP high voltage transmission lines from Gefersa substation and Addis North substation are connected to the power line for keeping the reliability of the train.

The GISs are usually modelled and analyzed by parameterization with different components. Some of the components used are busbars, SF6, circuit breaker, instrumental transformers, isolators, earthing switches, lightning arrestor and control cabinet as shown below.

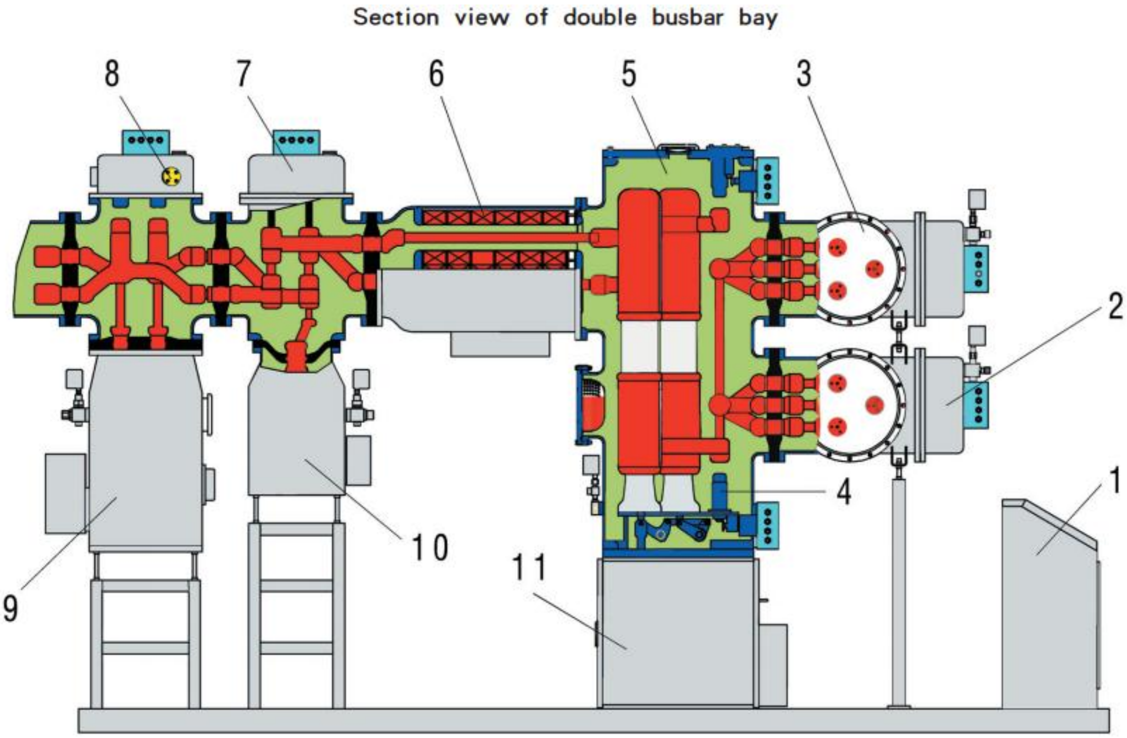

Figure 3.1: Sectional view of double busbar bay

1. Control cubicle
2. Busbar disconnector
3. Busbar
4. Earthing Switch
5. Circuit Breaker
6. Current Transformer
7. Disconnector
8. Line earthing Switch
9. Lightning Arrestor
10. Potential Transformer

From the above listed devices the heat loss of busbar has been done. For the other components the ratings have been selected from the IEC standards shown below.

Table 3.1 List of International Standards for the major components of GIS.

No	Name of components	Applicable standards
1	Circuit breaker	IEC 62271 -100
2	Current transformer	IEC 60186,IEC 60044-1,6 BS3938
3	Potential transformer	IEC 60186, IEC 60044-2
4	Isolator / disconnector	IEC 62271-102,61128
5	Lightning arrestor	IEC 60099-4
6	Fast Earthing switch	IEC 62271-102, IEC 61129
7	High voltage GIS switchgears	IEC 62271-203
8	Specification for SF6	IEC 60376

3.5 Busbars

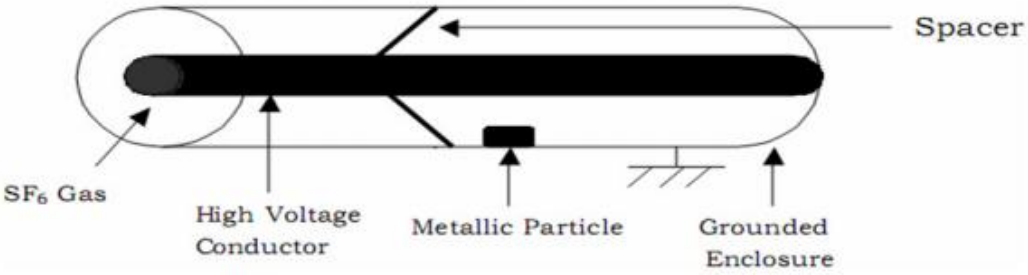

Figure3.2 busbar enclosed by metallic particle and filled by SF6

Busbar is one of the most elementary components of the GIS system. Co-axial bus bars are common in isolated-phase GIS as this configuration results in an optimal stress distribution. Two sections of bus are joined by using plug-in connecting elements energy can be transferred by interactions of a system and its surroundings, which is the case with the bus bar system. Electrical energy enters the system, however, not all of the electrical energy leaves the system due to the resistance of the bus bar conductors and Ohms Law. The remainder of the energy is dissipated as heat from the busbars into its surroundings. In any electrical circuit some electrical energy is lost as heat, which, if not kept within safe limits, may impair the long term performance or the safety of the system.

The current-carrying capacity of a bus bar is limited by the maximum acceptable working temperature of the system, taking into account the properties of the conductor material, the materials used for mounting the bars and the limitations of any cables (including their insulation) or devices connected to the bars [17].

There are two design limits; the maximum permitted temperature rise, as defined by switchgear standards, and the maximum temperature rise consistent with lowest lifetime costs - in the vast majority of cases, the maximum temperature dictated by economic considerations will be rather lower than that permitted by standards. National and international standards, such as British Standard BS 159 and American Standard ANSI C37.20, give maximum temperature rises as well as maximum ambient temperatures. For example, BS 159:1992 stipulates a maximum temperature rise of 50°C above a 24 hour mean ambient temperature of up to 35°C, and a peak ambient temperature of 40°C. Alternatively, ANSI C37.20 permits a temperature rise of 65°C above a maximum ambient of 40°C, provided that silver-plated (or acceptable alternative) bolted terminations are used. If not, a temperature rise of 30°C is allowed.

These upper temperature limits were chosen to limit the potential for surface oxidation of conductor materials and to reduce the mechanical stress at joints due to cyclic temperature variations. In practice these limitations on temperature rise may be relaxed for copper busbars if suitable insulation materials are used. A nominal rise of 60°C or more above an ambient of 40°C is allowed by EN 60439-1:1994 provided that suitable precautions, such as plating, are taken.

EN 60439-1:1994 states that the temperature rise of busbars and conductors is limited by the mechanical strength of the bus bar material, the effect on adjacent equipment, the permissible temperature rise of insulating materials in contact with the bars and the effect on apparatus connected to the busbars. In practice, this last consideration limits the maximum working temperature to that of the insulation of cables connected to the bar – typically 90°C or 70°C. Running busbars at a high working temperature allows the size of the bar to be minimized, saving material and initial cost. However, there are good reasons to design for a lower working temperature. A higher maximum temperature implies a wider variation in temperature during the load cycle, which causes varying stress on joints and supports as the bars expand and contract. Eventually, this may lead to poor joint performance and decreased reliability.

In some cases it is difficult to remove heat from bus bar compartments, resulting in ancillary equipment operating in an elevated ambient temperature. High temperatures indicate high energy losses. Lowering the temperature by increasing the size of the conductor reduces energy losses and thereby reduces the cost of ownership over the whole lifetime of the installation. If the installation is designed for lowest lifetime cost, the working temperature will be far below the limit set by standards and the system will be much more reliable.

The selection of busbars conductors is usually based on a balance of mechanical and electrical characteristics, economics, and availability. The materials that have been used for bus conductors in large quantity, listed in order of volume conductivity, are: silver, copper, aluminum and iron [26]. In Ethiopia most of busbars used are made from either copper or aluminum [17].

To achieve a long and reliable service life at the lowest lifetime cost, the conductor material needs the following properties:

a. Low electrical and thermal resistance.
b. High mechanical strength in tension, compression and shear.
c. High resistance to fatigue failure.
d. Low electrical resistance of surface films.
e. Ease of fabrication.
f. High resistance to corrosion.
g. Competitive first cost and high eventual recovery value.

This combination of properties is best met by copper. Aluminum is the main alternative material, but a comparison of the properties of the two metals shows that, in nearly all respects, copper is the superior bus bar material. Copper bus bar conductors are an integral part of any high current switchboard. A suitable switchboard design must be capable of withstanding the mechanical, electrical and thermal stresses which are likely to be encountered in normal service.

Table 3.2 – Properties of Typical Grades of Copper and Aluminum Property (at 20°C) BS EN 13601: 2013.

No	Property (at 20°C)	Copper	Aluminium	Units
1	Electrical conductivity (annealed)	101	61	% IACS
2	Electrical resistivity (annealed)	17.2		nΩmm
3	Electrical resistivity	16.8	26.5	nΩmm
3	Temperature coefficient of resistivity	0.0039	0.004	per °K
4	Thermal conductivity	397	230	W/m°K
5	Specific heat	385	900	J/kg °K
6	Coefficient of expansion	17 x 10^{-4}	23 x 10^{-6}	per °K
7	Tensile strength	200-250	50-60	N/mm^2
8	Elastic modulus	116-130	70	kN/mm^2
9	Density	8910	2700	kg/m^3
10	Melting point	1083	660	°C

Realistic mathematical temperature representations for bus bar are needed in order to achieve accurate and meaningful reliability of power flow in gas insulated substation.

3.6 Mathematical Methods of Temperature Calculation for Busbars

In engineering terms, the current rating for a busbar depends on the choice of working temperature. The busbar is heated by the power dissipated in it by the load current flowing through the resistance, and cooled by radiation to its surroundings and convection from its surfaces. At the working Temperature, the heat generation and loss mechanisms, which are highly temperature and shape dependent, are balanced [17]. Energy can be transferred by interactions of a system and its surroundings, which is the case with the busbar system. Electrical energy enters the system, however, not all of the electrical energy leaves the system due to the resistance of the bus bar conductors and Ohms Law. The remainder of the energy is dissipated as heat from the busbars into its surroundings which is SF6.

The specified enclosure is a complex system of heat dissipation, absorption and conduction calculations, and the formulas used and their inter-connections are detailed within the following sections.

3.6.1 Heat Generated by Busbars

The rate at which heat is generated per unit length of a conductor carrying a direct current is the product I^2R Watts, where I is the current flowing in the conductor and R is the resistance per unit length [17][28].

$$P=I^2 R_{new} S \quad 3.1$$

Where p= the power dissipated per unit length.

I = is the current in conductor.

R_{new} = is the dc resistance per unit length at the ambient temperature at 20 ℃.

S = is the correction factor for shape, proximity and skin effect.

The factor S, introduced above, is the product of the factors due to skin effect, S_k and proximity factor, S_p since in Ethiopia frequency in use is 50 HZ correction factor is negligible.

$$R = \frac{\rho l}{A} \quad 3.2$$

Where ρ =is resistivity of the busbar conductor

l = is the length of the busbar taken

A = is the area of busbars

Area of busbar is calculated by:

$A=\pi r^2$ = 3.14*$(0.01m)^2$= 3.14*0.0001m^2=0.000314m^2

The length of busbar taken is 2m and the resistivity of Cu conductor is 1.68 x10^{-8} ohm.

$R_o = \frac{1.68\ \text{x}10^{-8} ohm.m*2m}{314*10^{-6}m^2}$ = $0.011* 10^{-2} ohm$ = 0.00011ohm.

$$R_{new} = R_o(1 + \alpha(T - T_o)) \qquad 3.3$$

Where

R_{new} =conductor resistance at temperature T.

R_o= conductor Resistance at room temperature.

α = temperature coefficient of Resistance = 0.00393 for Cu.

T = temperature of conductor.

T_o = ambient temperature.

$$R_{new} = 0.00011\text{ohm } (1+0.00393(95-20)) = 0.000142\text{ohm}.$$

Finally the power loss for 2 m cupper busbar is calculated as follow:

$P=I^2R_{new}$

P = $(1600\text{A})^2 * 0.000142 ohm$= 364.6W at 95.℃

Table 3.3. Current carrying capacities of copper under specified condition with its thickness and width.

No	Current carrying capacity (A)	Busbar dimension (number * width X thickness in mm)		
		Single core	Two core	Three core
1	200	1 x 12.5 x 4		
2	250	1 x 16 x 4		
3	300	1 x 20 x 4		
4	400	1 x 25 x 6.3		
5	500	1 x 32 x 6.3	2 x 20 x 4	
6	600	1 x 38 x 6.3	2 x 25 x 6.3	
7	800	1 x 50 x 6.3	2 x 25 x 6.3	

No	Current carrying capacity (A)	Busbar dimension (number * width X thickness in mm)		
		Single core	Two core	Three core
8	1000	1 x 76 x 6.3	2 x 32x 6.3	
9	1200	1 x100 x 6.3	2 x50 x 6.3	
10	1600	1 x 100 x 8	2 x 63 x 6.3	3 x 50 x 6.3
11	2000	1 x 100 x 6.3	2 x 63 x 6.3	
12	2500	2 x 100 x 8	3 x 75 x 10	3 x100 x6.3

Note that the dimension of busbars are only related to their current carrying capacities without due regard other consideration such as mechanical strength.

3.6.2 Heat Dissipated by Busbars

Heat generated by busbars can be dissipated through the following heat transfer methods.

a. Convection.
b. Radiation.

The rate at which heat is dissipated per unit length of busbar is equal to the rate at which electrical power is generated per unit length of busbar and is described in Equation 3.4 below [17].

$$p = q_{conv1} + q_{rad1} \qquad 3.4$$

$$p = W_c A_c + W_r A_r$$

Where

q_{conv1} = heat dissipated from busbars due to convection, W.

q_{rad1}= heat dissipated from busbars due to radiation, W.

W_c = heat dissipated per square meter due to convection, W/m^2

W_r = heat dissipated per square meter due to radiation, W/m^2

A_c = surface area of conductor, m^2 (convection).

A_r = surface area of conductor, m^2 (radiation).

3.6.2.1 Busbar Heat Dissipated by Convection

The rate at which heat is dissipated per unit length of busbar via convection depends on the shape, size and temperature rise above the surrounding air. Convection heat dissipation from the busbar differs from vertical to horizontal surfaces and the tube as described in equation 3.5, 3.6, 3.7, 3.8 and Figure 3.3[17].

$$q_{conv1} = w_c A_c = w_v A_{cv} + w_h A_{ch} + w_c A_t \qquad 3.5$$

$$w_v = \frac{7.65\theta^{1.25}}{L^{0.25}} \qquad 3.6$$

$$w_h = \frac{5.92\theta^{1.25}}{L^{0.25}} \qquad 3.7$$

$$w_c = \frac{7.66\theta^{1.25}}{d^{0.25}} \qquad 3.8$$

$$\theta = \bar{T}_1 - \bar{T}_2 \qquad 3.9$$

w_v= heat dissipated per vertical square meter due to convection, W/m^2.

w_h= heat dissipated per horizontal square meter due to convection, W/m^2.

w_c=heat dissipated per tube square meter due to convection, W/m^2.

