

**DESIGNING AN OPTIMAL DISTRIBUTION SUBSTATION FOR ADAMA
SCIENCE AND TECHNOLOGY UNIVERSITY**



TAREKEGN UTA TONA

A Thesis Submitted to the Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master

Science in Electrical Power Engineering

Office of Graduate Studies

Adama Science and Technology University

March 2022
Adama, Ethiopia

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ADVISOR: MOLLA BIWETA (PhD)

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APPROVAL PAGE

I, the advisor of the thesis entitled “Designing an Optimal Distribution Substation for Adama Science and Technology University” and developed by Tarekegn Uta, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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DECLARATION

I hereby declare that this Master Thesis entitled “Designing an Optimal Distribution Substation for Adama Science and Technology University” is my original work and it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Tarekegn Uta

Name of the Student

Signature

Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Designing an Optimal Distribution Substation for Adama Science and Technology University” prepared under my guidance by Tarekegn Uta, submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Power Engineering. Therefore, I recommend the submission of the revised version of the thesis to the department following the applicable procedures.

Molla Biweta (PhD)

Advisor

Signature

Date

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LIST OF ACRONYMS

Abbreviations	Description
A	Ampere
AC	Alternating Current
ACO	Ant Colony Optimization
AMR	Ampere
ANSI	American national standard institute
ASAI	Average Service Availability Index
ASIDI	Average System Interruption Duration Index
ASIFI	Average System Interruption Frequency Index
ASTU	Adama Sciences and Technology University
ASUI	Average Service Unavailability Index
BB	Bus Bar
CADI	Customer Average Interruption Index
CC	Covered Conductor
Ckt	Circuit
CT	Current Transformer
DTEF	Distribution Temporary Earth Faults
DTSC	Distribution Temporary Short Circuit
DPEF	Distribution Permanent Earth Faults
DPSC	Distribution Permanent Short Circuit
DC	Direct Current
DG	Distributed Generation
Ds	Distribution Substation
DT	Distribution Transformer
ECOST	Expected Interruption Cost
EENS	Expected Energy Not Supply
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
EF	Earth Fault
ETAP	Electrical Transient and Analysis Program
ETB	Ethiopian Birr
ERP	Enterprise Resource Planning

Fig.	Figure
Fr	Frequency
GC	Gregorian calendar
GIS	Geographical Information System
GJ	Giga Joule
Hr	Hour
HV	High Voltage
I>>	Over Current
ICS	Interconnected System
IEC	International Electro Technical Commission
IEEE	International Electrical and Electronic Engineering
ISO	International Standard Organization
Ka	kilo Ampere
Kv	kilo Volt
kWh	kilo Watt-hour
L1-7	lines of an old distribution system
LP	Load Point
LV	Low Voltage
M1-5	Feeders of Mobile Substation
Mm	mill meter
MJ	Mega Joule
MSc	Masters of Science
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
MV	Medium Voltage
MVA	Mega Volt Ampere
MW	Mega Watt
NDs	Number of Distribution Substation
O&M	Operation and Maintenance
OC	Over Current
ONAF	Oil Natural Air Forced
ONAN	Oil Natural Air Natural
OP	Operational
PE	Polyethylene

P.f	Power Factor
PM	Probability of Mutation
PPM	Preventive and Predictive Maintenance
PSS	Proposed Switching Station
PVC	Polyvinyl Chloride
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SS1-8	Switching Stations Of Rehabilitant System
UPS	Uninterrupted Power Supply
USD	United States Dollar
V	Voltage
Vdrop	Voltage Drop
VT	Voltage Transformer
XLPE	Cross -Linked Polyethylene
Yr	Year
Z	Impedance

ABSTRACT

A power supply system's distribution system is the one that is nearest to the customer. As a result, its failures have a greater impact on customer service than transmission and generation system faults, which seldom create service interruptions. As a result, this thesis work on Adama Science and Technology University (ASTU) started to design its distribution system at the consumer level. The customer loads were then grouped for service from secondary lines connected to distribution transformers. The loads from the distribution system were then assigned to a single main substation, which would step down from the 33kV sub-transmission voltage. Control gear, switchgear, and other equipment requirements and ratings were derived using International Electro-Technical Commission (IEC), International Electrical and Electronic Engineering (IEEE), and American National Standard Institute (ANSI) standards, as well as various models that fit the specified specifications. A novel method for solving the optimal planning problem of distribution substations is proposed. The method does not require a candidate substation location and may automatically choose the optimal substation sizes, locations, and service areas in power distribution systems. Furthermore, an efficient solution algorithm is proposed. The optimal location and capacity are determined by reducing the investment and operational expenses of the electric power distribution system without violating the substation capacity (transformer capacity), feeder capacity (distribution capacity), voltage drop, energy not served and the reliability of the system to meet the load within the planning horizon. The results indicate that utilizing a Genetic Algorithm, the optimal sizing and placement distribution transformers problem in ASTU can be addressed in fewer than 300 generations. The result of the genetic programming briefed that 13 distribution transformers with five sphere transformers having a capacity of 15970 kVA and one main distribution substation with a having a capacity of 50 MVA are troubleshot the study area power demand. In general, based on simulation results of reliability index values, the new designed substation achieved a 95.6% improvement in SAIFI value, a 99.6% improvement in SAIDI value, a 92.84% improvement in ENS value, and a 99.5% improvement in ASUI value

Keywords: *distribution system reliability, planning, and expansion of distribution system, geographical information system, genetic algorithms, optimization techniques of distribution network.*

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Adama town found at a geographical coordinate of 8.54°N 39.27°E at 1712 meters elevation and 99 km southeast of Addis Ababa [30]. Adama has been supplied from the national grid. With the growth of the city and the high electricity demand, providing a reliable power supply becomes a formidable task to the power utility. Frequent power interruptions have posed serious problems to the city and mitigating the problem is very critical to improve the livelihood of the population.

The Adama new distribution system comprises eight switching stations with a 15 kV voltage rating. These switching stations act as small substations that are distributed in different parts of the city. These stations get their power from the Adama substation by seven express feeders without feeding loads on the way. To form a loop distribution configuration, at least one switching station is tied to another switching station by intermediate feeders. Because of this Adama Science and Technology University get supply through one of those switching station R6-2.

Because of numerous economic, technical, and political problems, low quality of electricity provided by the grid can be expected in some developing countries. This issue can be categorized by the intermittent and unreliable supply of electricity to the customers usually through regular grid outages, either planned or unplanned [31].

Design and expansion of distribution systems seem inevitable because of the need to satisfy the rise in energy consumption technically and economically. Distribution planners must ensure that there is adequate substation capacity (transformer capacity) and feeder capacity (distribution capacity) to meet the load within the planning horizon. A distinction is made as to the short-term or operational and the long-term or planning. This distinction is important because planning requirements are different in these terms, which may affect the method of problem solution and model definition. In summary, short-range planning is more primary feeder-oriented in contrast to long-range planning, which is concerned with substation capacity and location.

Optimal sizing and placement of distribution substation and transformer previously have been done by some other methods such as Ant Colony Optimization (ACO) [24], Tabu searching methodology, a multi-objective optimization method based on genetic algorithm [25], and other optimization methods. The differences between this thesis work method with other methods are the optimal locations of substation and distribution transformer. A Geo-Spatial Information-based genetic algorithm is a method that gets the best value. In a heuristic search, all possible cases for substation locations are investigated. Using this search, global optimum locations of substations are achieved.

1.2 Statement of the Problem

Ethiopia's government is now putting in a concerted effort to elevate the country's economic position from that of a least developed country to that of a medium-income country. One of the most important economic features of this effort is developing and improving the electric power supply industry.

Ethiopia's Adama Science and Technology University is one of the country's higher education institutions. There are a lot of employees and students at the university, and there are a lot of teaching-learning and research activities going on worldwide. It also offers a variety of community services that address a variety of socioeconomic and technical concerns in both the neighborhood and the country. The institution has plans in place to expand and improve its current status, as well as to install and implement new technology. Electric power outages, on the other hand, are growing more common. Not only at low voltage distribution systems, but also at medium voltage distribution systems, there are occasions when electric power disruptions happen many times every day.

Considering this fact, in this thesis work, a comprehensive investigation of Adama Science and Technology University's power distribution problems has been conducted. Based on the result of the investigation, design and performance improvement measures has been identified and considered.

One of the most important components of a power system is electrical power distribution. All aspects of power distribution system reliability and design improvement measures have been addressed, leading to a detailed investigation of the general features of ASTU's power distribution problems and a recommendation with a complete design of power distribution

system, including a detailed assessment of the power distribution and an economic analysis of the designed system.

1.3 Objectives

1.3.1 General Objectives

The main objective of this thesis work is to conduct a study and evaluation of the reliability and design of ASTU's power distribution system.

1.3.2 Specific Objectives

To accomplish the above requirements the following specific objectives were to be met:

- To study power distribution system reliability and compare with international benchmarks.
- The causes of power reliability problems in the existing distribution network were identified to address the power supply issues in the studied area.
- Both primary and secondary power distribution lines were to be designed to deliver power from distribution systems to customers while minimizing conductor losses.
- To do a comparative economic analysis of both the existing and the new proposed systems.

1.4 Significant of the Study

This thesis attempted to identify distribution system reliability issues as well as operational and maintenance practice gaps concerning the theoretical understanding of electrical distribution systems. Furthermore, it enhanced distribution system reliability by proposing a new substation design and optimal distribution substation location to meet increased power demand in the study area.

A new efficient and effective method for power distribution system expansion planning has been developed in this thesis. The technique optimizes numerous planning elements stated in one or more objective functions to determine the location and size of substations and feeders. In the planning process, the costs are estimated. The system's reliability and the energy non-supplied index are expressed as distinct objective functions. The voltage drop, capacity, and

radiality limits are all taken into account. The technique is based on a single-period planning model and assumes that the candidates for new facilities are identified beforehand.

1.5 Scope and Limitation of the Thesis

The purpose of this thesis is to examine and design a methodology through which techno-economical dimensioning of distribution substations in the power system is examined and designed.

The thesis covers the present power supply system and adjustments that have been made in the process of developing the new substation design. The substation's equipment is explained in detail. All relevant calculations are completed, and the equipment is chosen following state regulations. The placement of the substations was optimized using geospatial-based genetic algorithms, and the capacity of each distribution and main substation was determined. However, due to the breadth of the work, this thesis is time-constrained. For this reason, for more operational flexibility to keep the system dependable, some of the work is recommended as future work.

1.6 The Thesis Organizations

This thesis study has six chapters. The first chapter provides an introduction to the thesis, which includes the study's background, problem statement, limitations, the significance of the study, and thesis outline. The second chapter discussed the literature background of reliability and reviewed a related journal with the title of a thesis. The third chapter presented reliability indexes for Adama Science and Technology University manually by using data collected in Adama distribution systems. This identifies the types of faults and causes of outages in systems. The fourth chapter presented designing each parameter of the substation equipment and optimization and placement of the proposed substation. In the fifth chapter, the simulation results of the proposed substation and the optimized placement of each transformer location within the main substation were discussed. In addition to this, optimization techniques of genetic algorithms with load information obtained from geographic information systems (GIS) have been discussed. Finally, in chapter six, the thesis's conclusion and recommendations are discussed.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Background

An electrical substation is a part of an electricity generation, transmission, and distribution system that uses transformers to change the voltage from high to low or in reverse. It also acts as a link between various power system components such as transmission lines, transformers, generators, and loads. Circuit breakers are used as high-power switches to allow for flexibility in connecting the elements. Between the generating plant and the consumer, electric power may pass through several substations and be changed in voltage in several steps. Transmission substations, distribution substations, collector substations, switching substations, and other types of substations are all examples of substations. A substation's general functions may include:

- It steps up or step-down voltages and currents
- connection point for transmission lines
- switchyard for network configuration
- monitoring point for control center
- protection of power lines and apparatus
- Communication with other substations and regional control center

2.1.1 Electric Power System

The electric power system is a system of interconnected components that generates electricity by converting various sources of energy into electrical energy and transporting it to areas where it may be used. At the generating station, electricity is generated by converting a primary source of energy into electrical energy (potential energy, kinetic energy, or chemical energy). Power is sent from this receiving end substation to the secondary substation through the secondary transmission system. The distribution system then delivers power to the ultimate customer [7].

The distribution substation design mainly concerns the following parameters as constraints. These are:

- a) Distribution System
- b) Distribution System Planning
- c) Substation Layout
- d) Switching and Protection Functions of Distribution Substation
- e) Load of the Distribution System

a) Distribution System

The distribution system is the last stage in the process of delivering power to end customers. The network would typically consist of medium-voltage (less than 50 kV) power lines, electrical substations, and pole-mounted or pad-mounted transformers, as well as low-voltage (less than 1000 V) distribution wire.

b) Distribution System Planning

System planning is required to ensure that the rising energy demand can be met by distribution system upgrades that are both technically adequate and fairly priced. The distribution system is critical to an electrical utility for two reasons, closeness to the final consumer and its high investment cost [7].

Because a power supply system's distribution system is closest to the consumer, faults in it have a bigger influence on customer service than problems in the transmission and generation station, which often do not cause service interruptions.

As a result, distribution system planning begins with the customers. The type of distribution system required is determined by demand, type, load factor, and other customer load factors. After determining the customer's loads, they are grouped for service from secondary lines linked to distribution transformers that step down from primary voltage. The demands on the primary distribution system are determined by combining the distribution transformers. Substations that step down from transmission voltage are subsequently assigned to the principal distribution system loads. The size and position of the substation, as well as the routing and capacity of the related transmission lines, are all determined by the distribution system loads.

c) Substation Layout

The first stage in planning a substation layout is to create a one-line diagram that represents the needed switching and protection structure, as well as the incoming supply lines and outbound feeders or transmission lines [6].

The one-line diagram should incorporate key elements such as Lines Switches circuit breakers and transformers. Incoming lines should include a disconnect switch and a circuit breaker. A disconnect switch is used to create isolation since it cannot interrupt load current. A circuit breaker is a device that automatically interrupts fault currents. Switches and circuit breakers can be operated locally or remotely from a supervisory control center [6 and 7]. Following the switching components, the lines are connected to one or more buses. An electrical bus, which is derived from a bus bar, is a common electrical connection connecting several electrical types of equipment.