A_{cv} = vertical surface area of conductor, m^2.

A_{ch} = horizontal surface area of conductor, m^2.

$\bar{T}_1$ = average busbar temperature K.

$\bar{T}_2$= average temperature of SF6 in the enclosure.

L= height or width of busbars , mm.

d = diameter of the tube, mm.

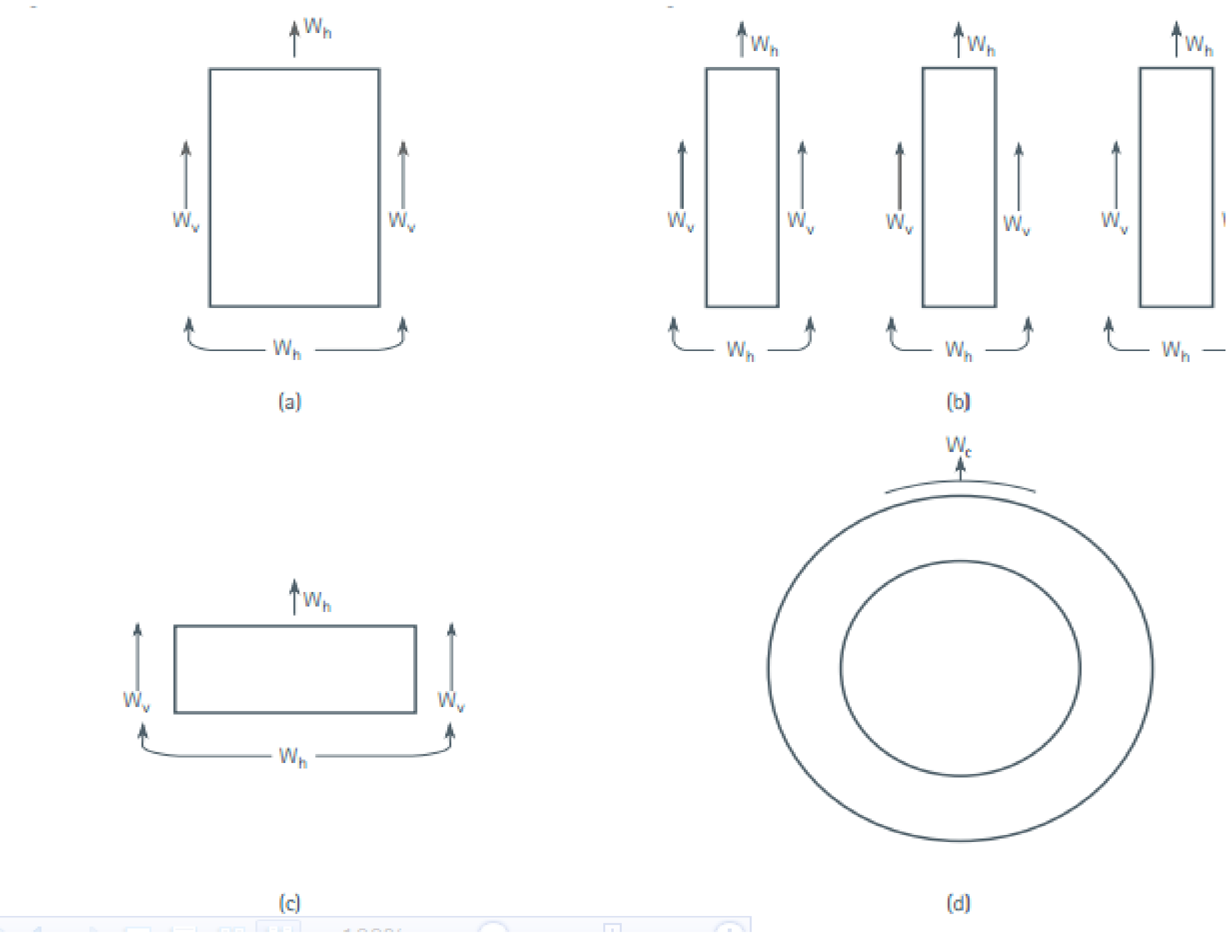

Figure 3.3: Convection loss from typical busbar section.

The diameter of busbar is assumed to be 20mm, the temperature for the busbar conductor and SF6 is 95 °C and 75 °C respectively, calculated as per above equation.

$$w_v = \frac{7.65\theta^{1.25}}{L^{0.25}} = w_v = \frac{7.65(20)^{1.25}}{2^{0.25}} = 272.1\text{W}/m^2$$

$$w_h = \frac{5.92\theta^{1.25}}{L^{0.25}} = w_h = \frac{5.92(20)^{1.25}}{2^{0.25}} = 210.55\text{W}/m^2$$

$$w_c = \frac{7.66\theta^{1.25}}{d^{0.25}} = \frac{7.66(20)^{1.25}}{0.02^{0.25}} = \frac{323.98}{0.376} = 861.5\text{W}/m^2$$

$$qconv1 = w_c A_t + w_h A_h + w_v A_v$$

Assume that the enclosure has a cylindrical shape with perimeter of 8m and height of 2m. From the perimeter the calculated Radius of the enclosure is 0.318m. By using the calculated radius and height, the area of the cylinder should be,

$$A = 2\pi r^2 + h(2\pi r) \qquad 3.10$$

$$A = 2\pi(0.318m)^2 + 2m(2 * \pi * 0.318m) = 4.63m^2$$

$$qconv1 = 861.5\mathrm{W}/m^2 x\ 4.63\ m^2 + 210.55\mathrm{W}/m^2 * 4.63m^2 + 272.1\mathrm{W}/m^2 * 4.63m^2$$

$qconv1$= 6.223 KW.

3.6.2.2 Busbar Heat Dissipated by Radiation

The rate at which heat is dissipated to its surroundings per unit length of busbar via Radiation is proportional to the fourth power of their absolute temperatures and the relative emissivity between the busbar and its surroundings. Radiation heat dissipation from the busbar is described in equation 3.11 and 3.12 below and from fig 3.4 [17].

$$q_{rad1} = WrAr = 5.70X10^{-8} * e\left(\overline{T}_1^{\ 4} - \overline{T}_3^{\ 4}\right) * Ar \qquad 3.11$$

$$e = \frac{\varepsilon_1 \varepsilon_2}{(\varepsilon_1 + \varepsilon_2) - (\varepsilon_1 \varepsilon_2)} \qquad 3.12$$

Where

e = relative emissivity.

$\overline{T}_1$= average temperature of busbars, K.

$\overline{T}_3$= average temperature of the enclosure inner surface, K.

ε_1= absolute emissivity of busbars =0.1 for bight metal oxide.

ε_2= absolute emissivity of the surface enclosure inner surface is 0.47.

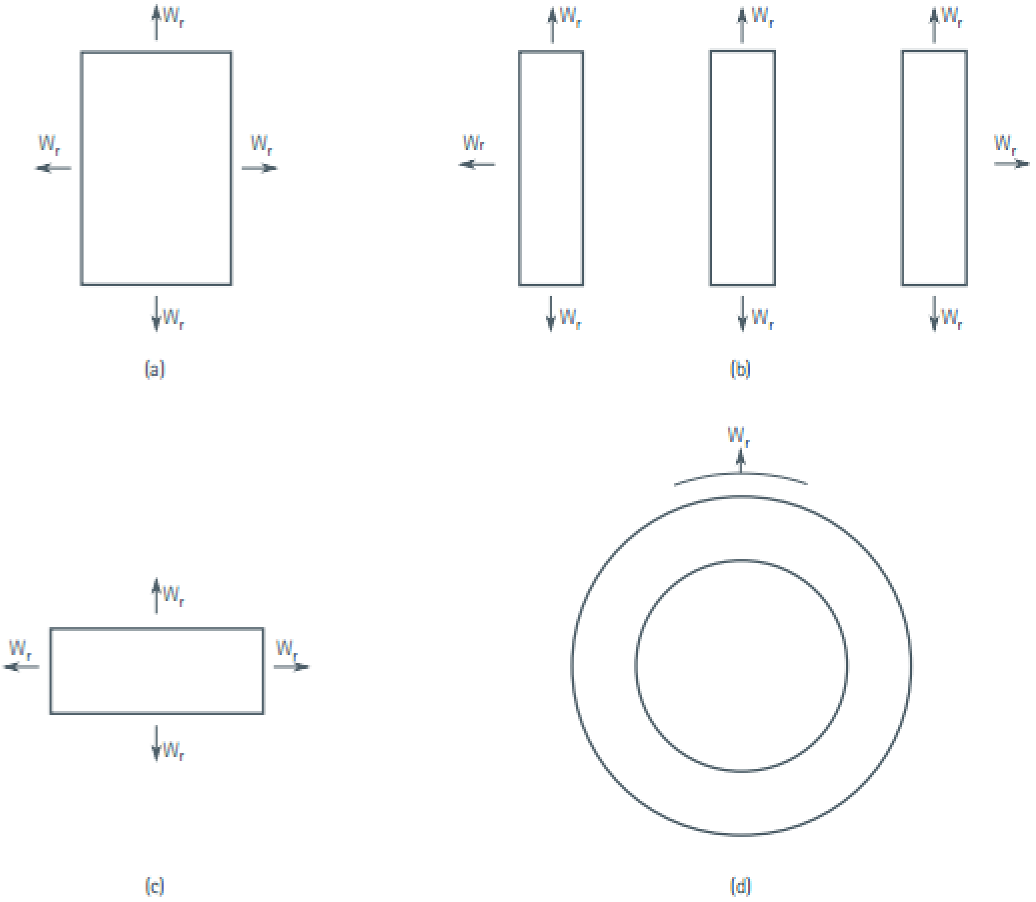

Figure 3.4: Radiation loss from typical bus section.

$$e = \frac{\varepsilon_1 \varepsilon_2}{(\varepsilon_1+\varepsilon_2)-(\varepsilon_1 \varepsilon_2)} = \frac{0.1\ x0.47}{(0.47+0.1)-(0.47x0.1)} = \frac{0.047}{0.57-0.047} = 0.89$$

$$\boldsymbol{q_{rad1}} = WrAr = 5.70 * 10^{-8} * e\left(\overline{T}_1{}^4 - \overline{T}_3{}^4\right) * Ar$$

$$\boldsymbol{q_{rad1}} = WrAr = 5.70 * 10^{-8} * 0.89\left(\overline{T}_1{}^4 - \overline{T}_3{}^4\right) * 4.63\ m^2$$

$$\boldsymbol{q_{rad1}} = 5.70 * 10^{-8} * 0.89(95^4 - 50^4) * \ 4.63\ m^2$$

$$\boldsymbol{q_{rad1}} = 17.54 \text{ W}$$

Opposing busbar faces have no radiation heat dissipation as it is assumed their temperatures are approximately equal.

3.6.3 Heat Absorbed by Enclosure

Heat generated by the bus bar is absorbed by the enclosure via the following methods:

a. Convection and
b. Radiation.

The rate at which heat is absorbed by the enclosure is equal to the rate at which electrical power is generated by the busbars, and is described in equation 3.13 below.

$$p = q_{conv1} + q_{rad1} \tag{3.13}$$

Where

p = power dissipated per unit length of busbars, W.

q_{conv1} = heat dissipated due to convention , W.

q_{rad1} = heat dissisipated due to radiation ,W.

3.6.3.1 Enclosure Heat Absorbed by Convection

The rate at which heat is transferred via convection within a cavity (dissipated by the busbars, absorbed via the enclosure) depends on the shape, size and temperature difference between surfaces. Convection heat absorbed by the enclosure differs from vertical to horizontal surfaces, as described in Equation 3.14 below.

$$q_{conv1} = h_{v1}A_v + h_{t1}A_{t1} \tag{3.14}$$

Where

h_{v1}= average vertical convection heat transfer coefficient, W/m^{2}k.

h_{t1} = average top convection heat transfer coefficient, W/m^{2}k.

A_v= vertical surface area of enclosure, m.

A_{t1}= top surface area of enclosure, m.

Convection heat absorbed by a vertical plane can be calculated through the use of equations 3.15, 3.16 and 3.17 below.

$$Ra_{v1} = \frac{g\beta(\bar{T}1 - \mathrm{T}3)}{v\propto} {G_1}^3 \qquad 3.15$$

$$\overline{Nu}_{v1} = 0.22\left(\frac{pr}{0.2+pr}Ra_{v1}\right)^{0.28}\left(\frac{H}{G_1}\right)^{-1/4}\begin{bmatrix} 2 \leq \frac{H}{G_1} \leq 10 \\ P_r \leq 10^5 \\ 10^3 \leq R_a \leq 10^{10} \end{bmatrix} \qquad 3.16$$

$$\bar{h}_{v1} = \frac{\overline{Nu}_{v1}}{H} K \qquad 3.17$$

Where

Ra = Rayleigh number.

$\bar{N}_u$ = average Nusselt number.

g = gravity constant, 9.8m/s^2.

β = volumetric thermal expansion coefficient, K^{-1}.

$\bar{T}_1$ = average temperature of busbar, K.

$\bar{T}_3$ = average temperature of the enclosure inner surface, K.

H = height of the enclosure, m.

G = gap between busbars and enclosure wall, m.

V = kinematic viscosity, m^2/s= $15.89 \ast 10^{-6}$m^2/s.

α = thermal diffusivity, m^2/s = $22.5 \ast 10^{-6}$m^2/s.

Pr = Prandtl number = 0.707.

k = thermal conductivity, W/m.K.

$$Ra_{v1} = \frac{g\beta(\bar{T}1-\mathrm{T3})}{v\propto} G_1{}^3 = \frac{9.8*0.0036*45}{15.89*10^{-6}*22.5*10^{-6}} 0.006^3 = 485.6*10^3$$

$$\overline{Nu}_{v1} = 0.22\left(\frac{pr}{0.2+pr}Ra_{v1}\right)^{0.28}\left(\frac{H}{G_1}\right)^{-1/4}$$

$$= 0.22\left(\frac{0.707}{0.2+0.707}485.6*10^3\right)^{0.28}\left(\frac{2}{0.006}\right)^{-1/4}$$

$$\overline{Nu}_{v1} = 1.877$$

$$\bar{h}_{v1} = \frac{\overline{Nu}_{v1}}{H}K = \frac{1.877*}{2}26.3*10^{-3} = 0.024\,\mathrm{W/m^2k.}$$

Similarly, convection heat absorbed by a horizontal plane, when heated from below, can be calculated through the use of equations 3.18, 3.19 and 3.20 below.

$$Ra_{t1} = \frac{g\beta(\bar{T}1-\mathrm{T3})}{v\propto} G_2{}^3 \qquad 3.18$$

$$= \frac{9.8*0.0036*45}{15.89*10^{-6}*22.5*10^{-6}} 0.006^3 = 485.6*10^3$$

$$\overline{Nu}_{t1} = 0.069Ra^{1/3}{}_{t1}\,p_r{}^{0.074} 3X10^5 \le R_a \le 7X10^9 \qquad 3.19$$

$$\overline{Nu}_{t1} = 0.069(485.6*10^3)^{1/3}0.707^{0.074} = 5.26$$

$$\bar{h}_{t1} = \frac{\overline{Nu}_{t1}\,k}{H} \qquad 3.20$$

$$\bar{h}_{t1} = \frac{5.26*}{2}26.3*10^{-3} = 0.069\,\mathrm{W/m^2.}$$

$$q_{conv1} = h_{v1}A_v + h_{t1}A_{t1}.$$

$$q_{conv1} = 0.024 * 4.63m^2 + 0.069 * 4.63m^2$$

=0.43059 W.