In Figure 2.1 thick line indicates the bus, which is made up of three wires. The slash between the bus's arrow and the "3" indicates that the bus is made up of three wires. The configurations of switches, circuit breakers, and buses have an impact on the cost and reliability of the substation. A ring bus, or double bus, is used for critical substations. Substations that serve a single industrial load may have few switching facilities. Once the buses for the various voltage levels have been constructed, transformers may be linked between the voltage levels. If a transformer fails, these will also feature a circuit breaker. A substation always contains control circuitry to operate the different breakers to open in the event of a component failure [6].

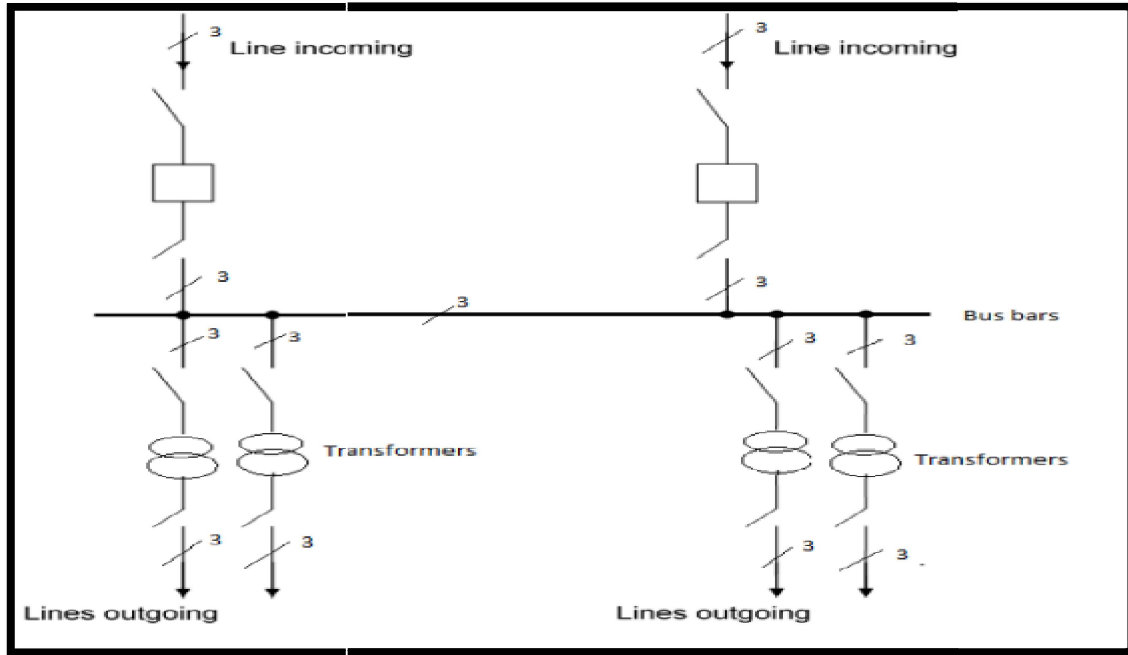


Figure 2.1 Single line diagram of substation [6]

d) Switching and Protection Functions of Distribution Substation

Switching is the process of connecting and disconnecting transmission lines or other system components. Switching occurrences can be both "planned" and "unplanned." For repair or new construction, a transmission line or other component may need to be de-energized. It is not cost-effective to shut down the whole power system for repair to preserve supply dependability. All maintenance, from basic testing to the addition of fully new substations, must be completed while the entire system remains operational. A problem can also occur in a transmission line or any other component, the substation's job is to isolate the faulty component of the system in the shortest period possible.

To reduce danger to humans and equipment damage, the distribution substation requires minimal protection. A substation's level of protection is defined by how essential a power outage is to the load. A hospital's loss of electrical power is quite severe, but a residence's lack of electricity is inconvenient. In the case of a power outage, the hospital's energy must be restored as soon as possible, although the house can be without power for many hours without major implications. It is costly to equip a substation with automated switching to restore power when it is lost and to ensure the least amount of damage and repair time possible after a breakdown [6]. A small substation at the end of a radial sub-transmission line, for example,

may be used to supply a small group of households, consisting of two dead-end poles to terminate the lines, two manual non-load break switches, and primary fusing. This substation may feed a small commercial area. It has a circuit breaker, a primary fuse for backup, and additional disconnect switches for isolation during the repair. The circuit breaker will be operated by relays, which will need a metal-clad enclosure, instrument transformers, and a DC power source for the trip circuit. The greater speed of fault clearance provided by this substation's circuit breaker has significantly raised its cost. Both substations are single-source, single-transformer, and single-feeder configurations. The cost variances increase in proportion to the size of the substation, as well as the size and number of transformers [6].

e) Load of the Distribution System

The capacity of a substation is determined by the size of the load to be supplied. The load must be allocated in such a way that it can be provided with an acceptable feeder loss or greater. Critical loads (industrial districts) are supplied by more complicated substations, which are built for optimum reliability and speed of power restoration in comparison to those used in residential areas, where a momentary power outage is typically not a problem. Other substations in the region have an impact on the design of a new substation. The presence of other substations will boost total power capacity and, as a consequence, can meet the need for high loads. Substations with important loads typically utilize more than one transformer to ensure that the load is serviced even if one transformer fails. Otherwise, a single massive three-phase transformer is utilized since it is less expensive per kVA of capacity and requires less space, bussing, and simpler protections [6].

2.2 Reliability of Distribution System

Power reliability can be defined as the degree to which the performance of the elements in a bulk System results in electricity being delivered to customers within accepted standards and in the amount desired. The degree of reliability may be measured by the frequency, duration, and magnitude of adverse effects on the electric supply [1, 2, 3, and 4]. There are many terms and definitions used in reliability engineering. Some of the frequently used terms and definitions are presented below.

Reliability: This is the probability that an item will carry out its assigned mission satisfactorily for the stated period when used under specified conditions. Or reliability refers to the probability that a component experiences no failure during a period.

Failure: This is the inability of an item to function within the initially defined guidelines.

Downtime: This is the time during which the item is not in a condition to carry out its stated mission.

Maintainability: This is the probability that a failed item will be repaired to its satisfactory working state.

Availability: This is the probability that an item is available for application or use when needed.

Meantime to failure (exponential distribution): This is the sum of the operating time of given items divided by the total number of failures.

Useful life: This is the length of time an item operates within an acceptable level of failure rate.

Failure Frequency (f): The failure frequency refers to the number of failures that may happen during a period. In this study, the dimension of the failure frequency is failures per year.

The reliability of the interconnected bulk power system is defined in two ways.

1. Adequacy: The ability of the electric systems to supply the aggregate electrical demand and energy requirements of their customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.

2. Security: The ability of the electric systems to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements.

In brief, reliability has to do with total electric interruptions and complete loss of voltage, not just deformations of the electric sine wave. Reliability does not cover sags, swells, impulses, or harmonics[1, 2, 3, and 4]. Reliability indices typically consider such aspects as;

- The number of customers
- The connected load
- The duration of the interruption measured in seconds, minutes, hours, or days
- The amount of power (kVA) interrupted and
- The frequency of interruptions.

2.2.1 Major Causes of Interruption in the Distribution System

An interruption to service, according to IEEE100-1992, is the separation of an electrical load from the system providing that load as a result of an irregularity in that system. The system abnormality might be a malfunction of a component in the system, a problem, or a system operation due to maintenance or repair. Interruptions are typically undesirable, regardless of the reason, because they leave energy unserved and consumers without service. Most disruptions occur as a result of the system responding to a failure. IEEE100-1992 defines a fault or short-circuits as an abnormal connection with relatively low impedance, whether established unintentionally or purposely, between two points of differing potential [8, 9].

Overloading, earth faults, and short circuits are the most common causes of outages in the distribution system. These large flaws are divided into two categories: transitory faults and permanent faults. The bulk of distribution system problems is caused by temporary faults. Temporary defects can arise for a variety of reasons, the most common of which are tree or animal contact and weather. Temporary failures can be quickly resolved with little or no system interaction. Many self-clearing events occur, such as a branch or animal contact that burns and falls off, conductors slapping together in high winds, or insulation flashover due to contamination. Lightning is another type of transitory problem. Failure of a lightning arrester, on the other hand, might constitute a permanent defect. Other transient faults are simply cleared when a substation trip is sent. Instantaneous reclosing de-energizes the line for a short period, allowing the arc or contact path to disappear and the fault path to be eliminated. The system returns to normal operation after the circuit is re-energized. Permanent faults, on the other hand, can't be fixed with reclosing action and won't be clear on their own. Permanent faults can be caused by equipment failure, cable failure, downed lines, or prolonged tree contact. It's worth noting that occasional tree interaction, such as a tree falling on a power line might result in permanent faults [8, 9].

There are many principal causes of electrical failure; such as dust and dirt accumulation, moisture, loose connections, the friction of moving parts, aging of conductors, clearance from trees and limbs and structures, equipment overloading, frequency, and so on. An effective maintenance program should aim to minimize these effects by keeping equipment clean and dry, keeping connections tight.

2.2.2 The Common Reliability Indices of the Distribution System

Systems reliability indices indicate the annual average performance of the network in terms of interruption frequency and duration. They are weighted by the number of customers or energy supplied. Quantitative reliability evaluation of a distribution system can be divided into two basic segments; measuring the past performance and predicting future performance [10].

Some of the basic indices that have been used to assess past performance are [10].

A) System Average Interruption Frequency Index (SAIFI):

It is the average frequency of sustained interruptions per customer over a predefined area. It is the total number of customer interruptions divided by the total number of customers served.

$$SAIFI = \frac{\text{Total number of customer interruption}}{\text{Total number of customers served}} = \frac{\sum N_i \lambda_i}{\sum N_i} \quad (2.1)$$

where,

λ_i is the failure rate at load point i and N_i is the number of customers at load point i .

SAIFI is also the average failure rate of a unit of the system. Another valuable measure is the mean time between failures (MTBF), which is the reverse of the failure rate.

B) System Average Interruption Duration Index (SAIDI):

It is commonly referred to as customer minutes of interruption or customer hours and is designed to provide information as to the average time the customers are interrupted. It is the sum of the restoration time for each interruption event times the number of interrupted customers for each interruption event divided by the total number of customers.

$$SAIDI = \frac{\text{Sum of all customers interruption duration}}{\text{Total number of customers served}} = \frac{\sum i U_i N_i}{\sum i N_i} \quad (2.2)$$

where,

U_i is the annual outage time at load point i and

N_i is the number of a customer at load point i .

Naturally, a utility's customers average between one and two continued interruptions per year.

C) Customer Average Interruption Duration Index (CAIDI):

$$CAIDI = \frac{\text{Sum of all customers interruption duration}}{\text{Total number of customers interruption}} = \frac{SAIDI}{SAIFI} \quad (2.3)$$

CAIDI is the repair time from the customers' perspective. It is generally much shorter than the real repair time due to utilities usually sectionalize circuits to reactivate as many customers as possible before technicians fix the real damage.

D) The Average Service Availability Index (ASAI):

ASAI specifies the fraction of time that a customer has received the power during a predefined interval of time. This is the ratio of the total number of customer hours that service was available during a given period to the total customer hours demanded. This is sometimes known as the "Service Reliability Index". ASAI is usually calculated on either a monthly basis (730 hours) or a yearly basis (8,760 hours) but can be calculated for any period. ASAI is calculated by Eq.(2.4).

$$ASAI = \frac{\text{Customer hours of available service}}{\text{customer hour demanded}} \times 100\%$$
$$ASAI = \left(1 - \left(\sum \frac{(r_i \times N_i)}{(N_t \times T)} \right) \right) \quad (2.4)$$

where,

r_i = interruption duration in hours

N_i = Total number of customers interrupted

N_t = Total number of customers served

T = Period under study in hours

E) Average Service Unavailability Index (ASUI):

The complementary value to ASAI. This is the ratio of the total number of customer hours that service was unavailable during a period to the total customer hours demanded. ASUI is calculated by the following Eq. (2.5).

$$ASUI = (100 - ASAI)\% \quad (2.5)$$

2.3 Software's Application on Power Distribution System Planning and Optimization

The following softwares are used to optimize the designing system.

1) Electrical Transient and Analysis Program (ETAP)

ETAP is the most comprehensive analytical platform for the generation, distribution, and industrial power systems' design, simulation, operation, and automation. This software is produced under a well-established quality assurance procedure and is utilized as high-impact software all over the world.

It is fully localized in four languages, with translated output reports in a further six. ETAP extends to a Real-Time Intelligent Power Management System as a fully integrated corporate solution to monitor, control, automate, simulate, and optimize the operation of the power system.

Create and test electrical power systems in a comprehensive simulation environment, with tools for creating and changing all types of objects and structures, including real-time load flow analysis, reliability analysis, short-circuit analysis, motor acceleration analysis, harmonic analysis, and transient stability analysis [11].

2) Geographical Information System (GIS)

There are several uses for geospatial technology in the power industry, including power. When it comes to electricity, the expense of maintaining a company's most valuable assets, transmission and distribution infrastructure, accounts for a significant amount of its yearly operational costs. Geospatial technology makes records easier to manage. This should result in a reduction in operational expenses for a utility company's critical assets [29].

Customer and asset data are linked to a geographic location. The position on a map helps service providers to see the broad picture, which makes for a valuable tool. As a tool for determining decisions, the flexibility of GIS to interact with other systems is also a plus. Software such as Enterprise Resource Planning (ERP) or Supervisory Control and Data Acquisition (SCADA) is employed in an enterprise. Makes it a simple-to-use tool for all utilities. Power management, generation, transmission, and distribution all benefit from GIS. GIS is a useful tool for connecting the many components of an electrical distribution system, resulting in better asset management and enhanced customer service [29].

3) Genetic algorithm (GA)

The best-known algorithms in the class of evolutionary algorithms are genetic algorithms (GAs). GA is powerful and broadly applicable to stochastic search and optimization techniques. They have been applied to optimization problems of different areas such as science, commerce, and engineering. The reasons for their success are their ease of use, global perspective, and the ability to solve problems that are difficult to be solved by conventional methods [12].