3.6.3.2 Enclosure Heat Absorbed by Radiation

The rate at which heat is absorbed by the enclosure, via radiation dissipated by the busbars, is proportional to the fourth power of their absolute temperatures and the relative emissivity between the busbars and the enclosure. Enclosure radiation heat absorption is equal to the radiation heat dissipation from the busbar as described in previous section.

3.6.4 Heat Conduction through Enclosure Wall

Heat generated within the enclosure passes through the enclosure walls via the following method.

1. Conduction

The rate at which heat is conducted through the walls of the enclosure is equal to the rate at which electrical power is generated by the busbars. This is described in Equation 3.21, 3.22 and 3.23 below.

$$p = q_{conv} \tag{3.21}$$

$$q_{cond} = k_t A \frac{\Delta T}{\Delta X} \tag{3.22}$$

$$\Delta T = \bar{T}_3 - \bar{T}_4 \tag{3.23}$$

Where

P = power dissipated per unit length of busbar, W.

q_{cond} = heat conducted through enclosure wall, W.

k_t = enclosure thermal conductivity, W/mK.

A = surface area of enclosure, m^2.

$\bar{T}_3$ = average temperature of the enclosure inner surface, K.

$\bar{T}_4$ = average temperature of the enclosure outer surface, K.

Δx = enclosure wall thickness, m.

$q_{cond} = k_t A \frac{\Delta T}{\Delta X}$ =26.3 $*10^{-3} * 4.63m^2 \frac{*5}{0.006}$ =101.5W.

3.6.5 Heat Dissipated by Enclosure

Heat generated within the enclosure passes through the enclosure walls and is dissipated via the following methods:

a. Convection and
b. Radiation.

The rate at which heat is dissipated per unit length of enclosure is equal to the rate at which electrical power is generated per unit length of busbar, and is described in equation below.

$$p = q_{conv2} + q_{rad2}$$

Where

P = power dissipated per unit length of bus bar, W

q_{conv2} = heat dissipated from enclosure due to convection, W

q_{rad2} = heat dissipated from enclosure due to radiation, W

3.6.5.1 Enclosure Heat Dissipated by Convection

The rate at which heat is dissipated via convection depends on the shape, size and temperature rise above ambient of the enclosure's outer surface temperature. Convection heat dissipation from the enclosure differs from vertical to horizontal surfaces as described in equation 3.24 below.

$$q_{conv2} = \bar{h}_{v2} A_v \ + \ \bar{h}_{t2} A_t \qquad 3.24$$

Where

h_{v2}= vertical average convection heat transfer coefficient, W/m^2.K.

h_{t2}= top average convection heat transfer coefficient, W/m^2.K.

A_v= vertical surface area of enclosure, m^2.

A_t= top surface area of enclosure, m^2.

Convection heat dissipation from a vertical plane can be calculated through the use of Equations 3.25, 3.26 and 3.27 below

$$Ra_{v2} = \frac{g\beta(\bar{T}_4-\bar{T}_5)H^3}{v\alpha} \qquad 3.25$$

$$Ra_{v2} = \frac{9.8*0.0036*21}{15.89*10^{-6}*22.5*10^{-6}}2^3 = 16.57*10^9$$

$$\overline{Nu}_{v2} = 0.68 + \frac{0.670Ra^{1/4}{}_{v2}}{\left[1+\left(0.492/pr\right)^{9/16}\right]^{4/9}} Ra_{v2} \leq 10^9 \qquad 3.26$$

$$=0.68 + \frac{0.670(16.57*10^9)^{1/4}}{\left[1+\left(0.492/0.707\right)^{9/16}\right]^{4/9}} = 1.716*10^9$$

$$\bar{h}_{v2} = \frac{\overline{Nu}_{v2}\ k}{H} \qquad 3.27$$

$$= \frac{1.716*10^9}{2} \quad 26.3*10^{-3} = 22.66*10^3 \text{W/m}^2\text{k}$$

Where

R_a = Rayleigh number.

N_u = average Nusselt number.

g = gravity constant, 9.8m/s^2.

B = volumetric thermal expansion coefficient, K^{-1}.

T_4 = average temperature of the enclosure outer surface, K.

T_5 = temperature of the enclosure surroundings, K.

H = height of the enclosure, m.

V = kinematic viscosity, m^2/s.

A = thermal diffusivity, m^2/s.

Pr = Prandtl number.

k = thermal conductivity, W/mK.

Similarly, convection heat dissipation from the top surface of a horizontal plane can be

Calculated through the use of Equations 3.28 and 3.29 below.

$$\overline{Nu}_{t2} = \frac{\bar{h}_{t2} L_c}{k} = 0.54 Ra^{1/4}{}_{t2} \qquad 3.28$$

$$lc = \frac{A_t}{p} \qquad 3.29$$

Where

L_c =horizontal plane Nusselt correlation number.

A_t= enclosure top surface area perimeter, m.

$L_c = \frac{A_t}{p} = \frac{4.63m}{8m}$ =0.579.

$\overline{Nu}_{t2}$ = $0.54(16.57 * 10^9)^{1/4}$ =0.54(358.78) = 193W/m^2.K.

$\bar{h}_{t2} = \frac{\overline{Nu}_{t2} * K}{lc} = \frac{26.3 * 10^{-3} * 193}{0.579}$ =8.67W/m^2.K.

$q_{conv2} = \bar{h}_{v2} A_v + \bar{h}_{t2} A_t$

=$22.66 * 10^3$W/m^2k *4.63m^2 +8.67W/m^2.K *4.63m^2

q_{conv2}= 104.9KW.

3.6.5.2 Enclosure Heat Dissipated by Radiation

The rate at which the enclosure's heat is dissipated into its surroundings via radiation is Proportional to the temperature difference between the enclosure and its surroundings, as described in Equation 3.29 and 3.30 below

$$q_{rad2} = \bar{h}_{rad}\, A3.27 \qquad 3.29$$

$$\bar{h}_{rad2} = \varepsilon\sigma(\bar{T}_4 + T_5)(\bar{T}^2{}_4 + {T_5}^2) \qquad 3.30$$

Where

$\bar{h}_{rad2}$ = average radiation heat transfer coefficient, W/m^2.K.

A = surface area of enclosure, m^2.

ε = enclosure surface emissivity.

σ = Stefan-Boltzmann constant, 5.67x10^{-8}W/m^2.K^4.

T_4 = average temperature of the enclosure outer surface, K.

T_5 = temperature of the enclosure surroundings, K.

$$\bar{h}_{rad2} = 0.1 * 5.67\text{x}10^{-8}(318 + 297)(318^2 + 297^2)$$

$$\bar{h}_{rad2} = 0.66\text{W/m}^2\text{.K.}$$

$$q_{rad2} = \bar{h}_{rad}\, A$$

$$q_{rad2} = 0.66 * 4.63 = 3.0558\text{W.}$$

The enclosure surface emissivity is determined by the enclosure surface finish. A surface finish emissivity closer to that of a black body will dissipate more heat via radiation into its surroundings**.**

From mathematical temperature calculation of current carrying capacity of busbar total loss observed in the GIS is with in limit according to the IEC 60439 standards.

3.7 Volume of SF6

SF6 can play a great role in compactness of GIS by minimizing clearance between phase, phase and ground in addition to this its dielectric strength is five time than air. It's rigorous to find gas insulated substation area without knowing volume of SF6. Volume of SF6 is assumed by the volume of enclosure which is cylindrical in shape minus the inner volume of busbar.

$$V = \pi r^2 h \qquad 3.31$$

$V =$ 3.14 (0.318m) ^{2} *2m = 0.635m^3. The outer volume (volume of the enclosure)

The volume taken by busbar is calculated by:

$V = \pi r^2 h$= 3.14 (0.0.01m) ^{2} *2m = 0.000628m^3 volume of busbar.

Volume of SF6 = Volume of enclosure - Volume of busbar

$$V_{SF6} = 0.635\text{m}^3 - 0.000628\text{m}^3$$

$$V_{SF6} = 0.634372\ \text{m}^3$$

The volume of SF6 would be 0.634372 m^3 which is very essential to find the area of enclosure which can play the great role for the size of substation and also the annual gas leakage of SF6 rate is less than 0.1 percent, this is one of the reason SF6 is preferred for insulation and quenching purpose.

3.8 Short Circuit Rating Design

A short circuit in a power system is clearly not a steady state condition. Such an event can initiate a variety of different dynamic phenomena in the system. However, when it comes to calculate the fault currents in the system, steady state (static) models with appropriate parameter values can be used. A fault current consists of two components, a transient part, and a steady state part, but since the transient part can be estimated from the steady state one, fault current analysis is commonly restricted to the calculation of the steady state fault currents [29].

When a short circuit fault occurs in a substation, the amount of current that flows toward that location depends on the source impedance of the system feeding that fault [29]. The magnitude of the current that may flow when a fault occurs at substation is known as the fault level at that point. A high fault level is undesirable due to the heating effect and electromagnetic forces produced by the fault current. Thus, it is clear that the switchgear controlling the faulted circuit must be rated adequately to interrupt the fault current.

Depending on the network location, different levels of short-circuit ratings are found depending on how far the fault is from the power plant and substation.

A GIS short circuit rating has to fulfil two requirements:

- To withstand the electromagnetic forces between conductor and ground.
- To limit the maximum conductor temperature due to the high current.

3.8.1 Power Transformer Parameters

The EEP network that provide supply for railway substations have a transformer with capacity of 25MVA, impedance percentage 10% and132kV/15kV.Depending on these data the grid short circuit capacity and equivalent impedance are calculated as follows.

Transformer full load current, $\mathrm{IF_L} = \frac{\text{TransformerMVA}}{\sqrt{3}\ \text{Secondary Voltage}} = \frac{25MVA}{\sqrt{3}\ 15KV}$ = 962.25A.

The short circuit current referred to secondary side becomes the ratio of full load current to impedance percentage.

$I_{Sc} = \frac{full\ load\ current}{\%\ of\ impedance} = \frac{962.25A}{0.1}$ = 9,622.5A =9.6225KA.

The short circuit capacity MVA,

$$MVA_{Sc} = \sqrt{3}\, V_{sec} I_{Sc} = \sqrt{3} * 15KV * 9.6225KA = 250MVA.$$

The equivalent supply reactance referred to the transformer secondary side is given by;

$Z_s = \frac{V^2{}_{sec}}{MVA_{Sc}} = \frac{(15KV)^2}{250MVA}$ =0.9Ω.

From the ANSI Standard C37.010, the X/R ratio for the transformer capacity of 25MVA is equal to 24. Taking this value for X/R, the equivalent source reactance and resistance will be determined from the equation,

$$Z^2 = X^2 + R^2$$

Through long calculation R=0.0375Ω and X=0.899Ω.

The transmission line parameters considered in this thesis are taken from EEP data collected. The impedance of the system for this typical case is:

Z= (1.98 +j3.291) Ω

The short circuit current for a system is given by

$$i(t) = i_{ac}(t) + i_{dc}(t) \qquad 3.32$$

$$= \sqrt{2}\frac{v}{Z}\left[sin(wt + \alpha - \theta) - \sin(\alpha - \theta e^{\frac{-t}{T}})\right] A \qquad 3.33$$

Where

$$i_{ac}(t) = \sqrt{2}\frac{v}{Z}[sin(wt + \alpha - \theta)] \text{ A} \qquad 3.34$$

$$i_{dc}(t) = \sqrt{2}\frac{v}{Z}\sin(\alpha - \theta e^{\frac{-t}{T}}) \text{ A} \qquad 3.35$$

$$\text{Z}= |R + j\omega l| = \sqrt{R^2 + X^2}\,\Omega \qquad 3.36$$

$$\theta = arctan\frac{X}{R} \qquad 3.37$$

$\theta = impedance\ angle.$

α =Initial phase displacement (offset) angle of the source voltage v (t)

Assume initial phase displacement is zero

$\theta = arctan\frac{X}{R} \quad = arctan\frac{3.291}{1.98} = 58.4$

$i_{ac}(t) = \sqrt{2}\frac{v}{Z}[sin(wt + \alpha - \theta)]$ A

$= \quad \sqrt{2}\frac{132KV}{3.84}[sin(2\pi * 50 * 0.1 + 0 - 58.4)]$

= 21.7KA.

The short circuit current of the system is 21.7kA which is cleared at 0.1 seconds.

3.9 Cost Comparison between GIS and AIS

Since the liberalization of the energy markets in the late 90s of the last century, the application of GIS becomes more important for the energy supply companies. With the use of GIS energy supply companies want to reduce their operating and maintenance costs.

In this thesis, the cost impacts of AIS and a typical Shiro Meda 132 kV GIS on the switchgear system is compared. The results depict the main cost-drivers as well as the most important elements of the system. Furthermore, it is shown how costs can be reduced by the application of different maintenance strategies. AIS stand out due to low investment costs, but on the other hand they are more susceptible to outer disturbances which has a negative effect on their operating costs. GISs, however, have high investment costs, but have a lower susceptibility and there with lower operating costs due to their encapsulated design. The result is compared with the help of the life cycle cost method (LCC-Method).

Life cycle costing is the process of economic analysis to assess the total cost of acquisition, ownership and disposal of a product. System cost of ownership is divided into scheduled, unscheduled maintenance and outage cost. A system failure results penalty cost for undelivered energy (including profit losses) and component replacement cost. The probability of an outage can be reduced by higher redundancy or by technologies with lower component failure probabilities. The greatest advantage of LCC-Method is that all costs of the system are included and taken into account over the complete life time.

The calculation of LCC in this thesis is performed in accordance to IEC 60300-3-3 “Dependability management Part 3-3: Application guide – Life cycle costing” [44].Within this standard, all cost units of components are clearly defined and sub-divided into the following six cost-causing phases:

a) Concept and definition;

b) Design and development;

c) Manufacturing;

d) Installation;

e) Operation and maintenance;

f) Disposal.