In general, a GA has five component:

- a) A genetic representation of solutions to the problem
- b) A method to create an initial population of solutions
- c) An evaluation function rating solutions in terms of their fitness
- d) Genetic operators
- e) Values for the parameters of the genetic algorithm

Genetic algorithms are based on the principle of natural genetics and natural selection a GA generates an initial population of individuals (chromosomes). Each individual represents a possible solution for the problem being optimized. These solutions are classified by an evaluation function, giving better value (fitness) to better solutions. The population evolves over several generations to a population with the optimal solution (or near-optimal solution) to the problem. This evolution is generated by selection, recombination, and mutation operations. In selection operation, individuals are selected from the current population according to their fitness for recombination operation (i.e. the more fit solutions have more probability of being selected). The recombination operation creates new solutions (offspring solutions) by combining parts from two individuals (parent solutions) and mutation operation makes changes in a single individual. Afterward, the new solutions are evaluated and a new population is created from the old population and the offspring solutions select the better individuals. This process is carried out in each iteration (generation) of the algorithm. The process is stopped by a predetermined stopping rule [12]. In Figure 2.2 the GA syntaxes below show how to begin and stop the process of optimization of the system.

Genetic Algorithm

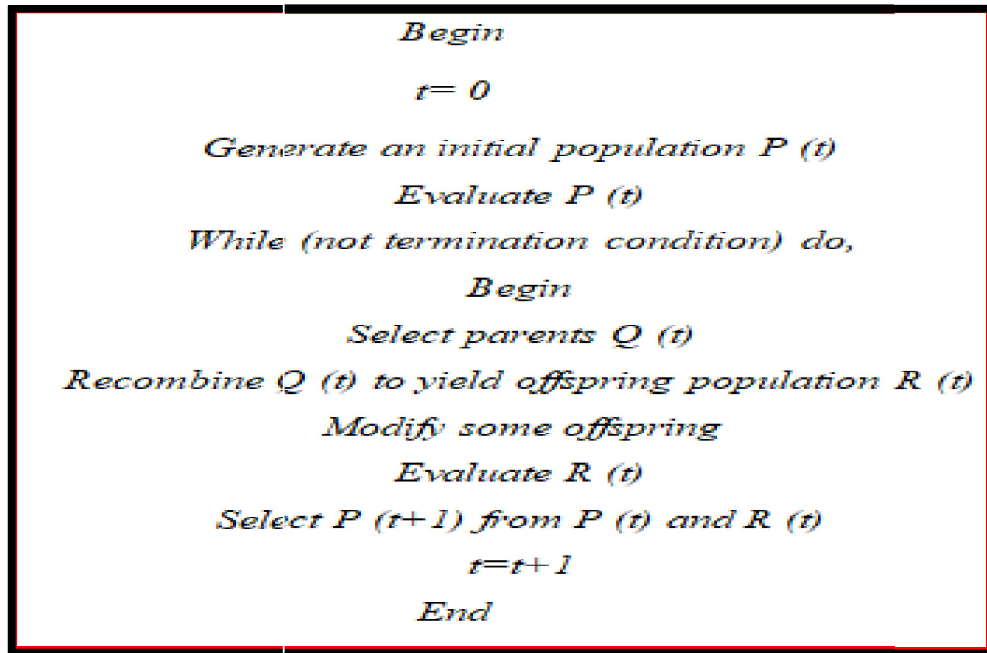


Figure 2.2 Genetic algorithms flow chart [12]

GA is a stochastic search method based mostly on natural genetic principles. Artificial chromosomes (strings) are first utilized to represent a problem solution variable. A string represents one search point in the solution space. GA is a parallel search strategy since it uses a fixed population of strings (i.e., multiple searching points). Within the initial population, the strings are generated at random. To change strings, natural selection and genetic operators such as cross-over and mutation are used (looking factors). After convergence, strings are decoded to the original solution variables, and final solutions are generated.

The algorithm follows the following process to obtain the problem solution:

i. Encoding and Decoding Techniques

In the problem's coding process, decimal numbers are used to encode chromosomes rather than binary data. The length of each chromosome is equal to the number of network nodes since each gene represents a load point in the coding procedure. The load points on the network will be numbered (from 1 to n) and arranged into groups. Each group is a substation service area that will be supplied by a substation. Each gene on the chromosome might be

chosen from a range of $[1-N_{Ds}]$, where (Ds) is the maximum number of substation installations that could be installed (transformers) [12].

N_{Ds} (number of distribution substations) can therefore be calculated as follows;

$$N_{Ds} = \frac{\sum_{i=1}^n P_i * \cos\phi_i}{S_{min} * UF(S_{min})} + IT \quad (2.6)$$

where,

P_i = Active power of i^{th} load point in the network area;

n = Number of load points in the network area;

$\cos\phi_i$ = power factor of i^{th} load point in the network area;

IT = a positive integer constant;

$S_{min} = \min\{S_i \mid S_i \in Q\}$;

$UF(S_{min})$ = the loading coefficient of the smallest transformer in the inventory where Q is the inventory of available standard transformer capacities to be built in the planning period.

Table 2.1 illustrates a typical chromosome (with $N_{Ds} = 3$ and n = number of load points); the first load point will be assigned to the second group, the second load point to the first group, the third load point to the first group, and so on. The n^{th} load point will be given to the third group in the same way (see Table2.1).Figure 2.3 depicts a region with 6 groups and 3 load points, with members of each group denoted by the symbols (*, o).This operation is carried out automatically by the above-mentioned coding and decodingsystems.

Table 2.1 Chromosome in a population ($N_{Ds}=3$, LPN load points)

LP1	LP2	LP3	LP4	LP5	LP6		n
2	1	1	2	3	1		3

Following the grouping of load points, each group will be assigned a substation (Ds), which will be located in the center of each group. To minimize total power loss of feeders, the optimal location of transformer $X(Ds)$, $Y(Ds)$ for the S^{th} LV substation transformer can be computed using Eq.2.7 in the center of the S^{th} group (see Fig.2.2).

$$X_{Ds} = \frac{\sum_{i=1}^n L_i^2 X_i}{\sum_{i=1}^n L_i^2}, \quad Y_{Ds} = \frac{\sum_{i=1}^n L_i^2 Y_i}{\sum_{i=1}^n L_i^2} \quad (2.7)$$

where,

(X_{Ds}, Y_{Ds}) = coordinates of Ds , (X_i, Y_i) = coordinates of load points i ,

n = number of load points in the study area,

L_i = horizon year demand of load point i .

The capacity of distribution transformers that will be installed in the center of each group is calculated as follows:

$$S_i = \{S_k | S_k \in Q\} \quad i = 1, 2, \dots, N_i \quad (2.8)$$

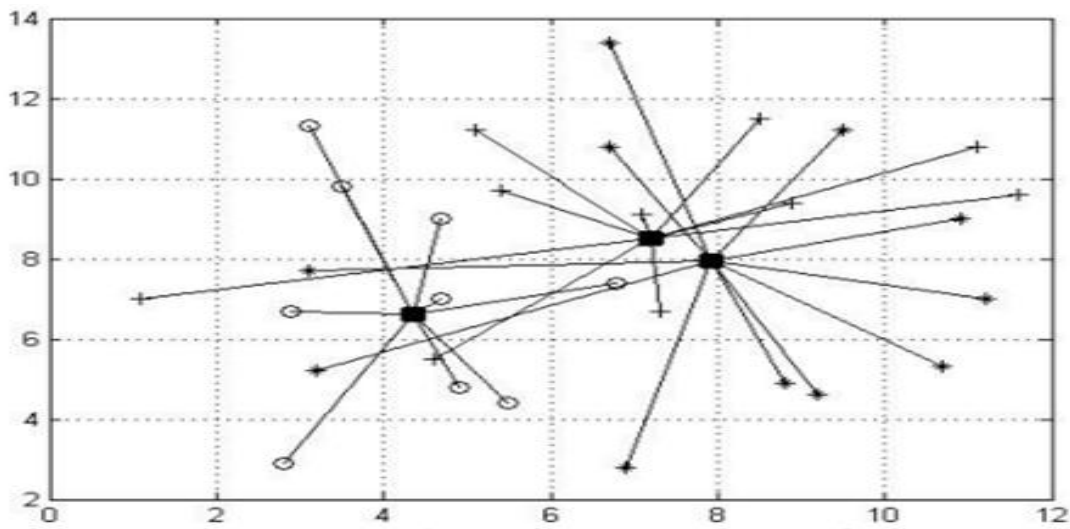


Figure 2.3 Groups of load points (NDs=3) in a typical chromosome [12]

Figure 2.3 shows the service area of each substation and the load points that will be fed from it. This service area is determined for this step and will be edited in the next iterations of the program. It seems that these service areas are mixed and are not acceptable in practice.

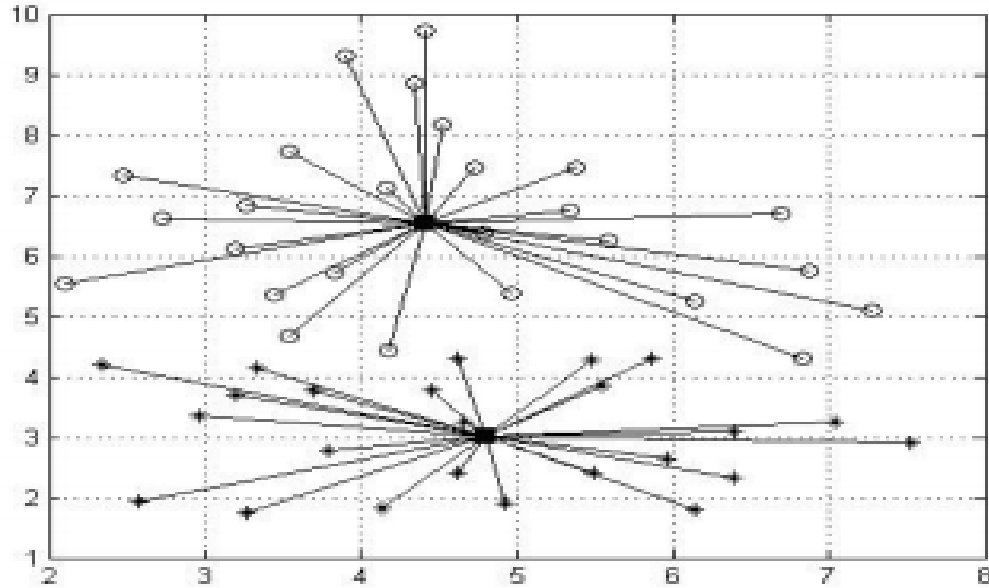


Figure 2.4 Location and service area of two HV/MV substations [12]

It should be noted that the number of substations at the beginning of the program was equal to NDs, but the number of transformers may be reduced. For example, in Fig.2.4, if any load points are not assigned to the second group by chance, or if the second group is removed from a chromosome by the GA operators, the number of substations on that chromosome will be reduced to two [12].

ii. Selection

The roulette wheel and the tournament have been used in the selection of parents. The tournament selection consists of choosing the fittest individual among a set of randomly chosen parents. This process determines which individuals from the present population will be selected to be added to the next population [12].

iii. Cross Over

Crossover creates a new solution (child) from a randomly chosen pair of parent solutions, passing on some of the parents' basic traits to the offspring. This operator is used to combine the data from two different individuals to create a new one that may be included in the next population. It produces candidate offspring by pairing chromosomes in pairs in the mating pool [12]. Table 2.2 shows the crossing of parent1 last traits (3,1) with parent2 last traits (2,2) produce new offspring one and offspring two.

Table 2.2 Cross over example

Parent 1	2	1	4	2		3	1
Parent2	1	1	4	3		2	2
Child 1	2	1	4	2		2	2
Child2	1	1	4	3		3	1

iv. Mutation

A mutation is used for random alteration of genes in string position. The gene will be varied from an existing decimal number to another number. With this operator, some of the genes in the candidate parents are varied from an existing decimal number to another number with probability P_m to add to the next population. The mutation operator is included to prevent premature convergence by ensuring population diversity. The third "set" of the new population is therefore generated. In this thesis, the probability of mutation (P_m) is assumed to be between 0.01 and 0.1[12]. Table 2.3 shows the mutated chromosomes from the string position of parent chromosome '1 and 3' and the child chromosome in string position '4 and 2' are different positions.

Table 2.3 Mutation example

Parent	2	1	4	2	3	1
Child	2	4	4	2	2	2

v. Perturbation

Perturbation is the process of random modification of one gene in the chromosome to another. It ensures that the probability of searching any region in the problem space is never zero. The operator will guide the problem to the optimum with a very small variation in a near-optimal solution. In Table 2.4 the fourth chromosome '2' is modified by '4' of the offspring chromosome [12].

Table 2.4 Numerical examples of Perturbation

Parent	2	4	4	2	3	1
Child	2	4	4	4	2	2

The components of the new population called “set”, which are created from GA operators, are described below [12].

Set 1: The chromosomes selected with the “Selection” stage.

Set 2: The chromosomes generated with “Cross Over” operator implementation on set 1.

Set 3: The chromosomes generated with “Mutation” operator implementation on set 1.

Set 4: The chromosomes generated with “Perturbation” operator implementation on set 1.

Set 5: Randomly generated chromosomes.

The number of chromosomes in each “set” to be combined to make a new population is proportional to the total number of chromosomes in that problem.

vi. Termination Criterion

It must be established whether the termination criterion has been met after calculating the fitness function of chromosomes. There are a few options for doing so. When a finite generation number is reached, the process comes to a halt, and the population with the best fit is deemed the winner and solution. The final solutions are produced when the strings have been decoded to the original solution variables [12].

vii. Cost function

Fixed and variable costs are both taken into account in this model. Installation and equipment expenditures are included in the fixed cost, whereas energy losses are included in the variable cost. The goal of the objective function is to reduce the total cost of the variable and fixed costs as much as possible. This can be formulated as follows.

$$Mini\ COST = C1 + C2 \quad (2.9)$$

$$\text{when,} \quad \sum_{k \in J_i} (W_k x \cos \phi_k) \leq (S_i \times UF(S_i)) \quad i=1, 2, 3 \dots N$$

where:

C1= the cost of energy losses on the feeders;

C2= the investment cost and operational cost of future substations;

S_i= the capacity of substation i

UF (S_i) = the loading coefficient of transformers in substation i.

The capacity of MV/LV substations must be sufficient to transport the electrical energy [14, 16]. It should be noticed that the ratio between the fixed and variable costs for a substation is much higher than the corresponding ratio for a feeder [13].

LV network model must be taken into account when planning for power loss and voltage drop modeling of downstream system. This model was one of the first models proposed for distribution planning and is relatively unsophisticated. The index (that is known as LP²) is added to the cost function for modeling the role of the LV network in total power loss.

$$C1 = \sum_{i=1}^N \sum_{j \in J_i} (W_j^2 d_{ij}), \quad C2 = [(cf_k)Q + (cv_k)Q(x_k)^2 Q] \quad (2.10)$$

where:

W_j= load magnitude of load point j;

γ = cost coefficient;

N = total number of future substations;

J_i = set of load points which are served by substation i;

(Cf_k)Q = investment cost of a substation of size Q, at the node k;

(cv_k)Q = cost coefficient of a substation of size Q, at the node k;

(x_k)Q = power flow, in kVA, supplied from a substation of size Q, at the node k;

$d_{ij} = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$ is the distance between substation i and load point j;

The first part of the C2 function is the investment cost of substation and the second part stands for the cost of power loss of transformers in substation (proportional with the square of injected power from the substation).

Generally, a straight line was used for calculating the distance between a load point and a substation [15,16], which is a straightforward but non-practical way of substation planning techniques.

2.4 Review of Related Research Works

The following research works took place on the electrical distribution system to satisfy and meet the current and future power demands of the customers.

The study in [17], presented the power availability improvement and power loss reduction in the Adama distribution system, by designing distributed generation (DG) to outgoing feeders. Using GIGSILENT software, the study evaluated the effect of DG on system reliabilities and improved the reliability of the Adama distribution system by sizing and placing DG along the radial feeder. However, one major that affects the reliability of a distribution system is configured. The work did not take distribution configuration into account, and there was no indication of the best location for the substation.

In [18], mainly discussed Adama town reliability by modeling grid-connected distributed generation (DG) power systems and designing a control mechanism between the DGs and the grid system to increase reliability and availability in both standalone and grid-connected DG power systems. That used HOMER simulator software to model the feasibility study, using Math lab to control the DG. That did not examine the reliability of the distribution system before the application of DG and did not indicate what the reliability problem of Adama town's power distribution network was.

In [19] discussed the assessment of power reliability and the use of smart reclosers to improve power reliability in the Adama power distribution system, which serves a big town in Ethiopia. The reliability of Adama city may be increased by up to 75% by linking two adjacent feeders via smart reclosers, according to the authors. To validate the application in the distribution system, the article used the Windmill program. The author attempted to demonstrate that the reliability problem in Adama city was caused by radial configuration, but low reliability in distribution systems is caused by a variety of factors. As a result, this research does not discuss the causes of unreliability or does not offer possible alternatives. Radial distribution networks while interloping increase fault currents in the system.

The reliability of upgraded and rehabilitated systems was assessed in [20], and it was confirmed that the existing distribution system was insecure. It primarily addressed the causes of power outages and distribution system reliability problems. Recommended a new distribution system with an extra substation to improve Adama city's power reliability. The

design and optimization of the distribution system, while keeping fundamental planning criteria such as voltage drop, energy not delivered, and substation placement about the load center, are the elements that determine the reliability of a distribution system. The study missed the elements that affect substation planning and distribution system layout.

The study [21], looks at the issues with distribution substations, such as frequent power outages owing to lighting and missing protection, system overload, power loss due to substation design, location, and substation type and configurations. The substation's design improves to suit new needs, and the installation of a grounding grid with precise spacing and a lightning rod with shielding wire reduces accidents while also lowering post costs. The recommended solution to the power supply problem with the distribution system is to protect workers from lightning strikes without losing their safety. While protection of the station and personnel must be automated and placed in an optimal location to respond the immediate action concerning any abnormality for the system to keep the system reliable.

In the study [22], discussed the challenges of substation design and installation in rapidly expanding cities and rural areas. which described the impact of network structure and design on the power supply and system dependability. It was determined that the design should take into account different tower design alternatives as well as the clearance between the line and the pole on an overhead line or buried cable. Of course, increasing the clearances between the line and the pole is advantageous for the transmission and distribution system's safety, but the prices and size of the huge pole must be considered. As a result, the investment cost and places limit the design constraints.

In [23] "Design of 11/0.415 kV Substation Using Applicable International Codes" discussed the issues of power loss due to line overloading, which was a direct result of system planning without rating and without considering future load demand. The that attempted to address this issue by designing an 11/0.415 kV substation that addressed current and future load demands. For the sake of system reliability, the substation design may consider all reliability and security constraints, or it may assemble the most use full constraints. When planning a substation, the first requirement for a planner is the center of the load, which leads to power loss and increases the cost of transmission line cable, thus the transformer should be installed

close to the maximum load requested area, in this scenario, the distribution system reliability problem is not often explored in this research.

In [24], describes another planning approach based on simulated annealing. This approach is presented to discover the location and size of feeders and substations while reducing investment and energy losses; however, the method was applied to theoretical distribution networks without considering substation expenses, and the varied feeder sizes employed are not indicated. The main disadvantage of the simulated annealing process is that annealing with time is extremely slow.

In [25], presented a planning method based on the tabu search methodology Using possibility distributions in the framework of fuzzy set theory, this technique considers explicit modeling of the uncertainties of future demands and expansion costs in distribution networks. The planning problem is to determine the location and size of substations and feeders while taking into account fixed and variable costs. The approach was applied to a large-scale system, although the costs considered in the problem are not given. Due to a large number of possible changes in big distribution networks, this strategy may be inefficient. Furthermore, distribution systems are challenging for this search strategy in the sense that large modifications might affect the solution's desirability.

In [26], a multi-objective optimization method based on genetic algorithms is presented. Due to its population approach (genetic algorithms utilize a population of solutions in each iteration; hence, the output is also a population of solutions), this method can produce a set of nearly Pareto-optimal solutions in a single simulation run. The approach is designed to determine the location and size of substations and feeders while balancing two target functions: reasonable cost and energy not supplied. The disadvantage of this strategy is that it requires running the genetic algorithm numerous times to generate solutions that are closer to the ideal ones. Furthermore, the algorithm employs genetic operators that yield a large number of unlawful solutions, and its encoding methodology has poor heritability, making it expensive and inefficient.

In [27], presented an inter-loop design to optimize the radial power distribution for improved reliability and to reduce the amount of energy that is not delivered. The author demonstrated how an inter loop system enhances power dependability while also saving cost over a

traditional radial power distribution system. To tackle optimization difficulties, this research employs genetic algorithm. This paper's strength is that it improves the reliability of radial distribution networks while interlocking increases fault currents in the system.

This method is based on the single-period planning model and it assumes that the candidates for facilities to be installed are known beforehand. In this study, the causes of the power supply interruption were identified, customer-based reliability indexes of the existing system in the study area were mainly determined, and the suitable solution for unreliability was to design a new distribution substation that reliably supplies the area for the next 25 years. The system was optimized through the power system optimizing tool, Genetic Algorithm, and the specific location and capacity of each load point and distribution transformer were determined. The method finds the site and size of substations and feeders to optimize several planning aspects expressed in one or more objective functions. optimizing various objectives, such as economic cost and reliability of the systems. The voltage drop limit, capacity limit, and radiality constraints are considered. The power demand forecast is the peak load. The magnitudes of voltage, current, and power flow in the systems are calculated using a power flow program. Finally, a gridded map of the study area was generated using the GIS and GA model. To demonstrate this, a real-life case study was conducted

CHAPTER THREE

METHODOLOGY AND SYSTEM DESCRIPTION

3.1 Introduction

The basic approaches used to fulfill the objectives of this thesis work, as well as a detailed analysis of reliability, distribution substation design, and distribution system location and optimization, are covered in this thesis.

Figure 3.1 Depicts a flowchart of the methodologies used to complete the thesis work.

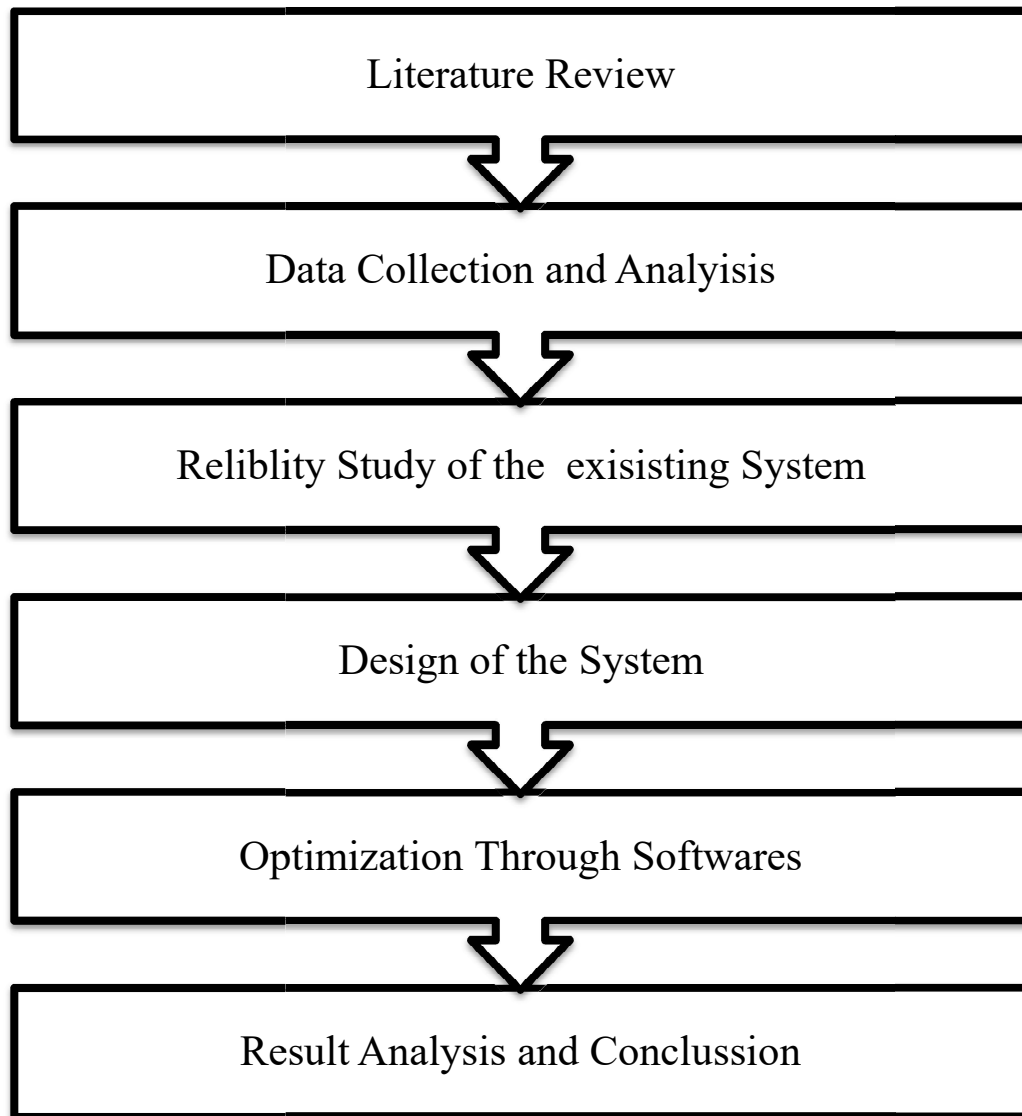


Figure 3.1 Flowchart of the proposed system

The above flow chart of the thesis methodology is discussed as the following:

1) Literature review

First, a review of the pieces of literature on the planning of the distribution substation and reliability study of the power supply of the distribution system are undertaken from the thesis, journals, articles, dissertation, and available books. In the same manner, the optimization of the distribution substation placement was reviewed from different sources. Theoretical descriptions of reliability and power system planning optimization and components, as well as designing of 33kV distribution substation and optimal location of distribution transformer with the respect to the center of the load, are investigated. Furthermore, planning and optimization approaches are employed by previous researchers to enhance electrical power system reliability issues have been explored. This assists in gathering important information and adopting different concepts and approaches as required.

2) Data collection and analysis

The second method adopted to carry out this thesis work is data collection. Various input data required for the reliability and design were gathered from the Nazareth-II substation, Ethiopian electric utility Adama district office, which is located in the Adama town. The data is collected through physical observation from the Adama Science and Technology University campus and the recorded data and equipment specifications. The geographical location of each load center and current distribution substation location, and the recorded reliability data of the current distribution system are all obtained for design, simulation, and analysis of the entire system.

3) Reliability analyses of the existing system

After gathering all distribution interruption data from the utility, the loads' data of each of customers, and the information and layout configuration of the distribution system the reliability analysis of the system has been conducted accordingly to confirm the condition of the distribution system and proceed to design the proposed solution.

4) Designing of distribution Substation parameters

The designing of a new proposed substation has been conducted after confirmation of the reliability condition of the existing system. The design processes are wisely done and every parameter is wisely sized according to national and international codes and standards.

5) Optimization through software

When the size of the distribution substation was determined the placement is the main issue to keep the system reliable and to reduce the investment and operational costs at all. For instance, the voltage drop, the line capacity limit, the energy not-served and the capacity of the distribution transformer, and the load center identification mostly affect the distribution system reliability, so all parameters should be optimized with the help of intelligent power systems optimization tools such as Genetic algorithm (GA) and geographical information system (GIS). Which are effective and efficient tools to locate and optimize the distribution system in this 21st-century electric power system planning.

6) Result analysis and Conclusion

Finally, depending on the simulation result of the given software the result was analyzed based on a detailed analysis of the simulation results, and the conclusion is reached.