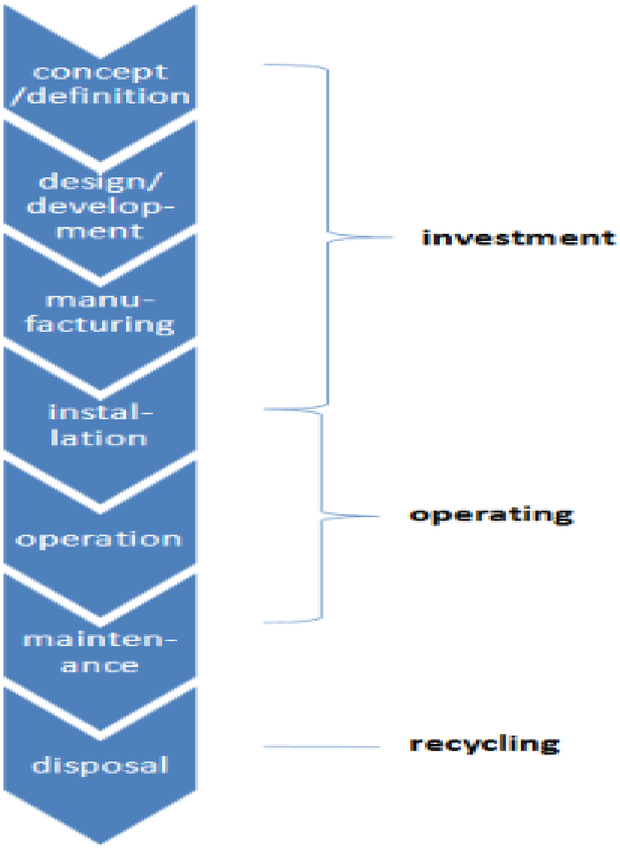

Figure3.5 Life cycle phases on the basis of IEC Standard 60300-3-3 [30].

When analyzing these six cost-causing phases, it makes sense to combine different cost elements into following three cost brackets:

- Investment.
- Operating.
- Recycling.

The main difference between investment (concept/definition, design/development, manufacturing, installation) and operating (operation, maintenance) costs is that the former cost group is already known before the investment is made. Installation costs form a special case, as they can be counted to either investment or operating costs [30].

The definition of all investment cost includes secondary equipment and land cost since both items are related to the component cost.

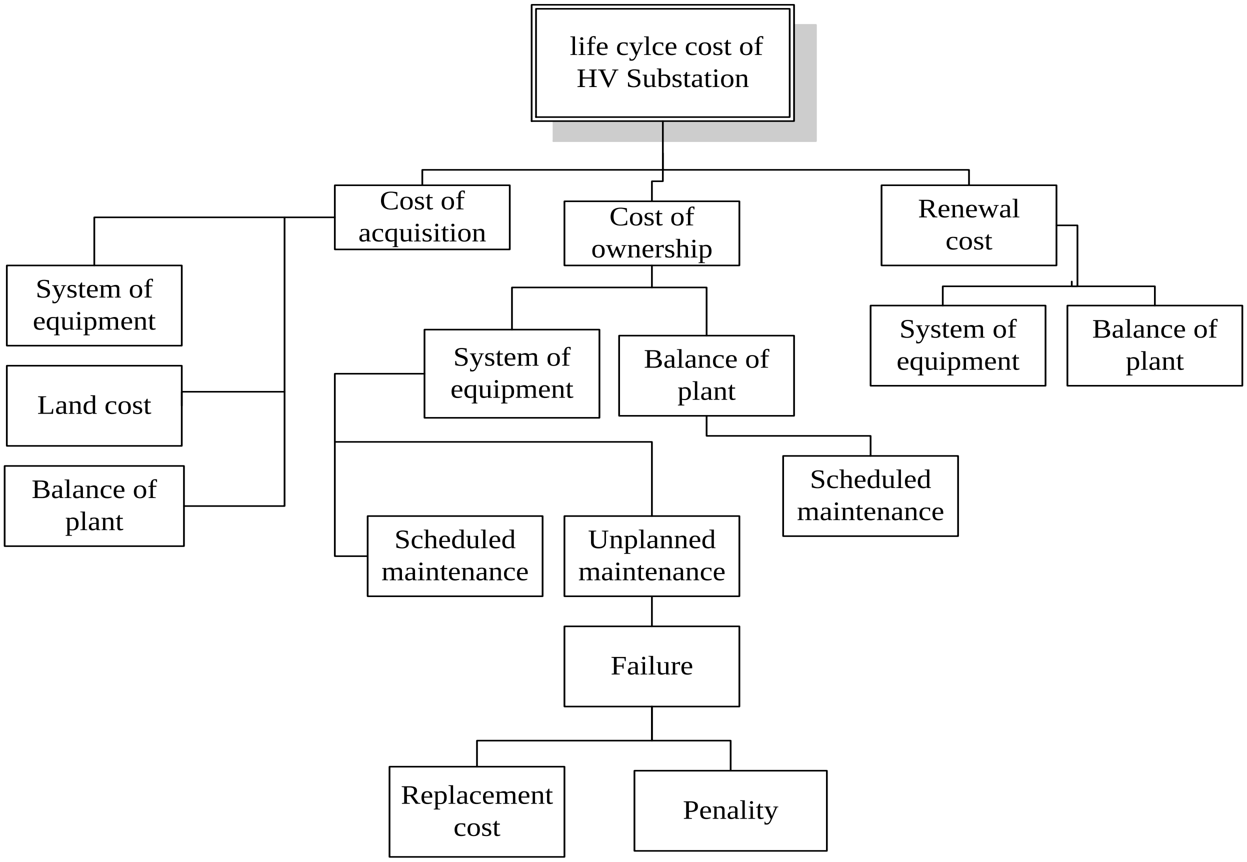

Figure 3.6 life cycle cost of high voltage substation.

Where

- The costs for system and equipment refer to primary equipment, secondary equipment and engineering.
- The costs for balance of plant consider buildings for secondary and primary equipment respectively portals, gantries, supporting structures, foundations earthing, secondary cabling transport, installation, commissioning.
- The costs shares for scheduled maintenance comprise maintenance of balance of plant and maintenance of system and equipment respectively.

For a better understanding the following terms are used to explain the different expenses:

- ❖ Concept/definition: Costs incurring in connection with the concept during the specification or planning phase.
- ❖ Design/development: Costs for design, documentation and engineering.
- ❖ Manufacturing: These costs contain the expenses for production and sale of the product on the contractor side. Therefore they represent the order value of the whole distribution system.
- ❖ Installation: Costs generated on site by installation before the system goes into operation.
- ❖ Operation: Costs arising for a sustainable operation of the whole system. Among other things these costs include expenses for power losses of overhead lines or transformers, controlling and staff training.
- ❖ Maintenance: Calculation of the complete maintenance expenditures due to different strategies e.g. time based, condition based or corrective.
- ❖ Disposal: Costs for work, material and disposal in conjunction with the decommissioning of the existing system. For example, charges for cultivation of overhead line traces are included. Possible profits in the disposal of steel, copper etc. have to be deducted as credit notes of the charges.

Final calculation is done based on the data collected from EEU. The details of cost used by both substation is mentioned in table below.

Table3.4 Cost comparison between AIS and GIS.

Cost name	**Cost of AIS**	**Cost of GIS**
Investment cost		
Land cost (75,000.00ETB/m^2)	123,750,000.00 ETB	11,550,000.00 ETB
Design Service	1,627,550.00 ETB	3,053,000.00 ETB
Installation and other service	1,774,569.00 ETB	3,903,549.00 ETB
Total Cost of each components	23,828,708.50 ETB	28,376,129.50 ETB
Estimated Operation Cost		
Unscheduled Maintenance cost (50 years)	12,500,000.00 ETB	1,000,000.00 ETB
TOTAL	163,480,827.50 ETB	47,882,678.50 ETB

Note: Unscheduled Maintenance cost per year for AIS is estimated to be 250,000.00 ETB taking in to account experts might be invited and for GIS 20,000.00ETB. The land cost is taken average between 7000.00ETB/m^2 to 305,000.00ETB/ m^2 which is 75,000.00 ETB/m^2 for different location here in Addis Ababa. The detail costs of each component are attached on the appendix A for AIS and appendix B for GIS.

Further data has to be used for the calculation of the LCC by the following formula.

The life cycle cost$C_{LC}(t)$ as described above, is given by

$$C_{LC}(t) = C_A(t) + C_O(t) + C_R(t) \qquad 3.35$$

Where

$C_{LC}(t)$ = Life Cycle Cost

$C_A(t)$ =Cost of Acquisition

$C_O(t)$ =Cost of Operation

$C_O(t)$ =Cost of Recycle

$C_{LC\ for\ AIS}(t)$ = (123,750,000.00 + 12,500,000.00 + 1,627,550.00 + 1,774,569.00 + 23,828,708.50) ETB

= **163,480,827.50 ETB**

$C_{LC\ for\ GIS}(t)$ = (11,550,000.00 + 3,053,000.00 + 3,903,549.00 + 1,000,000.00 + 28,376,129.50) ETB

= **47,882,678.50 ETB**

The operation cost $C_O(t)$ can be calculated by,

$$C_O(t) = C_M(t) + C_F(t) \qquad 3.36$$

Where

$C_M(t)$ = the maintenance and

$C_F(t)$ = the failure cost

The failure cost $C_F(t)$ is a summation of

$$C_F(t) = C_{CR}(t) + C_P(t) \qquad 3.39$$

Where;

$C_{CR}(t)$ = Component replacement cost

$C_P(t)$ = penalty cost for undelivered energy

Since there is no regulation for penalization during there is no light here in our country the author only reflected the LLC for acquisition, operation and recycling cost which are the major costs. Under operation cost only maintenance cost is studied.

For evaluation of the total life cycle costs, different costs are accumulated for up to 50 years for both substations. For GISs the maintenance cost is smaller where as for AIS maintenance cost and land cost is very high compared to GIS.

From table 3.4 the Author conclude that, the cost of GIS is Expensive on initial investment like design and installation service and cheaper by land cost and unscheduled maintenance when compared to AIS. But the overall cost GIS is cheaper than AIS especially relying on the land cost found in Addis and around Addis Ababa

Table 3.5 gives an overview of land costs for 132kV GIS and AIS. The costs are related to the investment costs and take into account three cost categories. For installation in rural areas land cost of 300 ETB/m^2, in moderate urban areas like Adama 3000 ETB/m^{2}and in expensive urban areas 75,000 ETB/m^{2}like Addis Ababa were assumed. As to be seen, in moderate and expensive urban areas the land costs can become dominant.

Table 3.5 Average Land usage of AIS and GIS in percentage.

	AIS	GIS
Rural	2	Not necessary
Moderate urban	17	2
Expensive urban	90	10

For moderate urban areas the LCC costs including land costs are comparable for GIS and AIS. In expensive urban areas the LCC costs are mainly affected by the land costs. In consequence the GIS solution becomes clearly more economic.

CHAPTER FOUR

4 SIMULATION RESULT AND DISCUSSION

4.1 Introduction

This section of the thesis is aimed at studying and analyzing how different operating Conditions of under voltage for load flow analysis and short circuit will affect the substation under the study. The purpose of this simulation is to evaluate load flow analysis and short circuit analysis performance of designed GIS for Shiro Meda case study. The research work highlights the effective use of advance software Electrical Transient Analyzer Program (ETAP). ETAP offers a suite of fully integrated electrical engineering software solutions including arc flash, load flow analysis, short circuit analysis, transient stability, relay coordination, cable capacity, optimal power flow, and more. Its modular functionality can be customized to fit the needs of any company, from small to large power systems by using adaptive Newton Raphson iteration up to iteration of 99 with precise 0.0001. The first step in simulating a GIS is creating a model (single line diagram) that represents components of a system by using an existing blocks or tools in the Electrical Transient analyzer program or from those created by the user. Then the analysis is done for load flow and short circuit which include different cases.

4.2 Load Flow Analysis

Power flow (load) analysis are used to calculate various bus voltages, current, and active and reactive power flow along the transmission system and also Power flow analysis is used to determine the condition of a power system operating at steady state [33]. The purpose of power flow studies is to plan ahead and account for various hypothetical situations. For example, if a transmission line is be taken off line for maintenance, can the remaining lines in the system handle the required loads without exceeding their rated values. Power flow or load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. In this thesis design analysis of 132/15 kV GIS. ETAP software is carried out with an approach to overcome the problem of an under voltage. Load Flow Studies using ETAP software is an excellent tool for system planning.

A number of operating procedures can be analyzed such as the loss of a transmission line, a transformer or a load. This can be used to determine the optimum size and location of capacitors to surmount the problem of an under voltage. Also, they are useful in determining the system voltages under conditions of suddenly applied or disconnected loads. Load flow studies determine if system voltages remain within specified limits under various contingency conditions, and whether equipment such as transformers and conductors are overloaded. It was often used to identify the need for additional.

4.3 Simulation Parameter for Substation under Study

Table 4.1 Simulation parameters.

No	Parameters	Rating
1	Source voltage/ grid system	132 KV
2	Cable	150 AAAC / cu 240 mm^2
2	Transformer	25MVA
3	Static load	13MVA
4	Dynamic load	14MVA
5	Frequency	50HZ
6	Circuit breakers	132KV, 1600A
7	Current transformers	**150-800/1 A**
8	Potential transformers	**$132/\sqrt{3}$, $0.1/\sqrt{3}$, KV**
9	Busbars	132KV

4.3.1 Single Line Diagram of 132kV Shiro Meda GIS

GIS model is developed for the maximum of 12 possible number of traction loads. Depending on the data collected from EEP for power transformer which is 25MVA.

Fig. 1 shows the overall single line diagram of GIS which takes grid power from Gefersa and North Addis Power Grid and sends to the 132 kV Bus 10 and Bus 11 respectively. 132kV/15kV, 25 MVA Power Transformer 1 supplies power to bus 5 while the other transformer gives it to bus 6.

Two feeders are emanating from Bus5 and the other two feeders are emanating from Bus 6 which are lumped load and static load.