3.2 Reliability of Current Distribution System of ASTU

Adama Science and Technology University now supplied electricity from Adama substation that is, an interconnected system (ICS). Ethiopian Electric Power and Ethiopian electric utility are providers of electric power in the country. A 132 kV transmission line is stretched into the Adama substation. The feeder line three of the Adama substation which supply 15 kV to the ASTU and the switching station of ASTU R6_2. Then, the university has a primary voltage of 15 kV and also, this voltage value is stepped down to 380V three phases and 230V single phase to the customer's level. The network topology that ASTU supplied for the Adama substation is radial. The bus bar scheme or bus bar layout is a parallel Single bus bar system. The single bus bar scheme has only one three-phase bus to which the various incoming and outgoing circuits are connected. It is not preferred for major substations and it lacks operational flexibility in case of bus fault or CB failure the entire bus has to be de-energized, but it is low cost, simple to operate, and requires simple protection.

Data has been collected from ASTU campus and from Adama distribution system. The year (2019/2020) 12 months recorded data that incorporates a type of fault, duration, and frequency of interruption and a peak load of 15 kV outgoing feeders of the distribution system. More are collected from Adama substation and remaining data are collected from Ethiopian electric utility

Adama district. The current installed capacity of Adama Science and Technology University is 9830 kVA.

The following data and issues determine the reliability of the ASTU distribution system :

a) Duration and frequency of interruption of incoming feeder and switching station

The duration and frequency of interruption of ASTU in the year of (2019/2020) are presented in Table 3.1 below. As observed in Table 3.1, higher fault frequency and duration are recorded in feeder L3, due to distribution permanent short circuit.

Table 3.1 Annual frequency and duration of interruption of ASTU

Types of fault		DPEF	DPSC	DTEF	DTSC	DLOL	OP	SUM
Feeder Name	S/station	F	F	F	F	F	F	
L3	R6-2	5	72	2	31	1	29	140
		D(Hr)	D(Hr)	D(Hr)	D(Hr)	D(Hr)	D(Hr)	SUM
		5.4997	156.5845	0.6663	15.6672	5.0833	32.998	216.499

b) Major Causes of ASTU Interruptions

Over-loading, earth fault, and short circuits are the major cause of interruptions in the ASTU distribution system. These major faults are classified into two main categories: temporary and permanent faults.

There are many principal causes of electrical failure; such as dust and dirt accumulation, moisture, loose connections, the friction of moving parts, aging of conductors, clearance from trees and limbs and structures, equipment overloading, frequency, and so on. An effective maintenance program should aim to minimize these effects by keeping equipment clean and dry, keeping connections tight.

According to the data collected from the substation, in Table 3.1 the causes of non-momentary (unplanned) interruptions are;

- ✓ Distribution Permanent Earth Faults (DPEF)
- ✓ Distribution Permanent Short Circuit (DPSC)
- ✓ Distribution Temporary Earth Faults (DTEF)
- ✓ Distribution Temporary Short Circuit (DTSC)

Based on Table 3.1, it is possible to analyze the percentage contributions of each cause of interruptions for the total frequency and duration of interruptions of feeder and the overall system. Figure 3.2 and Figure 3.3 represent the percentage of the causes of interruptions for the total duration of interruptions of the existing system.

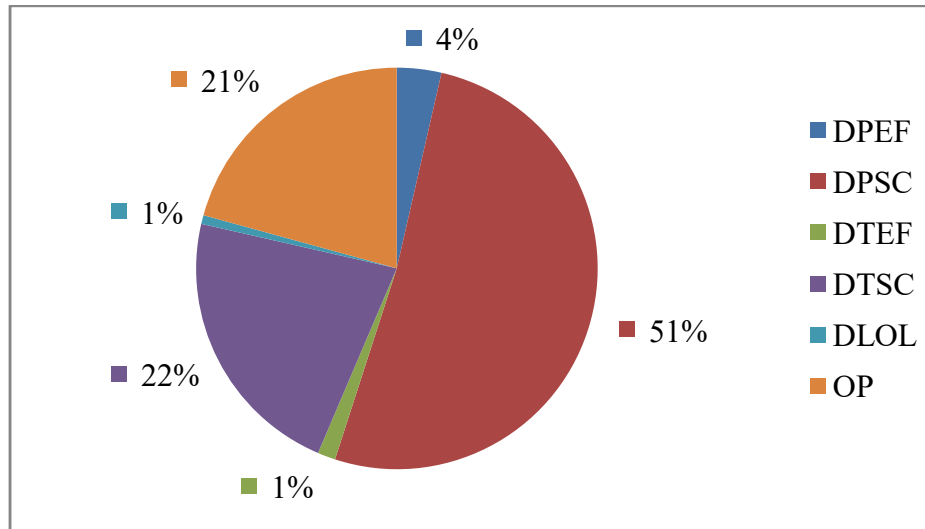


Figure 3.2 Percentage value of frequency of interruption of ASTU

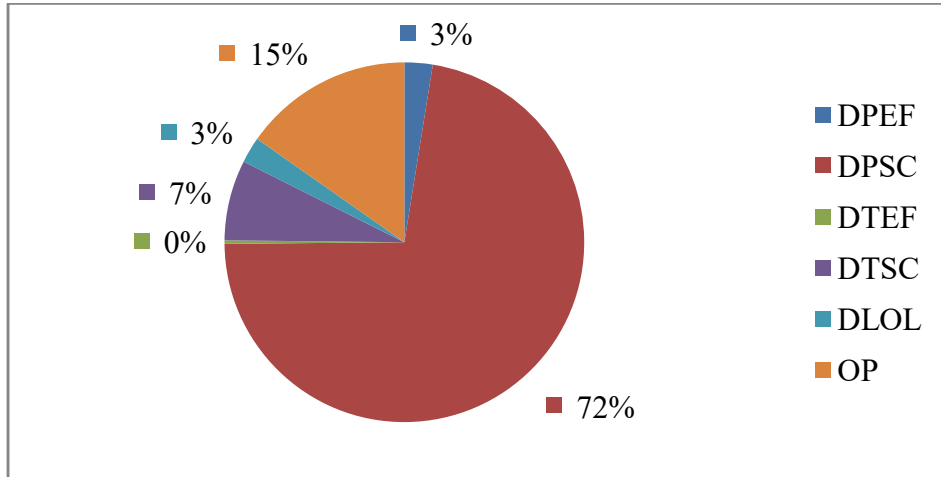


Figure 3.3 Percentage value of the duration of the interruption of ASTU

In general, based on the analysis results illustrated in Figures 3.2 and in Figure 3.3, from the total duration of the interruption, 72% is occurred due to the distribution permanent short circuit (DPSC). Similarly, 15% of the total duration of interruptions is caused by planned (operational) interruptions. 51% of frequency of interruption is caused by permanent short circuit and 21% is also caused by operational interruption. This shows that the distribution

system was more affected by permanently happening faults and distribution technicians take more time to locate a fault that occurred during maintenance since, as there is no automatic fault locating mechanisms.

3.2.1 Evaluation of Selected Reliability Indices of the System

The reliability indices can be calculated using Equations from (2.1) to (2.5) chapter two literature review. The data given in Tables 3.1 and 3.2 are used to calculate some of the reliability indices of the ASTU feeder line three and the switching station of R6_2. Similarly, it is possible to calculate the average reliability indices using the data given in Table 3.3. Therefore, Tables 3.3 show the SAIFI, SAIDI, CAIDI, ASAI, and ASAU values of ASTU incoming feeder and switching station of feeder from October 2019 to September 2020 GC (2012 E.C). All the calculated values of each selected reliability indices as described by the above equations from (3.2-3.6) of ASTU feeders and switching station from October 2019 to September 2020 GC tabulated below in Table 3.3.

Table 3.2 Annual frequency and duration of interruption of astu feeder and switching station

No.	Feeder name	October 2019 to September 2020	
		Frequency of Interruption	Duration of Interruption(hr)
	L3	68	92.25
	R6-2	140	215.92

Table 3.3 Customer-based reliability indexes of ASTU distribution system

Feeder	SAIFI (Fr/yr.)	SAIDI (Hr/yr.)	CAIDI (Hr/Fr)	ASAI (%)	ASUI (%)
L3	68	92.25	1.36	98.93	1.07

3.2.2 Comparison of the calculated values of reliability indices with different standards

The assessment of reliability indices for a power system network or of parts thereof, is the assessment of the ability of that network to provide the connected customers with electric energy of sufficient availability, as one aspect of power quality. Once we calculate the reliability indices then we have to compare it with the benchmark values of that network, in this case the calculation results is compared with benchmark value set by EEP to say the part of network (the distribution system of ASTU) is reliable or not. And also the result is compared with standards of different countries by selecting three most widely used reliability indices which are SAIFI and SAIDI values. Figures.3.4 and 3.5 shows the comparison of the most commonly used reliability indices (SAIF, and SAIDI). Their calculated value for each year is given in Table 3.1, 3.2 and 3.3.

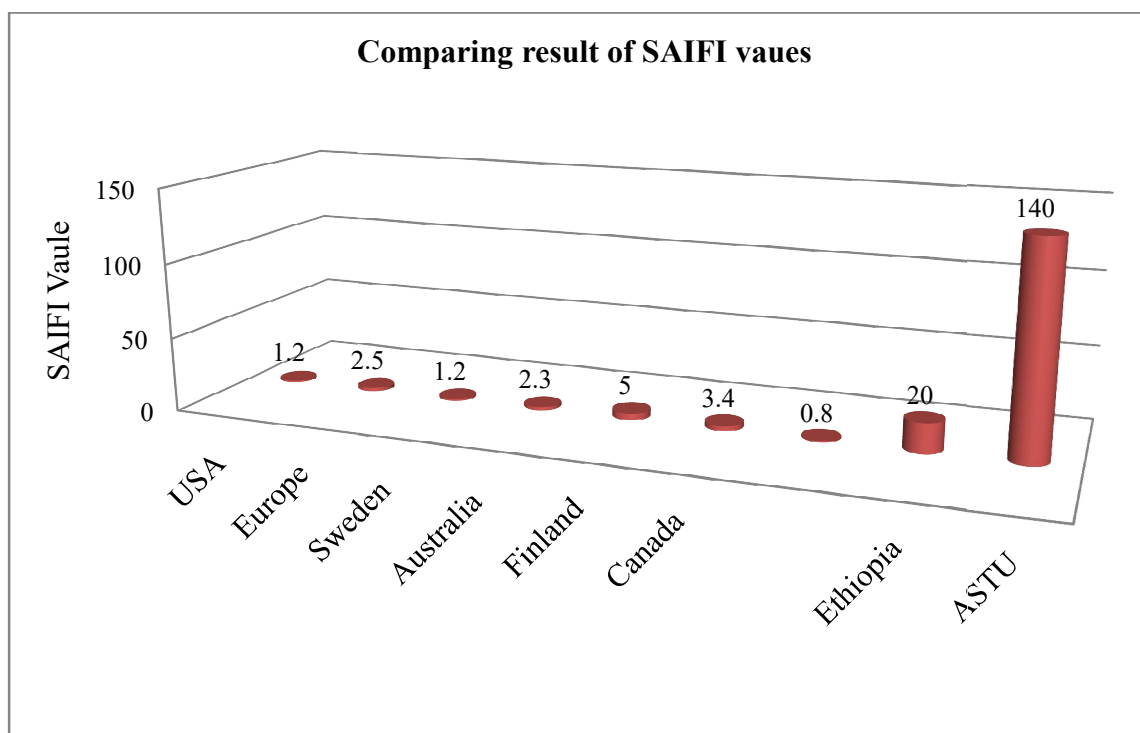


Figure 3.4 Comparison of the SAIFI value with different standards

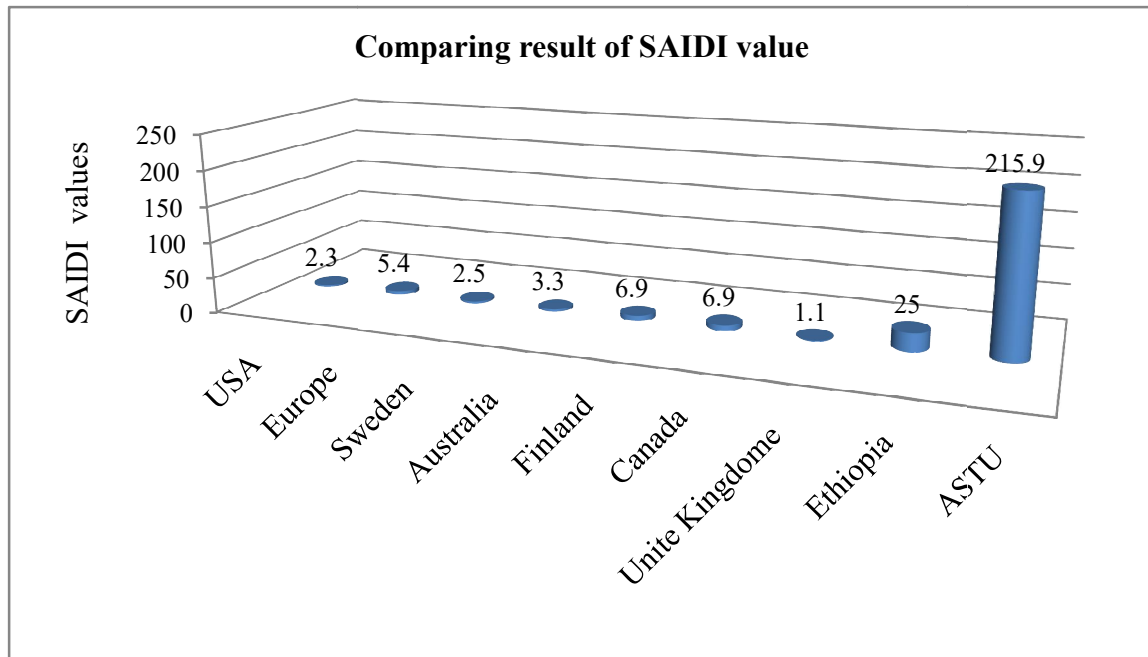


Figure 3.5 Comparison of the SAIDI value with different standards

As identified during the evaluation process, the most common reliability issues with the distribution system are overloading and placement. As a result, there must be developed mechanisms to overcome reliability issues. One of these major mechanisms is the design and optimal location of distribution substations to mitigate power reliability issues and solve overloading issues, which will be discussed in the following chapter.

CHAPTER FOUR

DESIGNING OF DISTRIBUTION SUBSTATION

4.1 Introduction

The ASTU power system was served by one existing 15kV primary distribution line having the necessary protection for both substation and distribution equipment. The most viable way of supplying and distributing electrical power was found by first quantifying the installation's electrical power requirements (maximum demand).

During the early stages of design (system sizing), the power demand was based on the sum of all the loads to be served, tempered by appropriate diversity factors.

The power utility industry is strictly governed by international laid-down codes and standards. Ethiopia and many other 50 Hz countries are governed by the IEC, ANSI, and the IEEE, therefore all applicable national and local laws, codes, and standards were adhered to.

4.1.1 The Need for Designing a New Substation

As it was discussed in Chapter three of this thesis, the reliability evaluation of the existing distribution substation of ASTU has two serious problems: overloading and poor reliability because the substation is a radial system and not optimal locating distribution transformer to the load point.

To solve the above problems of the distribution system and meet consumers' demand with great capacity and reliability, it is necessary to design a new optimized distribution substation with a proper rating of distribution substation equipment and by making the system capable of performing some distribution automation functions.

This chapter provides important mathematical design calculations and decisions for selecting the necessary equipment for designing the substation to improve distribution system performance in terms of determining distribution substation size and optimal distribution transformer location concerning load center.

The following chronological order was used to design the distribution substation:

(a) Load Assessment

Load estimation necessitates an examination of load characteristics, as well as consideration of the diversity factor relationship between connected loads and the actual demand placed on the system [31].

(b) Preliminary loads

Preliminary estimates of projected maximum demands and electrical energy consumption were calculated using the load data in the table.

The kind of a load of the proposed system is the general load categories according to the present condition of the existing system.

Table 4.1 Typical diversity factories [33]

Typical diversity factories				
Elements of a system between which				
Diversity factories are stated	Residential	Commercial	General	Large users
Between individual users	2	1.46	1.45	-
Between transformers	1.3	1.3	1.35	1.05
Between feeders	1.15	1.15	1.15	1.05
Between substation	1.1	1.1	1.1	1.1
From users to transformers	2.0	1.46	1.45	-
From users to feeder	2.6	1.9	1.95	1.15
From users to substation	3.0	2.18	2.24	1.32
From user to general station	3.29	2.4	2.46	1.45

The estimated installed capacity of loads power consumption of the ASTU is 8.5MW and the current load demand is given as below.

$$\text{Load demand of ASTU} = \frac{8494.22 \text{ kW}}{2.46} = 3.45294 \text{ MW} \quad (4.1)$$

(c) Primary and Secondary Voltage Levels in Ethiopia

The standard utility service voltages in Ethiopia are 380V in three phases and 230 V in a single phase. Primary distribution voltage levels are usually 33kV or 15kV. The advantages of a higher voltage system were apparent in that it would carry more power for a given current. Less current means lower voltage drop, smaller conductors, fewer losses, more power carrying capability, and much longer distribution circuits. Higher voltage systems will also need fewer voltage regulators and capacitors for voltage support. Table 4.2 shows maximum power levels typically supplied by various distribution voltages.

Table 4.2 Typical power supplied by each distribution voltage [33]

System Voltage(kV)	Total Power(MVA)
0.380	0.268
15	10.60
33	22.8
66	46.67

For primary distribution, 15kV distribution voltage was found to provide a good balance of cost, reliability, and safety. The secondary distribution transformers then reduced this voltage to the utility service voltage.

Secondary distribution is the component of an alternating current distribution system that spans the voltage range where the end-user consumes the delivered electrical energy. Typically, the secondary distribution system is a 380V, three-phase, and four-wire system

Criteria used for the secondary distribution substations sizing and locations:

- Loads located next to each other were lumped together so that they shared one transformer, therefore minimizing costs.
- They were located as close as possible to the consumers to minimize losses due to the high currents resulting from the stepped-down voltage.

- Each transformer had to be able to serve the connected consumers at their peak loads. A 20% load growth was allowed and the next higher rating was selected from the standard sizes available.
- The transformers' sizes were harmonized to a few standard sizes (400kVA, 630 kVA, 800 kVA, 1000kVA, 1250kVA, and 1600kVA). This would reduce the number of transformers needed as spares. In this case, six were required rather than ten, hence improving reliability and reducing system downtime in case a transformer was lost.

Table 4.3 Demand on individual ring circuits

Ring circuit	Maximum Demand (MVA)	Diversity Factor (User to Feeder)	Maximum demand (on Feeder in MVA)
1	25	1.95	12.82
2	25	1.95	12.82
Total	50	-	25.64

(d) Distribution Substation Planning

Load forecasting addresses the annual changes in demand caused by population and GDP changes. Although the weather is a major driver for short-term forecasting with an explicit role, it plays a substantial role in long-term forecasting. For a modeling framework, the weather is not assumed to change completely throughout the year [31,32].

Currently, there are two official forecasts used by EEP, namely the moderate, which presumes an annual average growth of 14 percent and the ambitious target of 17 percent [30]. To be more realistic, the World Bank's annual average growth rate of 6 percent of a power demand forecast has been used to estimate the capacity of the distribution substation. This estimated power demand forecast is tabulated in Table B.1.

The forecasted power demand after 25 years was approximately 38.50MW of active power and 39.78MVA by considering a power factor of 0.9. Therefore the power demand after 25 years will be approximately 45MW and 50MVA which are the next recommendable standards.

From the above analysis substation capacity was chosen to be 50 MVA, achieved by having two 25MVA transformers in parallel for improved reliability. The choice of parallel operation depends on the following advantages:

- Paralleling the two transformers will cater for the additional demand in the future in case of an increase in capacity.
- It will save on downtime during a changeover in case one transformer becomes faulty.
- It will allow for remote selection of one transformer in case there is no need of loading both transformers at the same time.

(e) General Substation Layout

A sectionalized 15kV bus, which links the transformers in Figure 4.1, has been suggested to take full use of this transformer system and to enhance reliability.

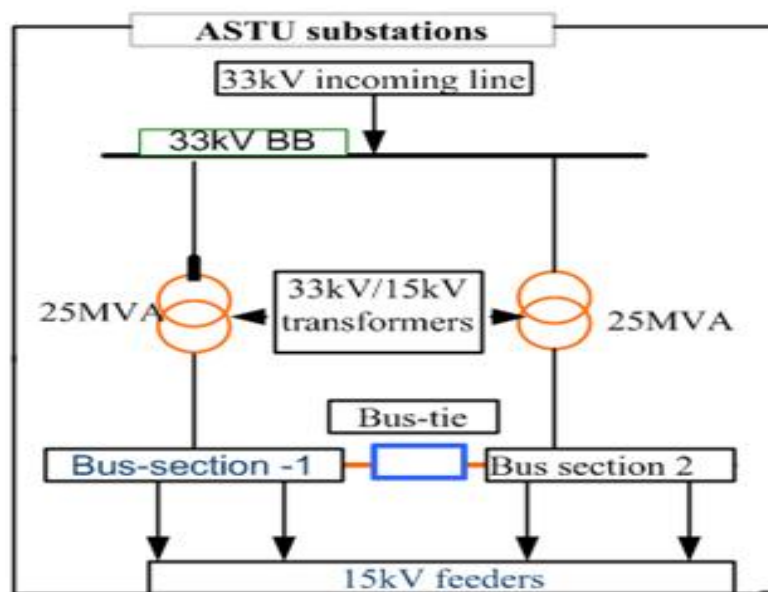


Figure 4.1 Substation general layouts

(f) General Plan of the System

The radial feeder system is the most basic and has the lowest initial cost, but it has the lowest service dependability. The parallel system improves supply reliability, especially if the circuits take different paths. The ring system provides backup power to several distributed substations and is extremely reliable [34,35]. Voltage drop, sizing, and protective engineering, on the

other hand, are more difficult than in radial systems. Interconnected networks are a popular extension of the basic ring system.

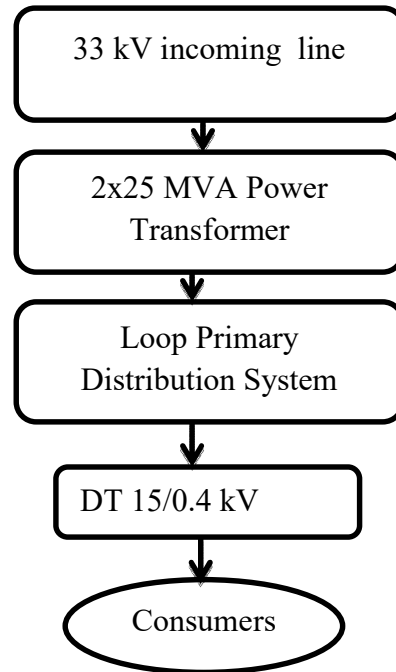


Figure 4.2 General plan of the proposed network

4.2 Substation Specific Design

The substation would be a combination of switching, controlling, and voltage step-down equipment arranged to reduce sub-transmission voltage to primary distribution voltage for residential, commercial, and industrial loads.

It consists of:

- 1) Switchgear, isolators, circuit breakers, earthing switches, etc.
- 2) Control gear: current transformers, voltage transformers, contractors, etc.
- 3) Protection equipment such as relays, fuses, surge arrestors, etc.
- 4) Power Transformers.

1) Designing of Switchgear and Control Gear

According to IEC 60694, the common ratings of switchgear and control gear, including their operating devices and auxiliary equipment, are chosen from the list below. The medium-

voltage switchgear and control gear equipment rated at 33kV and 15kV were rated according to the following main specifications.

Table 4.4 Substation switch gear rating and control gear rating

Specification	33kV (Outdoor)	15kV(Indoor)
Nominal Voltage	33 kV	15 kV
Rated maximum Voltage	36 kV	16 kV
Power frequency withstand voltage	70kVRMS	36kVMRS
Rated lightning impulse withstand voltage	170kV peak	95kVpeak
Rated frequency	50hz	50hz
Rated nominal current	874.78A	1924.5A
Rated short-time withstand current	20kA RMS	20kA RMS
Short circuit making current	31.5kA RMS	25kA RMS
Peak withstanding current	100kA peak	63kA peak
Nominal current of bus-bar	250A	630A
Rated continuous bus-bar current	250A	1250A

2) Rating of Surge Arrestors

In applying surge arrestors the voltage rating, lightning density, and surge rating is usually considered in determining the insulation coordination of the power system.

Table 4.5 Minimum characteristics for 33kV and 15kV surge arrestors

Type	Nominal discharge current	Description (33 kV and 15 kV)
1	10kA	A distribution class metal oxide surge arrestor for use along 33kV power lines and substations.
2	20kA	Surge arrestor for use along 33kV power lines and substations in high lightning intensity areas.

Geographically ASTU is located in a high-intensity lightning region. Hence type two was chosen and it has the following specifications in Table 4.6.below.

Table 4.6 Rating of surge arrestors for 33 kV and 15 kV substations

Specification	33kV	15kV
Rated voltage and frequency	27kV;50Hz	9kV; 50Hz
Insulation withstand	95kV	95kV
Continuous operating voltage (minimum)	22kV	15kV

3) Selection of Power Transformer

By using the IEC standards for power transformer ratings the power transformer is selected. As the future power demand is approximately 50MVA.The selection of two 25 MVA power transformers with 33/15kV ONAN/ONAF is suitable.

Table 4.7 Technical specification of a proposed power transformer

Specification	33kV	15kV
Rated Voltage(HV winding)	33kV	15
Rated Voltage(LV winding)	15kV	0.380
KV Ratio	33/15kV	15/0.380kV
Cooling	ONAN/ONAF 80/100%	ONAN
Reactance	7.15%	-
Connection (HV)	33kV	15kV
Connection(LV)	15kV	0.380kV
Maximum system voltage	36/16kV	15kV
OLTC high voltage taps required (above/below)	15%/5%	-
Temp Rise (Oil/Winding)	50/55 ^{0c}	-
Vector Group	Dyn11	-
Phases	3	3
Frequency	50Hz	50Hz
BIL Rating	170kV	95kV
Tap oil	≤55K	-
Average winding	≤60K	-
Site altitude	2500M	2500M
Service location	Outdoor	Outdoor

The voltage drop in the power transformer is due to the leakage reactance and the winding resistance. Rather than expressing the impedance in ohms per phase the normal convention with the transformer is to express the impedance as a percentage value referred to as the kVA or MVA rating of the transformer. The change in the transformer terminal voltage from no load to full load is the regulation of the transformer. The voltage drop is calculated as:

$$\Delta U = [(R \times P)^2 + (x \times Q)^2]^{\frac{1}{2}} \div 100\% \quad (4.2)$$

where:

x is Leakage reactance =8%

R is Winding resistance =10%

P is Power factor cos =0.9%

Q is sin Φ =0.41%

ΔU is % voltage drop at full load

Then according to equation (4.2), the voltage drop at each transformer is 0.096%.

4) Selection of Bus-Bars

The main functional requirement of a bus bar system is:

- To carry I_{rated} continuously and limited overloading
- To withstand the rated voltage of the system (V_{rated}) and the specified transient overvoltage of the system without flashover
- To provide a low resistance path for current flow
- Outdoor bus bars should have minimum corona losses

The bus bar for the new substation is selected by using the IEEE standards for bus bar ratings. The bus bar is designed with the consideration of not only the present load but also the future loads.

Rating calculations for the bus bar:

- ✓ Rated Load Capacity = 45MW which is the forecasted 25 years load demand of the area
- ✓ Voltage = 33kV

The rated current (I_{rated}) of the bus-bar is calculated by Eq. (4.3);

$$I_{rated} = \frac{P}{\sqrt{3}V \cos \Phi} \quad (4.3)$$

$$I_{rated} = \frac{45 \times 10^6}{\sqrt{3} \times 33 \times 10^3 \times 0.9} = 874.78 \text{ A}$$

So a busbar with a current rating of 874.78A is selected for the 33 kV side.