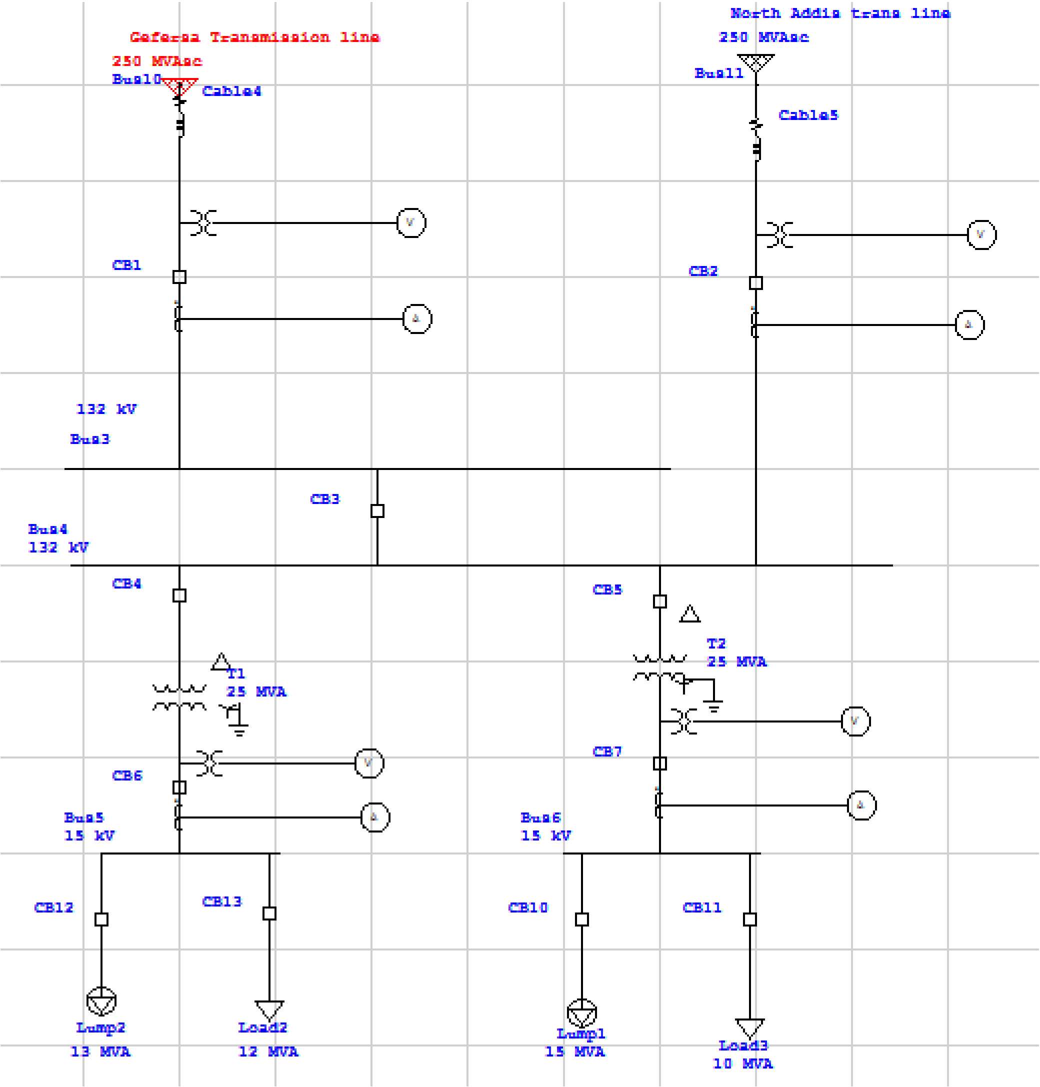

Figure 4.1 Single line diagram of gas insulated substation for the case of Shiro Meda

4.3.2 Simulation Result of Load Flow Analysis

The simulation of load flow analysis done by using simulation parameters. In this section, the results for the following cases are explored:

Case 1.When the system is under voltage

Case 2. When under voltage is corrected by capacitor bank

Figure 4.2 shows the Load Flow Analysis of the 132 kV substation carried out using ETAP in which Newton-Raphson method is used and it is observed that at the Bus5 and Bus 6 there is

Under voltage which can be clearly seen from Fig 4.2 showing the sectional view of the feeders. At Bus 5 the voltage level is 94.01% and at bus 6 the voltage level is 95.92%.

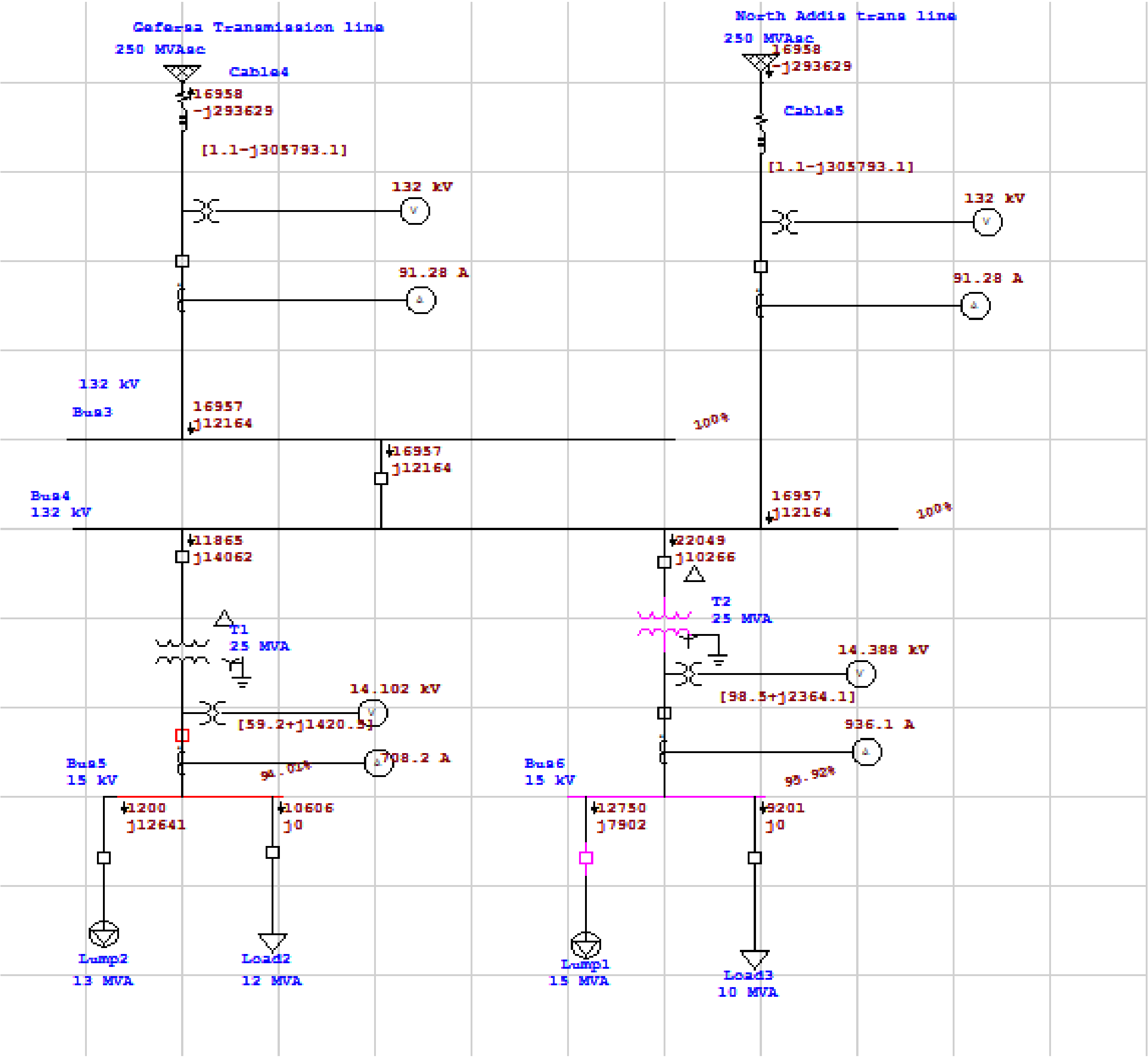

Figure 4.2 Load flow analysis of gas insulated substation

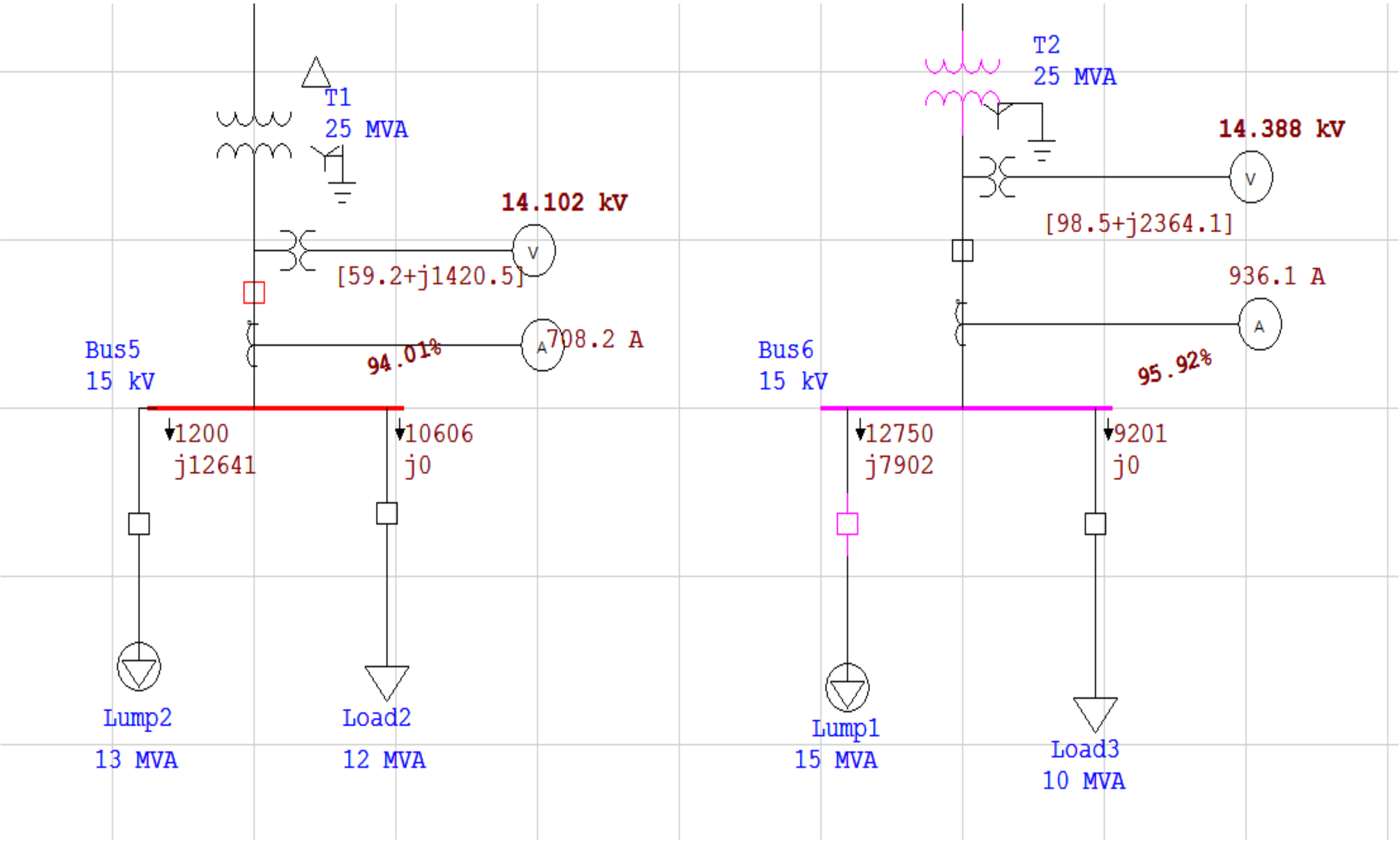

Figure 4.2 (a) Sectional view of substation for under voltage bus

4.3.2 ETAPs Alerts during Load Flow Analysis

Table 4.3 after carrying out load flow analysis using ETAP an alert summary report is generated which tells us which part of the system needs immediate attention and it can be clearly seen from the Table 4.2 that the Bus5 and Bus 6 are operating at an under voltage. Transformer 1 and 2 is also overloaded and also the following high voltage circuit breakers are overloaded.

Table 4.2 Alert report of load flow analysis for GIS

Device ID	Condition	Rating	Operating	% operating
Bus 5	Under voltage	15KV	14.102	94
Bus 6	Under voltage	15KV	14.388	95.9
CB 6	Over load	630 A	708.153	112.4
CB 10	Over load	630A	601.9	95.5
Transformer	Over load	25MVA	24.322	97.3

4.4 Load Flow Analysis with Power Factor Corrector to Overcome the Problem of Under Voltage

To improve the under voltage of the busbars it’s highly recommended to add a capacitor bank to buses 5 and 6. The simulation of the 132 kV substation is carried out in ETAP software by placing the capacitors in shunt with the feeders. The rating of a capacitor is calculated from the following equations:

Rating of Capacitor Bank

$$(\mathrm{MVAr}) = \mathrm{MW} * (\mathrm{Tan}(\phi 1) - \mathrm{Tan}(\phi 2)) \quad 4.1$$

Where $\phi 1$ and $\phi 2$ can be calculated by the following

For bus 5Cos $\phi 1$ = Existing Power Factor =0.7

$\phi 1 = \mathrm{Cos}^{-1}(0.7) = 35.9°$

Cos $\phi 2$ = Required Power Factor=0.95

$\phi 2 = \text{Cos}^{-1}(0.95) = 18.9°$

(MVAr) = MW * (Tan ϕ1 – Tan ϕ2) =34.58MW (tan (57.9) - tan (18.9))

= 16.956MW (0.625) =10Mvar

For bus 6

Cos ϕ1 = Existing Power Factor =0.7

$\phi 1 = \text{Cos}^{-1}(0.7) = 45.9°$

Cos ϕ2 = Required Power Factor=0.95

$\phi 2 = \text{Cos}^{-1}(0.95) = 18.9°$

(MVAr) = MW * (Tan ϕ1 – Tan ϕ2) =34.58 (tan (35.9) - tan (18.9))

= 21.951MW (0.324) =7.112Mvar

Under voltage is improved to 98.26 and 98.82 %for bus 5 and bus 6 respectively by using calculated capacitor bank

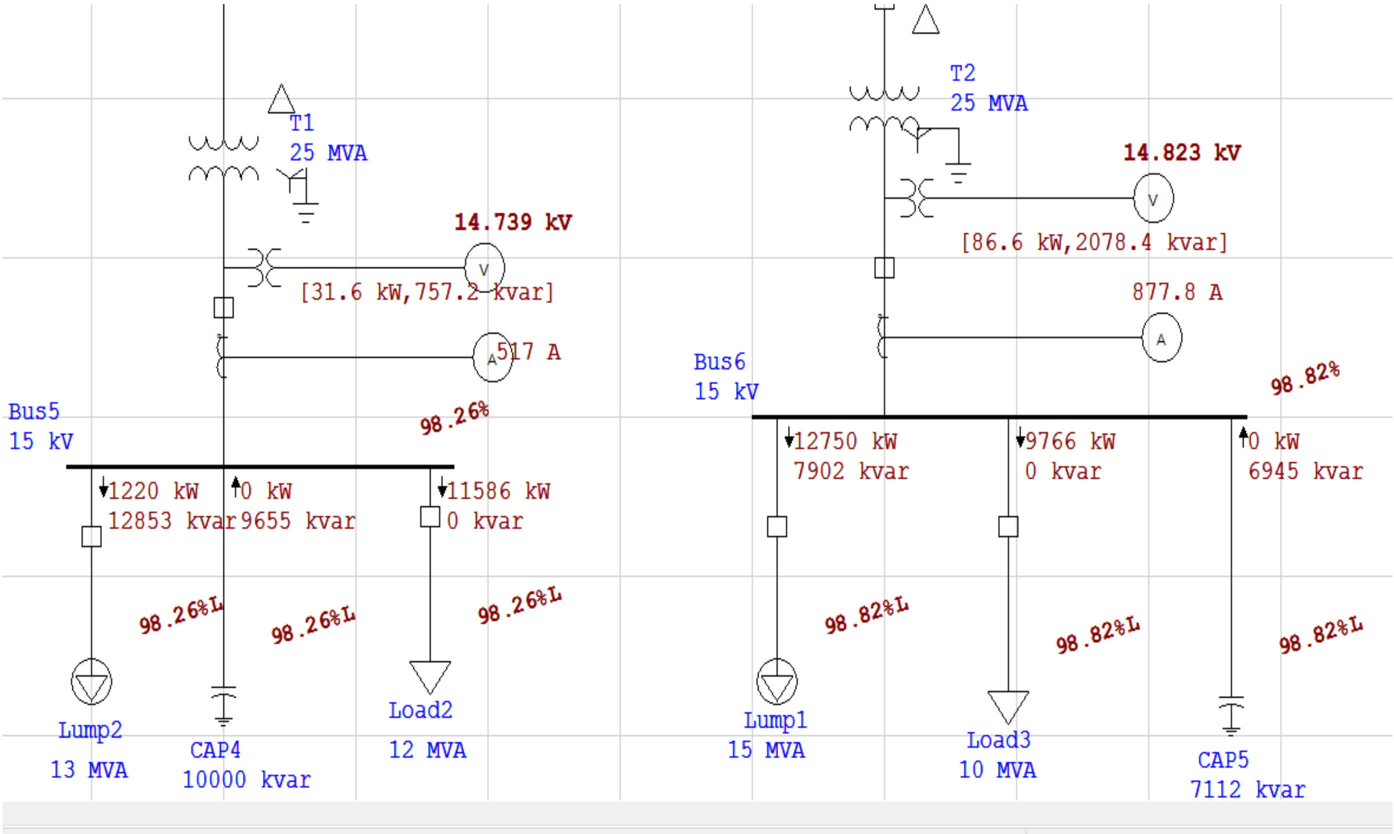

Figure 4.3 sectional view of substation with capacitor bank

From the above figure the author conclude that the previous under voltage is totally changed to normal operation after capacitor bank is inserted. Power factor of bus 5 and 6 is improved to 0.98 and 0.91 respectively.