- ✓ Rated Load Capacity = 45 MW
- ✓ Voltage = 33 kV

The rated current (I_{rated}) for the 15kV busbar is calculated by equation (4.4).

$$I_{rated} = \frac{45 \times 10^6}{\sqrt{3} \times 15 \times 10^3 \times 0.9} = 1.9 \text{ kA} \quad (4.4)$$

So a busbar with a current rating of 2kA is selected for the 15kV side.

Short Time Withstand Current

This is the maximum RMS total current that can be carried momentarily without electrical, thermal, or mechanical damage. Standard ratings for a bus and its extensions should be matched to the breaker rated value [6].

Table 4.8 Ratings of bus-bars within the guidelines of ANSI/IEEE Std.C37.20.2

Description	For 33kV
Type of Bus-bar	Copper
Rated Current	2kA
Rated Insulation Voltage	1000 kV
Rated Short Time Withstand Current	100 kA
Conductors	
a) Bar Dimensions	2 × 200 mm × 6 mm ²
b) Cross Sectional Area	2400 mm ²
Resistance	(0.0091 mΩ/m)
Reactance	(0.0025 mΩ/m)
Impedance	(0.0094 mΩ/m)
Voltage Drop (line to line at a Power factor of 0.9)	(0.08 V/m)

5) Selection of Circuit Breakers

Circuit breakers are a piece of electrical device that:

- ✓ Make or break a circuit either manually or by remote control under normal conditions.
- ✓ Break a circuit automatically under fault conditions.
- ✓ Make a circuit either manually or by remote control under fault conditions

The rated voltage, rated current, and rated short-circuit breaking (interrupting) capacity of the circuit breaker must be determined. The short circuit capacity of the circuit breaker must be above the maximum short circuit current that exists in the location.

The ratings of 33 kV and 15 kV circuit breakers are indicated in Table 4.9. Standard rating structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

Rated Short-Circuit Current

The rated short-circuit current of a circuit breaker is the highest value of the symmetrical component of the polyphase or line-to-line short-circuit current in RMS amperes measured from the envelope of the current wave at the instant of primary arcing contact separation that the circuit breaker is required to interrupt at rated maximum voltage and on the standard operating duty. It also establishes, by fixed ratios as defined in ANSI/IEEE Std. C37.04-5.10.2, the highest currents that the breaker is required to close and latch against, to carry, and to interrupt[6].

Rated insulation levels consist of two items:

- 50 Hz, oneminute withstand voltage, and Impulses withstand voltage or BIL [6].
- The standard values are defined in IEEE Std. C37.20.2.

Table 4.9 Ratings of Circuit Breaker

No	Item		Unit	Data	
1	Rated voltage		kV	33	
2.	Rated frequency		Hz	50	
3	Rated insulation level	One minute power frequency withstand voltage	kV	95	
		lightning impulse withstand voltage (peak)		185	
4	Rated current		A	630, 1250 ,2000	
5	Rated short-time withstand current		kA	25 31.5	
6	Rated short-time duration time		sec	3	
7	Rated short circuit Breaking Current		kA	25 31.5	
8	Rated short circuit Making Current		kA	63 80	
9	Open-close rated capacitor bank current		A	400~1750	
12	Rated operation sequence			0-0.3s-CO-180s-co O-180s-CO-180s-CO	
13	Rated short circuit breaking current breaking times		Times	20	
14	Opening time		ms	45±4 (SF)	65 (FP)
15	Closing time		ms	68±4 (SF)	70 (FP)
16	Mechanical life		Times	10000	

6) Selection of Isolator

Isolator shall be designed such that in the fully open position, it shall provide adequate electrical isolation between the contacts on all three switches. Isolator shall be horizontal side opening, double side break rotating post type for use on a 33kV, 50 Hz, 3- phase system. The isolator shall be motorized and also fitted with a manual operation facility. All three switches shall be arranged to ensure simultaneous operation of all switches by drive rods and operating handle for both manual and motor operation. Auxiliary dry contacts, five normally open and five normally closed shall be provided for electrical interlocks such that the isolator and associated 33kV circuit breakers can be interlocked with each other. The contacts shall be

rated to continuously carry at least 10Amps at voltages up to 500V alternating or direct current.

The ratings of 33 kV and 15 kV isolators according to ANSI/IEEE C62.2, including their operating devices and auxiliary equipment are indicated in table 4.10.

Table 4.10 Ratings of 33 kV and 15 kV Isolators According to ANSI/IEEE C62.2

Description	33 kV	15kV
Rated Service Voltage	33 kV	15 kV
Rated Maximum Voltage	36 kV	16 kV
Rated Current	1250A	1250A
Rated Short-time- Current	31.5 kA	20.5kA
Number of Poles	3	3
Rated Frequency	50 Hz	50Hz
Rated Maximum Withstand current	100 kA	105kA
Closing or Opening Time	≤ 30 Sec	30sec
Insulation level:		
a) Power Frequency Withstand Voltage (kV RMS for 1 min)	70kV	45kV
b) Impulse Withstand Voltage (1.2/50 μsec) kV Peak	170kV	50kV

7) Selection of Current Transformers (CTS)

A CT is essentially a step-up transformer that steps down a current to known ratio. The primary of this transformer consists of one or more turns of thick wire connected in series with the line. The secondary consists of a large number of turns of a fine wire and provide for the measuring instruments and relays a current which is a constant fraction of current in the line. For example, protection devices and revenue metering may use separate CTs to provide isolation between metering and protection circuits and allow current transformers with different characteristics (accuracy, overload performance) to be used for the devices. Current

transformers are used for the measurement of current and to provide secondary current for protection purposes.

Table 4.11 Ratings of 33 kV and 15 kV current Transformers According to ANSI/IEEE Std

Rated Service Voltage	33 kV	15 kV
Rated Maximum Voltage	36 kV	16 kV
Rated Primary Current : - For line feeder - For transformer feeder	400 - 200 - 100 800 - 400 - 200	400-200-100
Rated secondary currents	1 - 1 - 1	1 - 1 - 1
Short-time- Current Ratings	31.5 kA	
Rated Short Circuit Maximum Current	60 kA	
Rated Frequency	50 Hz	50Hz
Insulation level : Power Frequency Withstand Voltage (kV RMS for 1 min) Impulse Withstand Voltage (1.2/50 μ sec) kV Peak	70 kV 170 kV	45kV 125kV

8) Selection of RTU and Computers

Remote Telemetry Units (RTUs) are multiplexed addressable I/O devices with communications. They have input and output points and are connected to a more intelligent controller. The controller is responsible for the control algorithm. This kind of RTU has very little computing power and is specified for use in installations like substation automation. The Remote Telemetry Unit is strictly a slave device.

Table 4.12 Ratings for RTU

Discretion	Size
Temperature range	+10 to +50 pC
CPU size	32 bit 50MHz
Total memory	16MB
Ethernet ports	2/2
Input isolation	2.5 kV AC
mechanical vibrations	0.035 mm @ 50 Hz

It is not programmable and cannot be used as a stand-alone controller, but it is usually addressable. We can use it to relay status and values both from the remote site to a controller and from the controller down [6].

9) Current Rating Calculations

To select the appropriate cable size, it is necessary to know the voltage and load current in Amperes or as MW or MVA. The rated current of the secondary cable is calculated by Eq. (4.5) as follows [6].

$$I_{rated} = \frac{MVA}{\sqrt{3} \times V} = \frac{25MVA}{\sqrt{3} \times 15} = 962.5 \text{ A} \quad (4.5)$$

De-rating is a technique used in electrical power where devices are operated at a condition greater than their rated maximum power dissipation. De-rating increases the margin of safety between part design limits and applied stress thereby providing extra protection for the part. By applying de-rating in an electrical design its degradation rate is reduced, the reliability and life expectancy are improved [6]. By considering a De-rating factor of 0.85, the standard current that flows through the secondary cable is given by:

$$I_{standard} = \frac{I_{rated}}{\text{derating factor}} = \frac{962.53}{0.85} = 1132 \text{ A} \quad (4.6)$$

The stranded copper conductors Table B.5 shows that a 3x1000 mm² single core unarmored XLPE insulated PVC sheathed 600/1000V stranded copper conductors cable would be capable of carrying a load of 1149A.

The rated current of the primary cable is also calculated by Eq. (4.7) as follow;

$$I_{rated} = \frac{MVA}{\sqrt{3} \times V} = \frac{25MVA}{\sqrt{3} \times 33KV} = 437.4 \text{ A} \quad (4.7)$$

$$I_{standard} = \frac{I_{rated}}{\text{derating factor}} = \frac{437.4}{0.85} = 514.57 \text{ A} \quad (4.8)$$

From the stranded copper conductors table, we can get a 3x300 mm² single core unarmored XLPE insulated PVC sheathed 600/1000V stranded copper conductors cable that would be capable of carrying a load of 584 A.

10) Voltage Drop Calculations

Permissible voltage drop is computed by calculating the highest current drawn by the load multiplied by an appropriate factor. The maximum voltage drop according to IEEE standard for distribution system is 5% for secondary feeders and 10% for primary feeders. The voltage drop can be calculated by multiplying the current by the impedance of the length of the cable. Calculate the percentage voltage drop by reference to the phase-to-neutral voltage [6].

The voltage drop is calculated by Eq.(4.9):

$$V_{drop} = \sqrt{3} \times I_{rated} \times z \times D \quad (4.9)$$

where:

D Is distance in Km

z Is impedance in Ω/km

From the data Table, B.4 of conductor specifications impedance per kilometer for $3 \times 300 \text{ mm}^2$ cable is $0.1131 \Omega/\text{km}$ and considering a distance from Adama substation to ASTU substation is 15km.

The voltage drop in the primary feeder is calculated as follows;

$$V_{drop} = \sqrt{3} \times \frac{0.1131 \Omega}{\text{km}} \times 437.4 \text{ A} \times 15 \text{ km} = 1285.2 \text{ V}$$

Percentage voltage drop = $(1285.2 / 33000) \times 100 = 3.9 \%$, if $(3.9\% \leq 10\%)$ which is acceptable.

From the data Table, B.4 of conductor specifications impedance per kilometer for $3 \times 1000 \text{ mm}^2$ the impedance per kilometer is $0.0819 \Omega/\text{km}$, and considering an average distance from to the load is 1.2km, the voltage drop in the primary feeder is calculated as follows;

$$V_{drop} = \sqrt{3} \left(\times \frac{z}{\text{km}} \right) \times I_{rated} \times D$$

$$V_{drop} = \sqrt{3} \times \frac{0.0819 \Omega}{\text{km}} \times 1132 \text{ A} \times 1.2 \text{ km} = 192.69 \text{ V}$$

Percentage voltage drop = $(192.69 / 15000) \times 100 = 1.28\%$ ($1.28 \leq 5\%$) which is acceptable value.

Fault Current Calculations

Electric cables are designed to operate below a certain maximum temperature, this being dependent on the conductor material and the type and the thickness of the insulation. Cable selection for a particular installation must therefore be made based on not exceeding these temperature limits.

For a power transformer with 33/15 kV with a 25 MVA rating, the short-circuit capacity is 1000 MVA [IEC 60076-5]. The earth fault level is 100 MVA, and it may be assumed that a fault will be cleared in half a second.

The supply impedance seen from the primary side is given by Equation (4.10).

$$Z_{sys} = \frac{V_p^2}{S_{sc}} = \frac{33^2}{1000} = 1.089 \Omega \quad (4.10)$$

The short circuit current that can exist on the primary feeder is calculated by Equation (4.11)

$$\begin{aligned} I_{sc} &= \frac{(V_p)}{\sqrt{3} \times Z_{sys}} \\ &= \frac{(33kV)}{\sqrt{3} \times 1.089} = 17.5 kA \end{aligned} \quad (4.11)$$

Or the short circuit current that can exist on the secondary feeder can be calculated by Equation (4.12)

$$I_{sc} = \frac{\text{short circuit MVA}}{\sqrt{3} \times \text{Voltage rating}} \quad (4.12)$$

$$I_{sc} = \frac{1000 \text{ MVA}}{\sqrt{3} \times 33kV} = 17.5 kA$$

The short circuit current withstand capacity of the cable is calculated by Equation (4.13);

$$I_{sc} = \frac{K \times A}{\sqrt{t}} \quad (4.13)$$

where:

A Is a Cross-section of the conductor (mm²)

I_{sc} Is Short circuit rating of cable (kA)

t Is time to trip (in seconds)

K Is a constant that depends on conductor material and temperature

$K = 143 \text{ A/mm}^2$ for XLPE, Copper conductor

$K = 92 \text{ A/mm}^2$ for XLPE, the Aluminum conductor

$$I_{scw} = \frac{143 \times 300}{\sqrt{0.5}} = 60.67 \text{ kA}$$

Therefore, the cable can withstand the prospective short circuit current.

The cable earth fault current that can exist in the primary feeder is calculated by Equation (4.14);

$$I_{EF} = \frac{\text{Earth Fault MVA}}{\sqrt{3} \times \text{Voltage Rating}} \quad (4.14)$$

$$= \frac{100 \text{ MVA}}{\sqrt{3} \times 33} = 1.75 \text{ kA}$$

The cable earth fault current withstand capacity of the cable is calculated by Equation (4.15)

$$I_{EF} = \frac{K \times A}{\sqrt{t}} \quad (4.15)$$

where:

I_{EF} Is Earth fault current rating of cable (kA)

A Is a Cross-section of the conductor (mm^2)

t Is time to trip (in seconds)

K Is a constant that depends on conductor material and temperature:

$= 143 \text{ A/mm}^2$ for XLPE, Copper conduct

$= 92 \text{ A/mm}^2$ for XLPE, the Aluminum conductor

$$I_{EFw} = \frac{143 \times 300}{\sqrt{0.5}} = 60.67 \text{ kA}$$

Therefore, the cable can withstand the prospective earth fault current.

In many cases, the cable conductor size is larger than dictated by the full load current and is chosen to withstand the prospective short-circuit current. The use of large conductors can be avoided by improving the speed of protection and in the case of earth fault current, by the use of sensitive earth fault protection.