4.5 Short Circuit Analysis

In this section, short circuit analysis is carried out by using ETAP. In electrical devices unintentional short circuits are usually caused when a wire's insulation breaks down, or when another conducting material is introduced, allowing charge to flow along a different paths than the one intended. In mains, short circuits may occur between two phases, between a phase and neutral or between a phase and earth (ground). Such short circuits are likely to result in a very high current and therefore quickly trigger an over current protection device. However, it is possible for short circuits to arise between neutral and earth conductors, and between two conductors of the same phase. Such short circuits can be dangerous, particularly as they may not immediately result in a large current and are therefore less likely to be detected. Possible effects include unexpected energisation of a circuit presumed to be isolated. A short circuit fault current can, within milliseconds, be thousands of times larger than the normal operating current of the system. Short circuit analysis discussion start with the following single line diagram. Different components are used with different rating based on IEC 60909 for short circuit between LL, LLG and LG, IEC61363 for run transient short circuit.

Fig.4.4 shows the sectional view of short circuit current flow Analysis of the 132kV substation carried out using ETAP. It is observed that at Bus 3 and Bus 4 there are fault currents of 275A and 580A respectively. At Buses 5 and 6 the respective currents are 11.69 kA and 10.91 kA. That means when 3 phase short circuit is happened on this bus the fault currents flowing from them are 11.69 kA and 10.91 kA respectively. Both the buses are connected with the help of tie breaker. The voltage level of 132 kV bus is decreased to 106.38 kV and the voltage level of 15KV kV bus is decreased to 8.09 kV and 8.8 kV. This short circuit is done with Reference of IEC60909. The manual calculation of this fault current is time consuming, but as ETAP software work on the both standards either ANSI or IEC the results are more accurate . These values give us the components rating which can be used to design condition as well as current condition of the protection system for the substations.

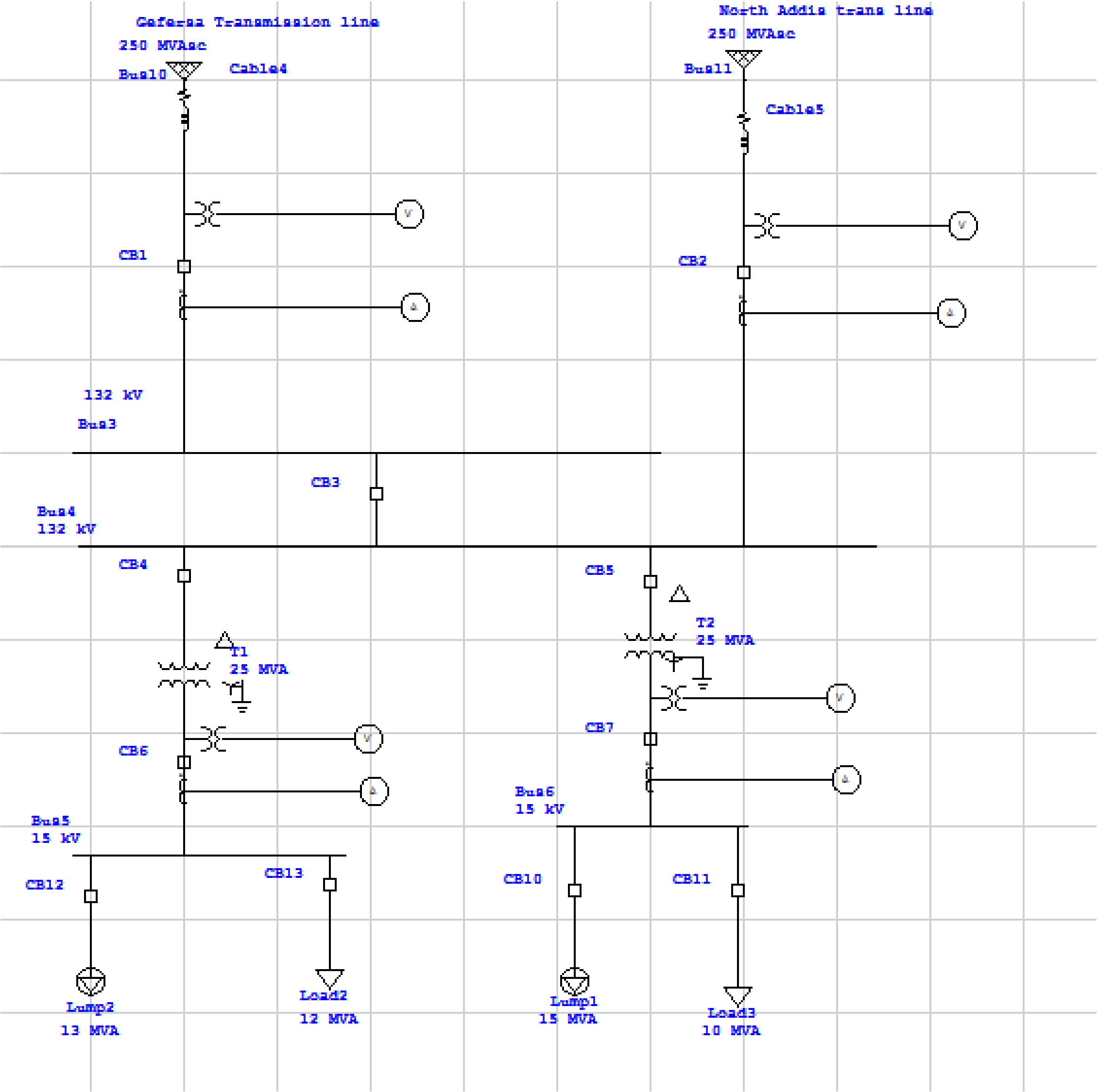

Figure 4.4 single line diagram of the 132 KV.

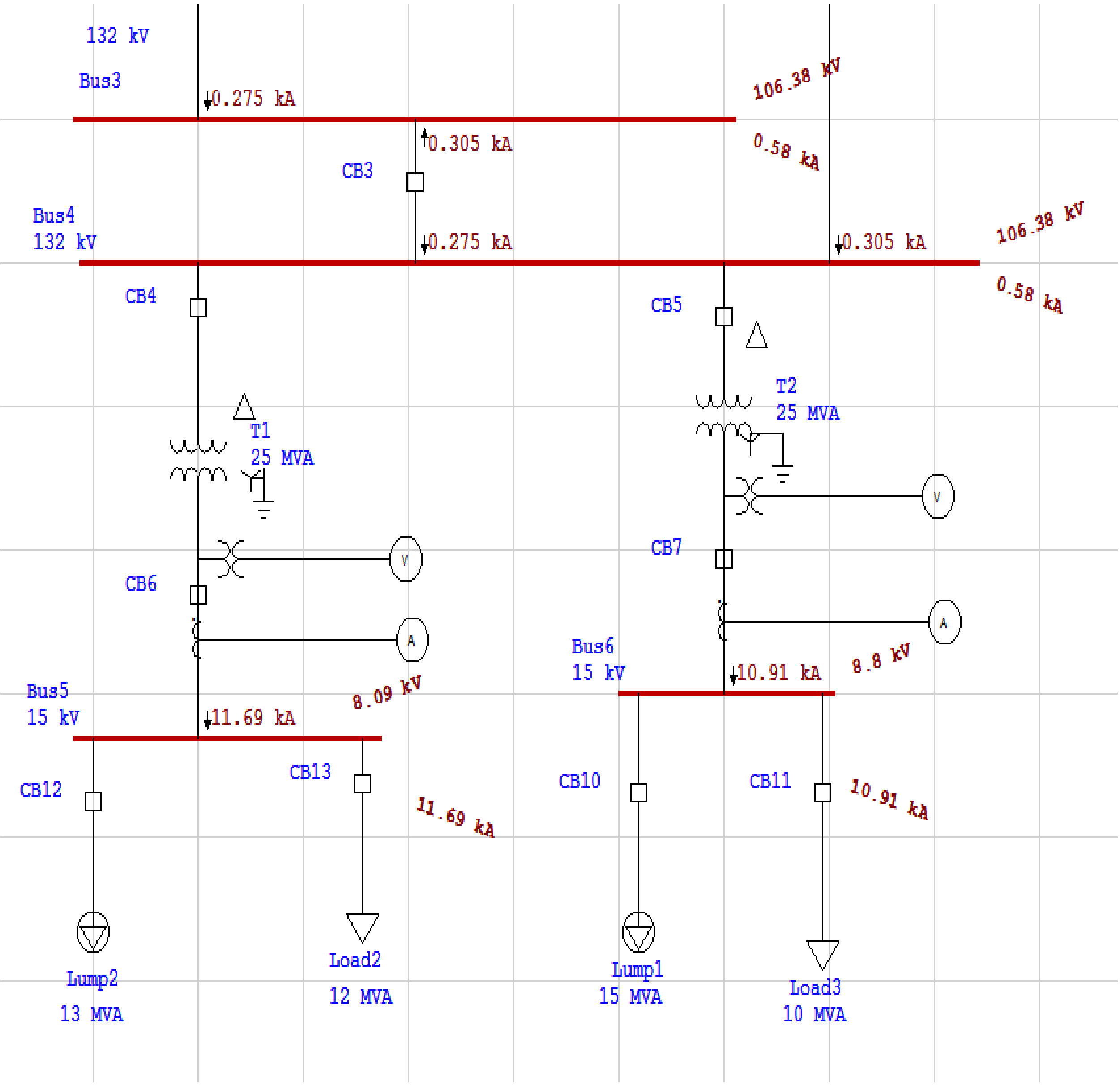

Figure 4.5 Sectional view of simulation for short circuit analysis of substation

Bus 3, 4, 5 and 6 are selected for fault the result is shown in the following wave

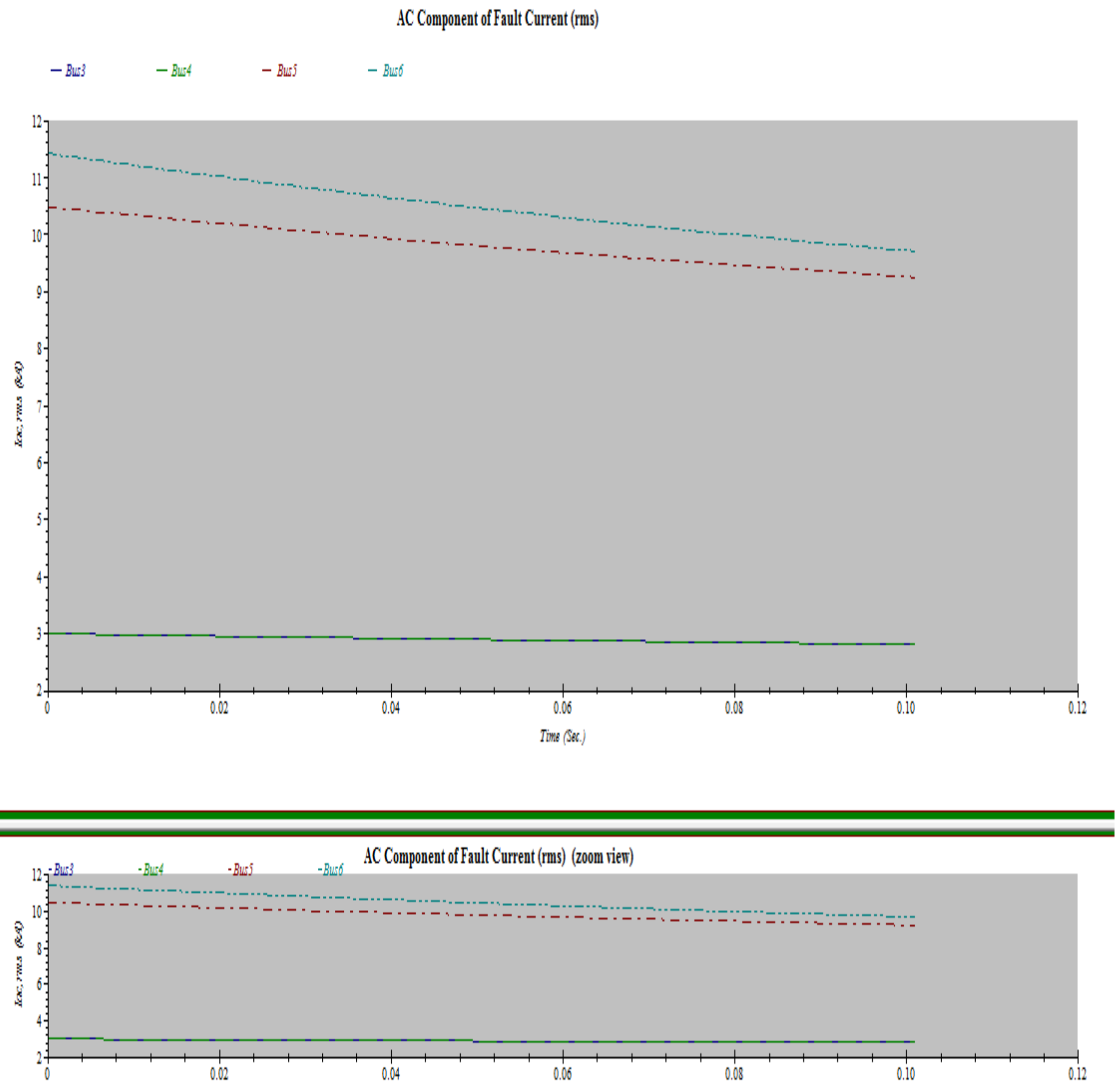

Figure 4.6 AC components of fault current

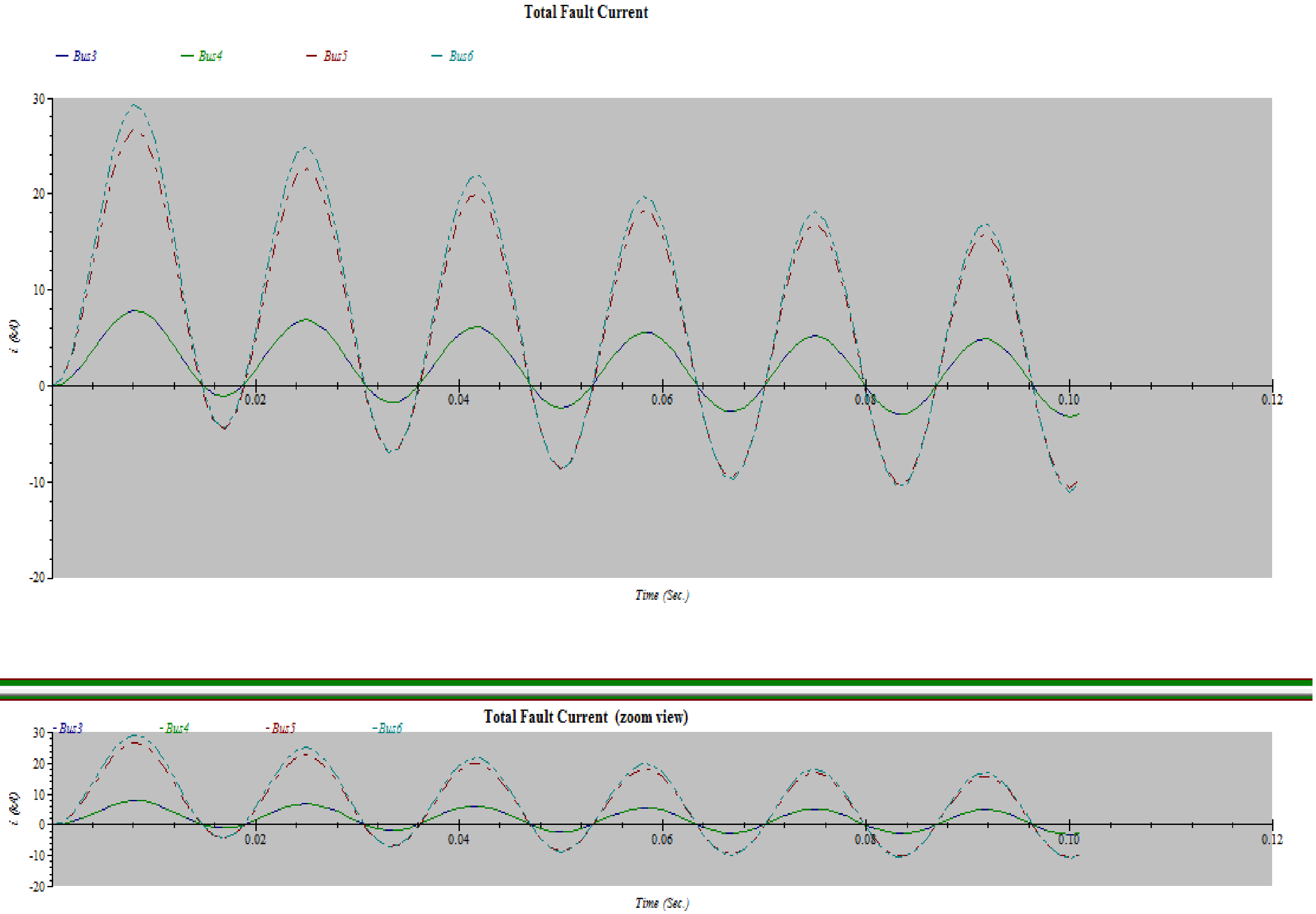

Figure 4.7 Overall short circuit simulation for bus 3, 4, 5 and 6

From the above figure, the maximum short circuit current recorded at bus 3,4,5 and 6 in the system cleared at 0.1s.

4.6 Summary of Finding

GIS, which becomes essential in this rapid energy demanding era, has inspired many with its varied characteristics. Apart from being compact, it provides a failsafe solution, economic solution and easier for both installation and maintenance. The tech savvy and aesthetic GIS can be adopted almost anywhere this days, which seemed a dream earlier. GIS has been used worldwide for many years because of its size and low maintenance cost. This has made it an attractive option in many applications. In addition to this, Safety and reliability are the two major concerns in the operation and design of any electrical power system. These concerns also pertain to the design of substations. To ensure substations are safety and reliability, the substation must have a properly designed grounding system. In case of GIS all metal enclosures are connected to ground. Therefore GIS can fulfill the requirement of 21st century substation design.

It has been noted that, Addis Light Rail has planned to expand its routes in different direction in the vicinity of Addis as time goes by. For this infrastructural development obviously demands more land, which is a scarce resource especially in Addis and around. Beyond this, the construction of AIS substations causes resettlement of the people. These AIS substations in turn has a bearing on economic, social and environmental costs. The project cost due to high mitigation and compensation payment becomes higher. The social cost is the psychological traumas that create in the parts of the displaced. The environmental cost is associated with clearing of the land for AIS substation construction and discharge of affluent substances during operation as well as aesthetic degradation due to its large transmission towers and lines. Unlike these GIS substations, are compact, do not require much space for its construction so that there is no heavy displacement of people by the project , economical, do not pose aesthetic degradation, social and environment for which both ISO 9000 & ISO 14000 accredited, to demonstrate world class management systems in both quality and environment friendly.

With regard to cost comparisons, the GIS substations have cost advantages over that of AIS substations for installation cost and site development cost (the site development costs for a GIS is lower than that of AIS because GIS is compact and require less space. The site development advantage of GIS increases as the system voltage increases, because high voltage AIS take very large areas to maintain long insulating distances between the conductors in atmospheric air. With respect to equipment cost the GIS substation require more due to its additional protective components like grounded metal enclosure, the provision of an LCC, and higher degree of factory assembly. Empirical evidence suggested that, cost comparisons on a total installed cost basis earlier for GIS was projected that, GIS costs would equal AIS costs at 345 kV. For higher voltages, GIS was expected to cost less than AIS. However, here in Addis Ababa since the cost of land is too expensive the cost of GIS at 132 kV is less than AIS.

GIS has been a well-established technology for a long time, with a proven high reliability, durability and least maintenance requirement, in spite of these, it is perceived costly and is only applicable in special cases where space is limited. Since Addis Ababa is both the capital city of the country and a sit for African union it becomes growing faster so that the author of this paper forecast the power demand for the city for the next five years to grow by 45%. This signifies that, on the one hand the energy ladder for the society will become upward i.e. they are using more electrical appliances more industries and factories will be opened and on the other hand, new substations will be required to meet the projected power demand. It is inevitable that these substations are GIS since the value of land in Addis is skyrocketing.

The Author finally observed the following from the methodology of the thesis and what physical of AIS and GIS of the study area.

- ✓ The earthed metal enclosure makes for safe working environment for attending personnel and elimination of interference.
- ✓ Compartmentalized enclosure of the live parts makes for very reliable system due to disruption of the insulation system by reducing the distance between active and non-active switch gear parts less space is required than the normal AIS system.

  This comes in handy in densely populated areas and unfavorable terrain (minimum requirements for AIS is about 1,650(55m*30m) for Ayat substation only for switchgear, while GIS with the same power properties will require about 154m^2(14m *11m). Therefore the Author can conclude that, AIS requires meters of air insulation to do what SF6 can do in centimeters in GIS.

  30m * 55m =1,650m^2

  1,650m^2* 75,000 ETB/m^2=123,750,000.00ETB

For GIS Area…11m * 14m = 154 m^2

154m^2*75,000ETB/m^2= 11, 550, 000.00ETB

- ✓ Height of substation also plays a very vital role undertaking the structural size. In AIS height of highest element of substation is 28m high. Meanwhile GIS has building height equal to 11m for 400kV substation. This can be helpful for beauty of the city as well in reducing the overall costs.
- ✓ By using AIS switchgears, risk of failures due to human error and environment aspect but none of mentioned AIS risk factor will not appear by using GIS.
- ✓ It is very much required to establish a substation at load center. Establishing a substation at load center is quite economical and profitable in following ways:
    - Reduction in length of feeder.
    - Improvement of the quality of voltage regulation due to short length feeders
    - Reducing the transmission losses and expenditure of distribution networks.

Generally main load center of any place is situated at very congested place where, sufficient land for establishing conventional AIS is very hardly available. This problem can be solved by using GIS technology taking in account the reason mentioned above GIS will be preferred for Addis Ababa city.

CHAPTER FIVE

5 CONCLUSION, RECOMMENDATION AND FUTURE WORK

5.1 Conclusion

This chapter discusses the main conclusions and recommendations via recalls the key parts of the work undertaken. Future research and recommendations are also proposed. In this thesis, design and simulation of 132kV GIS for electrified railway system for the case of Shiro Meda has been studied. GIS have been designed, short circuit simulations and load flow analysis were performed using the ETAPs power, and discussions were made based on the simulation results obtained with respect to voltage, current, active and reactive power.

A detailed background and literature survey of GIS and its major components such as SF6, circuit breakers, instrumental transformers, disconnectors, surge arrestors, busbars and power transformers which are the core of one substation. Mathematical method of temperature calculation for busbar of GIS designed beside this heat dissipated by bus bar and also heat dissipated and absorbed by enclosure through different heat transfer method are obtained. Accordingly comparison of space, maintenance and operation in terms of cost has been made for both substations.

Therefore, the result of the cost comparison for the space, maintenance and operation indicates that gas insulated substation is superior to AIS; as the result from the survey indicates maintenance, space and operating cost of GIS has reduced by 12.5, 90 and 92 Percent respectively when compared to AIS. Although, AIS substations in turn has a bearing on economic, social and environmental costs. In addition to this GIS is a part from being compact, it provides a failsafe solution, economic solution and easier for both installation and inspection. In account of all this result, it is possible to conclude that the objective for design and simulation of GIS for the case of Shiro Meda has met. Besides it is inevitable that these substations are GIS since the value of land in Addis is skyrocketing.

5.2 Recommendation

Based on the result of this thesis work, it is strongly recommended that the Ethiopian Railway Corporation has to consider GIS for all its routes in different direction in the vicinity of Addis as time goes by.

5.3 Future Work

The designed GIS system used in this thesis is to operate in normal feeding conditions. However, GIS are designed to operate in innumerable conditions such as very fast over voltage during switching the disconnector and partial discharge. The extension of partial discharge and very fast transient voltage inside the enclosure would need to be further researched.

Moreover, further investigation is required into the economic benefit when the GIS is operated at a higher voltage, such as 500kV for Renaissance dam project at Holeta which is more cheap when compared to AIS

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7 Appendix A

Table A1: specific cost of air insulated substation components

No	Name of Equipment for AIS	Unit	Unit Price Birr	Cents
1. 132kV Busbar arrangement				
1.1	132kV strand Aluminium busbar 31.5kA	mt	12,900	00
1.2	132KV, CVT 132/$\sqrt{3}$, 0.1/$\sqrt{3}$,0.1/$\sqrt{3}$,		116,229	00
1.3	Conductors insulator string connector, clamp and hardware	No	4,235	50
2. 132kV Incoming line				
2.1	Lightning Arrestor, 120kV,10kA	No	26,208	50
2.2	132KV, CVT 132/$\sqrt{3}$, 0.1/$\sqrt{3}$,0.1/$\sqrt{3}$,	No	116,229	00
2.3	Line disconnector 3pole 1250A, 31.5kA	No	276,812	50
2.4	132kV CT, 200-400/1/1/1A	No	111,993	50
2.5	132kV CB, 31.5kA Outdoor	No	1,234,035	00
2.6	132kV busbar disconnector 31.5kA	No	234,546	50
2.7	Line trap	No	84,516	50
2.8	PLC phase – ground coupler	No	84, 516	50
2.9	Complete bay set of 132kV	No	42,269	00
3. 132kV side of Transformer bays (T1 and T2)				
3.1	132kV Busbar disconnector	No	234,543	00
3.2	132kV CB 31.5kA	No	1,234,035	50
3.3	132kV CT 200-400/5/5/5A	No	111,993	00
3.4	Lightning arrestor 120kV 10kA	No	26,208.	50
3.5	Complete bay set of 132kV conductors,		38,033	00
4. Power Transformer				
4.1	Power Transformer 132/15kV, 25MVA	No	1,924,3510	00
4.2	Earthing and Auxiliary Transformer	No	680,410	50
Total			23,828,708	50

Appendix B

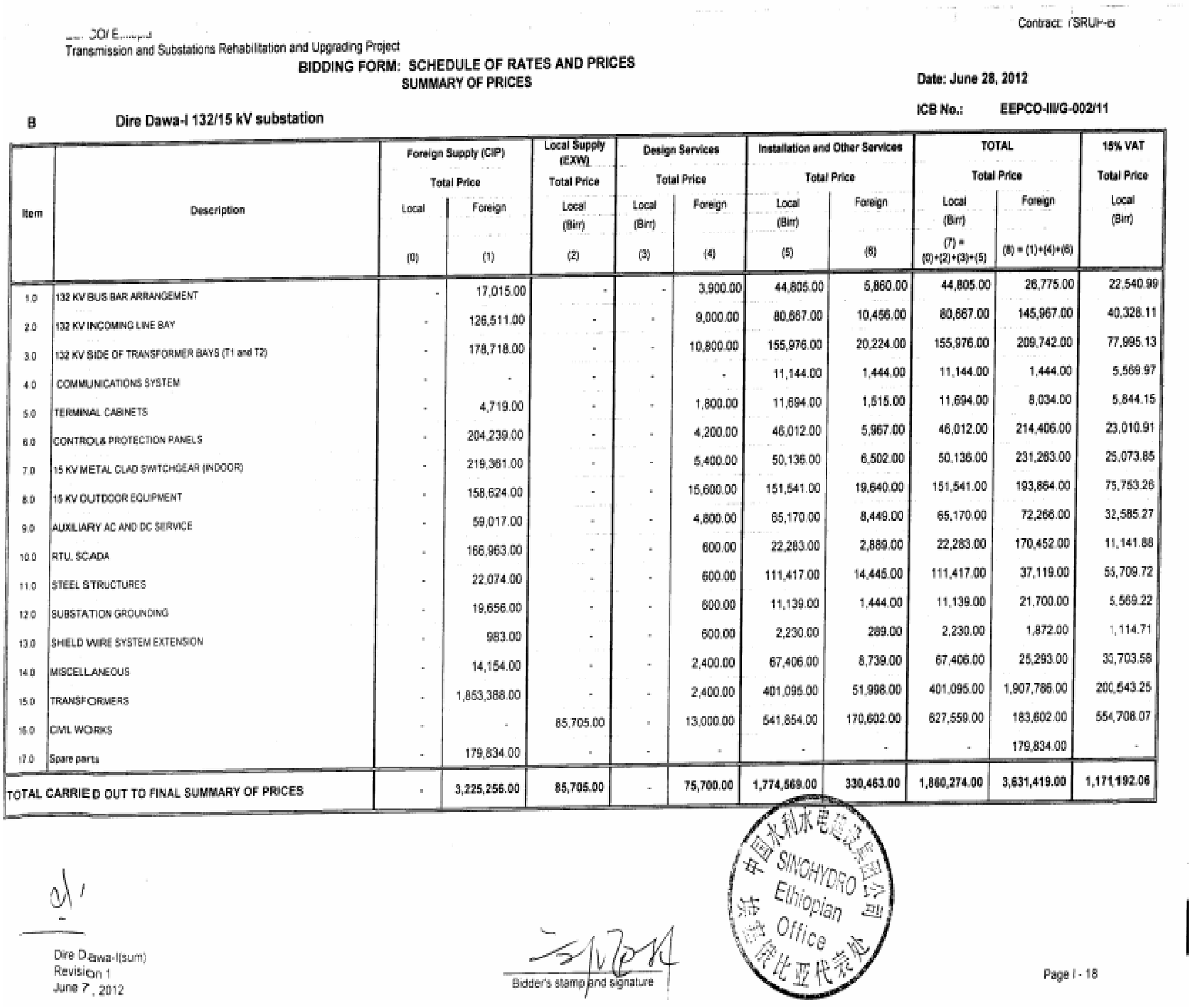
Table B1: specific cost of gas insulated substation components

No	Name of equipment for GIS	Unit	Unit price Birr	cents
1. 132kV line bay GIS				
1.1	132kV , GIS busbar disconnector 31.5kA	No	359,222	00
1.2	132kV, CB SF6, 3 pole operation, 1600A	No	718,444	00
1.3	132kV line disconnector with 31.5kA	No	359,222	00
1.4	132kV GIS line high speed earthing	No	190,167	50
1.5	132KVGIS VT $132/\sqrt{3}$, $0.1/\sqrt{3}$,$0.1/\sqrt{3}$,	No	105,651	00
1.6	132kV GIS CT, 300-600/1/1/1/1A	No	126,785	50
1.7	132kV GIS bus ducts with complete supporting structure	No	384,570	50
1.8	132kV GIS Surge Arrestor 120kV, 10kA	No	105,651	00
1.9	Local control Cabinet	No	211,302	00
2. 132kV Busbar coupler Bays				
2.1	132kV GIS busbar disconnector 31.5kA	No	359,222	00
2.2	132KV, CB SF6, 3 pole operation, 1600A	No	718,444	00
2.3	132KV, CT 600-1200/1/1/1A	No	105,651	00
2.4	Local control cabinet	No	211,302	00
2.5	132kV Gas Insulated bus ducts with complete supporting structure	No	359,222	00
3. 132kV Busbar System				
3.1	132kV Busbar 1600A 31.5kA	No	452,188	00
3.2	132KV GIS VT $132/\sqrt{3}$, $0.1/\sqrt{3}$,$0.1/\sqrt{3}$,	No	253,571	00
3.3	132kV Earthing maintenance switch	No	202,852	00
3.4	Lightning arrestor 120kV 10kA	No	105,651	00
3.5	Complete bay set of 132kV conductors,	No	452,188	00
4. 132/15kV Transformer Feeder Bays GIS (T1 and T2)				
4.1	132kV GIS busbar disconnector 31.5kA	No	359,222	00
4.2	132KV, CB SF6, 3 pole operation, 1600A	No	718,444	00
4.3	132kV GIS disconnector with maintenance earthing pole 31.5kA	No	359,222	00
4.4	132kV gas Surge arrestor 120kV 10kA	No	105,651	00
4.5	132kV GIS CT, 150-300/1/1/1/1A	No	316,953	00
4.6	132kV Gas Insulated bus ducts with complete supporting structure	No	371,907	00
4.7	Local control cabinet	No	211,302	00
4.8	132kV cable for connection to transformer	No	228,201	00
4.9	Power Transformer 132/15kV, 25MVA	No	19,243,510	00
4.10	Earthing and Auxiliary Transformer	No	680,410.	50

Total	28,376,129	50

Appendix C

Over all investment cost of AIS



[illegible]CO/ E[illegible]
Transmission and Substations Rehabilitation and Upgrading Project

Contract: [illegible]SRUP-B

BIDDING FORM: SCHEDULE OF RATES AND PRICES
SUMMARY OF PRICES

Date: June 28, 2012

ICB No.: EEPCO-III/G-002/11

B Dire Dawa-I 132/15 kV substation

Item	Description	Foreign Supply (CIP) Total Price		Local Supply (EXW) Total Price	Design Services Total Price		Installation and Other Services Total Price		TOTAL Total Price		15% VAT Total Price
		Local (0)	Foreign (1)	Local (Birr) (2)	Local (Birr) (3)	Foreign (4)	Local (Birr) (5)	Foreign (6)	Local (Birr) (7) = (0)+(2)+(3)+(5)	Foreign (8) = (1)+(4)+(6)	Local (Birr)
1.0	132 KV BUS BAR ARRANGEMENT	-	17,015.00	-	-	3,900.00	44,805.00	5,860.00	44,805.00	26,775.00	22,540.99
2.0	132 KV INCOMING LINE BAY	-	126,511.00	-	-	9,000.00	80,667.00	10,456.00	80,667.00	145,967.00	40,328.11
3.0	132 KV SIDE OF TRANSFORMER BAYS (T1 and T2)	-	178,718.00	-	-	10,800.00	155,976.00	20,224.00	155,976.00	209,742.00	77,995.13
4.0	COMMUNICATIONS SYSTEM	-	-	-	-	-	11,144.00	1,444.00	11,144.00	1,444.00	5,569.97
5.0	TERMINAL CABINETS	-	4,719.00	-	-	1,800.00	11,694.00	1,515.00	11,694.00	8,034.00	5,844.15
6.0	CONTROL& PROTECTION PANELS	-	204,239.00	-	-	4,200.00	46,012.00	5,967.00	46,012.00	214,406.00	23,010.91
7.0	15 KV METAL CLAD SWITCHGEAR (INDOOR)	-	219,361.00	-	-	5,400.00	50,136.00	6,502.00	50,136.00	231,263.00	25,073.85
8.0	15 KV OUTDOOR EQUIPMENT	-	158,624.00	-	-	15,600.00	151,541.00	19,640.00	151,541.00	193,864.00	75,753.26
9.0	AUXILIARY AC AND DC SERVICE	-	59,017.00	-	-	4,800.00	65,170.00	8,449.00	65,170.00	72,266.00	32,585.27
10.0	RTU, SCADA	-	166,963.00	-	-	600.00	22,283.00	2,889.00	22,283.00	170,452.00	11,141.88
11.0	STEEL STRUCTURES	-	22,074.00	-	-	600.00	111,417.00	14,445.00	111,417.00	37,119.00	55,709.72
12.0	SUBSTATION GROUNDING	-	19,656.00	-	-	600.00	11,139.00	1,444.00	11,139.00	21,700.00	5,569.22
13.0	SHIELD WIRE SYSTEM EXTENSION	-	983.00	-	-	600.00	2,230.00	289.00	2,230.00	1,872.00	1,114.71
14.0	MISCELLANEOUS	-	14,154.00	-	-	2,400.00	67,406.00	8,739.00	67,406.00	25,293.00	33,703.58
15.0	TRANSFORMERS	-	1,853,388.00	-	-	2,400.00	401,095.00	51,998.00	401,095.00	1,907,786.00	200,543.25
16.0	CIVIL WORKS	-	-	85,705.00	-	13,000.00	541,854.00	170,602.00	627,559.00	183,602.00	554,708.07
17.0	Spare parts	-	179,834.00	-	-	-	-	-	-	179,834.00	-
TOTAL CARRIED OUT TO FINAL SUMMARY OF PRICES		-	3,225,256.00	85,705.00	-	75,700.00	1,774,569.00	330,463.00	1,860,274.00	3,631,419.00	1,171,192.06

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Revision 1
June 7, 2012

Bidder's stamp and signature

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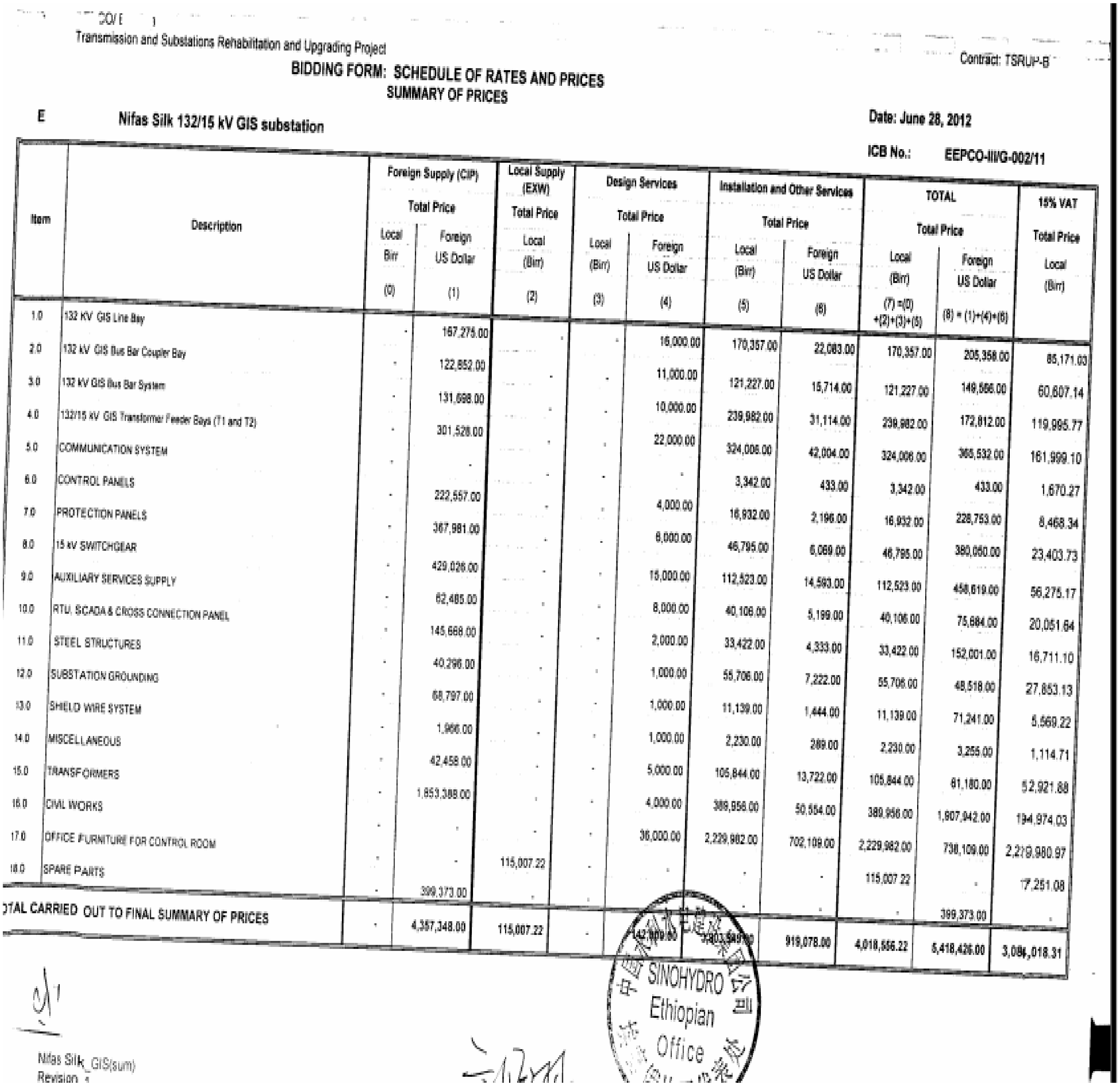
Appendix D

Over all investment cost for GIS



Transmission and Substations Rehabilitation and Upgrading Project

Contract: TSRUP-B

BIDDING FORM: SCHEDULE OF RATES AND PRICES
SUMMARY OF PRICES

E Nifas Silk 132/15 kV GIS substation

Date: June 28, 2012

ICB No.: EEPCO-III/G-002/11

Item	Description	Foreign Supply (CIP) Total Price		Local Supply (EXW) Total Price	Design Services Total Price		Installation and Other Services Total Price		TOTAL Total Price		15% VAT Total Price
		Local Birr (0)	Foreign US Dollar (1)	Local (Birr) (2)	Local (Birr) (3)	Foreign US Dollar (4)	Local (Birr) (5)	Foreign US Dollar (6)	Local (Birr) (7) =(0) +(2)+(3)+(5)	Foreign US Dollar (8) = (1)+(4)+(6)	Local (Birr)
1.0	132 KV GIS Line Bay	-	167,275.00	-	-	16,000.00	170,357.00	22,083.00	170,357.00	205,358.00	85,171.03
2.0	132 kV GIS Bus Bar Coupler Bay	-	122,852.00	-	-	11,000.00	121,227.00	15,714.00	121,227.00	149,566.00	60,607.14
3.0	132 kV GIS Bus Bar System	-	131,698.00	-	-	10,000.00	239,982.00	31,114.00	239,982.00	172,812.00	119,995.77
4.0	132/15 kV GIS Transformer Feeder Bays (T1 and T2)	-	301,528.00	-	-	22,000.00	324,006.00	42,004.00	324,006.00	365,532.00	161,999.10
5.0	COMMUNICATION SYSTEM	-	-	-	-	-	3,342.00	433.00	3,342.00	433.00	1,670.27
6.0	CONTROL PANELS	-	222,557.00	-	-	4,000.00	16,932.00	2,196.00	16,932.00	228,753.00	8,468.34
7.0	PROTECTION PANELS	-	367,981.00	-	-	8,000.00	46,795.00	6,069.00	46,795.00	380,050.00	23,403.73
8.0	15 kV SWITCHGEAR	-	429,026.00	-	-	15,000.00	112,523.00	14,593.00	112,523.00	458,619.00	56,275.17
9.0	AUXILIARY SERVICES SUPPLY	-	62,485.00	-	-	8,000.00	40,106.00	5,199.00	40,106.00	75,684.00	20,051.64
10.0	RTU, SCADA & CROSS CONNECTION PANEL	-	145,668.00	-	-	2,000.00	33,422.00	4,333.00	33,422.00	152,001.00	16,711.10
11.0	STEEL STRUCTURES	-	40,296.00	-	-	1,000.00	55,706.00	7,222.00	55,706.00	48,518.00	27,853.13
12.0	SUBSTATION GROUNDING	-	68,797.00	-	-	1,000.00	11,139.00	1,444.00	11,139.00	71,241.00	5,569.22
13.0	SHIELD WIRE SYSTEM	-	1,966.00	-	-	1,000.00	2,230.00	289.00	2,230.00	3,255.00	1,114.71
14.0	MISCELLANEOUS	-	42,458.00	-	-	5,000.00	105,844.00	13,722.00	105,844.00	61,180.00	52,921.88
15.0	TRANSFORMERS	-	1,853,388.00	-	-	4,000.00	389,956.00	50,554.00	389,956.00	1,907,942.00	194,974.03
16.0	CIVIL WORKS	-	-	-	-	36,000.00	2,229,982.00	702,109.00	2,229,982.00	738,109.00	2,219,980.97
17.0	OFFICE FURNITURE FOR CONTROL ROOM	-	-	115,007.22	-	-	-	-	115,007.22	-	17,251.08
18.0	SPARE PARTS	-	399,373.00	-	-	-	-	-	-	399,373.00	-
TOTAL CARRIED OUT TO FINAL SUMMARY OF PRICES		-	4,357,348.00	115,007.22	-	142,000.00	3,903,549.00	919,078.00	4,018,556.22	5,418,426.00	3,084,018.31

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