The supply impedance transferred to the secondary side is given by Equation (4.16).

$$Z_L = Z_{sys} \times \left(\frac{V_S}{V_P}\right)^2 = 1.089\Omega \times \left(\frac{15}{33}\right)^2 = 0.225\Omega \quad (4.16)$$

The short circuit current that can exist on the secondary feeder is calculated by Equation (4.17).

$$I_{sc} = \frac{V_S}{\sqrt{3} \times Z_L} = \frac{15}{\sqrt{3} \times 0.225} = 38.49 \text{ kA} \quad (4.17)$$

Or the short circuit current that can exist in the secondary feeder is calculated by Equation (4.18);

$$I_{sc} = \frac{\text{short circuit MVA}}{\sqrt{3} \times \text{Voltage rating}} = \frac{1000 \text{ MVA}}{\sqrt{3} \times 15 \text{ kV}} = 38.49 \text{ kA} \quad (4.18)$$

The short circuit current withstand capacity of the cable is calculated by Equation (4.19);

$$I_{scw} = \frac{K \times A}{\sqrt{t}} \quad (4.19)$$

where:

I_{sc} is short circuit rating of cable (kA)

A is a cross-section of the conductor (mm^2)

t is time to trip (in seconds)

K is a constant that depends on conductor material and temperature:

= 143 A/mm^2 for XLPE, Copper conductor

= 92 A/mm^2 for XLPE, the Aluminum conductor

$$I_{scw} = \frac{143 \times 1000}{\sqrt{0.5}} = 202.232 \text{ kA}$$

Therefore, the cable can withstand the prospective short circuit current.

The cable earth fault current that can exist in the secondary feeder is calculated by Equation (4.20).

$$I_{EF} = \frac{\text{Earth Fault MVA}}{\sqrt{3} \times \text{Voltage Rating}} \quad (4.20)$$

$$= \frac{100 \text{ MVA}}{\sqrt{3} \times 15} = 3.849 \text{ kA}$$

The cable earth fault current withstand capacity of the cable is calculated by Equation (4.21).

$$I_{EF} = \frac{K \times A}{\sqrt{t}} \quad (4.21)$$

where,

- I_{EF} Earth fault current rating of cable (kA)
- A Cross-section of the conductor (mm^2)
- A Cross-section of the conductor (mm^2)
- t time to trip (in seconds)

$$I_{EFw} = \frac{143 \times 1000}{\sqrt{0.5}} = 202.23 \text{ kA}$$

Therefore, the cable can withstand the prospective earth fault current.

In many cases, the cable conductor size is larger than dictated by the full load current and is chosen to withstand the prospective short-circuit current. The use of large conductors can be avoided by improving the speed of protection and in the case of earth fault current, by the use of sensitive earth fault protection.

4.2.1 Substation Grounding Design

Safety and reliability are the two major concerns in the operation and design of an electrical substation. These concerns also pertain to the design of substations. To ensure that substations are safe and reliable, the substation must have a properly designed earthing (grounding) system. Earthing or grounding means connecting all parts of the apparatus (other than the live part) to the general mass of the earth by wire of negligible resistance. This ensures that all parts of the equipment other than the live part shall be at earth potential (i.e., zero potential) so

that the operator shall be at earth potential at all the time, thus will avoid shock to the operator. The neutrality of the supply system is also solidly earthed to ensure its potential is equal to zero.

The substation ground grid design is based on the substation layout plan. The following points serve as guidelines to start a grounding grid design [6].

- The substation should surround the perimeter and take up as much area as possible to avoid high current concentrations. Using more area also reduces the resistance of the grounding grid.
- Typically conductors are laid in parallel lines. Where it is practical, the conductors are laid along the structures or rows of equipment to provide short ground connections.
- Typical substation grid systems may include 4/0 bare copper conductor buried 0.3-0.5 m below grade and spaced 3-7 m apart in a grid pattern. The conductors should be securely bonded at cross-connections.
- Ground rods may be installed at grid corners and junction points along the perimeter. They may also be installed at major equipment, especially near surge arresters.
- The grid should extend over the entire substation and beyond the fence line.
- The ratio of the sides of the grid meshes is usually 1:1 to 1:3.

Conductors can be of various materials including copper, copper-clad steel, aluminum, or steel. Each type of conductor has advantages and disadvantages. Copper is the most commonly used material for grounding. Copper has high conductivity. Also, it is resistant to most underground corrosion because it is a cathode concerning most other metals. It also has good temperature characteristics and thermal capacity [6].

Generally, the grounding design contains the following parameters:

(a) The resistivity of a soil

The earth's soil can be considered to be a pure resistance and thus is the final location where a fault current is dispersed. Soil resistance can contain a current up to a critical amount which varies depending on the soil and at this point, electrical arcs can develop on the surface of the soil that can electrify objects on the surface such as a person [6]. Table 4.13 shows a basic collection of soil resistivity depending on the moisture and temperature.

Table 4.13 Basic Range of Soil Resistivity Ref. IEEE Std.80

Type of earth	Average Resistivity(Ω -m)
Wet organic soil	10
Moist soil	100
Dry soil	1000
Bedrock	10000

Table 4.13 shows that wet or even moist soil has very small resistances so it is beneficial to keep the grounding soil as damp as possible. To greatly reduce the shock current and increase the contact resistance between the soil and the feet of people in a substation, a thin layer of a highly resistive protective surface material just as a crushed rock (gravel) is spread above the earth grade at a substation.

(b) Resistance of the Human Body

The internal resistance of a human body is approximately 300 Ω . The body resistance including skin ranges from 500-3000 Ω [6]. For simplicity, IEEE Std. 80-2000 represents the resistance of a human body from hand-to-feet and also from hand-to-hand, or from one foot to the other as (RB = 1000 Ω).

Grid Current Calculation

A portion of the fault current will flow through the grounding grid to the earth. This is called the grid current and must be calculated. The maximum grid current, I_G is calculated by Equation (4.22);

$$I_G = D_f * I_g \quad (4.22)$$

where:

I_G = maximum grid current/ asymmetrical fault current (A)

D_f = the decrement factor for the duration of the fault (From Table 4.14)

$I_g = I_{EF}$ = RMS symmetrical grid/fault current (A)

Table 4.14 Typical Values of Df Ref. IEEE Std. 80-2000

Fault Duration, tf (Seconds)	Decrement factor, Df				
	Cycles at 50 Hz	X/R=10	X/R = 20	X/R= 30	X/R= 40
0.00833	0.4165	1.576	1.648	1.675	1.688
0.05	2.5	1.232	1.378	1.462	1.515
0.1	5	1.25	1.232	1.316	1.378
0.2	10	1.064	1.125	1.181	1.232
0.3	15	1.043	1.085	1.125	1.163
0.4	20	1.033	1.064	1.095	1.125
0.5	25	1.026	1.052	1.077	1.101
0.75	37.5	1.018	1.035	1.052	1.068
1	50	1.013	1.026	1.039	1.052

Using Table 4.14 for a fault duration of 0.5 seconds and the X/R ratio of 10, the decrement factor

$$D_f = 1.026, I_G = 1.026 * 60.67 = 64.3102 \text{ kA}$$

(c) Earth Conductor Sizing

The cross-section area of the main earth conductor should be decided by considering mechanical thermal and electrical considerations. The equation (4.23) is based on referred ANSI/IEEE standard.

$$A = \frac{I_G}{\sqrt{\left(\frac{TCAP * 10^{-4}}{t_c a_\gamma \rho_\gamma}\right) \ln\left(\frac{K_o + T_m}{K_o + T_a}\right)}} \quad (4.23)$$

where:

I_G Asymmetrical fault current (kA) = 64.310 kA

A Conductor cross-section (mm^2)

T_m Maximum allowable temperature ($^{\circ}\text{C}$) = 1084 $^{\circ}\text{C}$

T_a Ambient temperature ($^{\circ}\text{C}$) = 40 $^{\circ}\text{C}$

α_r Thermal coefficient of resistivity at a reference temperature

T_r ($1/^{\circ}\text{C}$) = 0.00381 ($1/^{\circ}\text{C}$)

ρ_r resistivity of the ground conductor at reference temperature T_r ($\mu\Omega\text{-cm}$) = 1.78

t_c Duration of fault current (sec) = 0.5

K_0 Equals $1/\alpha_0$ or $(1/\alpha_r) - T_r$ ($^{\circ}\text{C}$) = 242

TCAP thermal capacity per unit volume ($\text{J}/\text{dn}2\text{-}^{\circ}\text{C}$) = 3.42

Common values of α_r , K_0 , T_m , ρ_r , and TCAP values can be found in Table B.3.

The cross-section area of the earth conductor is then calculated by Equation (4.23) as follows

$$A = \frac{64.3102kA}{\sqrt{\left(\frac{3.42*10^{-4}}{0.5*0.00381*1.7}\right) \ln\left(\frac{242+1084}{242+40}\right)}} = 162.76 \text{ mm}^2$$

The diameter of a conductor (d_c) can be calculated by Equation (4.24)

$$d_c = 2\sqrt{\frac{A}{\pi}} = 2\sqrt{\frac{162.76}{\pi}} = 14.4 \text{ mm} \quad (4.24)$$

From the results of the cross-section area of the earth conductor determination, we get 162.76mm^2 .

(d) Grid Resistance Calculation

The ground resistance for a substation needs to be very low to minimize the ground potential rise and increase the safety of the substation. The ground resistance is usually 1Ω or less for transmission and other large substations [6]. In distribution substations, the usual acceptable range is $1\text{-}5\Omega$. Resistance primarily depends on the area to be occupied. Also, resistance can be decreased for a given area by using ground rods and adding more grid conductors. If it is impossible to reach the desired ground resistance by adding more grid conductors and/or

ground rods, the soil surrounding the electrode can be modified [6]. Considering the area occupied by the grounding grid a layout of $200 \times 150 \text{m}^2$ with equally spaced conductors in ETAP software we can see the results of ground grid design as shown in Figure 4.3 with spacing distance $D = 25 \text{m}$ and a grid burial depth $h = 0.5 \text{m}$. Earth-Mat Design is done according to design procedure on referred ANSI/IEEE standard. In Table 4.15 all the input data for ETAP to design the grounding system are given.

Table 4.15 Basic Data for Earth-Mat design

Parameters	Designed value
Design rectangle (total area)	$200 \text{m} \times 150 \text{m} = 30,000 \text{ m}^2$
Area occupied (A)	10000m^2
Fault current (IEF = I_g)	60.67kA
Fault duration	0.5 sec
Soil resistivity	1000 ohm-m
Depth of burial	0.5 m
Earth electrode	40 cm dia. hard-drawn copper wire, 3 m long
Earth mat conductor	Copper Round
X/R ratio	10

The grid wire pattern is $200 \times 150 \text{m}^2$ and the grid conductor combined length (L_C) is

$$L_C = (8 \times 200) + (150 \times 6) = 3,200 \text{ m}$$

Assume that the 32 ground rods, 3m long are used as shown in Figure 4.3,

$$L_R = 32 \times 3 = 96 \text{ m}$$

The total length of the buried conductor (L_T) is

$$L_T = L_R + L_C = 96 \text{m} + 3,200 \text{m} = 3296 \text{ m}$$

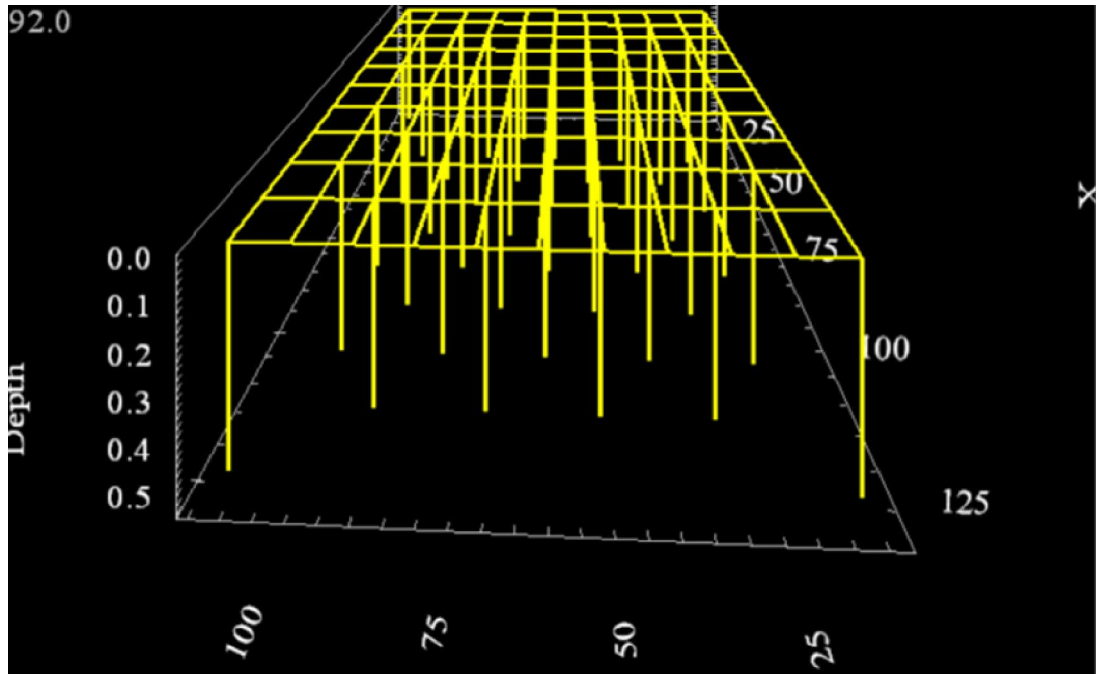


Figure 4.3 ETAP Earth Mat –Design of Proposed System

Using the total length of the buried conductor calculated in the previous step $L_T = 3296\text{m}$ and having the grid area $A = 30000 \text{ m}^2$, the substation grounding resistance (R_g) is calculated by Equation (4.25) by considering dry soil.

$$R_g = \rho \left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}} \left(1 + \frac{1}{h \sqrt{\frac{20}{A}}} \right) \right] \quad (4.25)$$

where:

R_g Is substation ground resistance (Ω)

ρ Is soil resistivity ($\Omega\text{-m}$) = $1000 \text{ }\Omega\text{-m}$

L_T Is the total length of buried conductor = 3296 m

A Is area occupied by the ground grid (n^2) = 30000 m^2

h Is ground rod height = 3m

$$R_g = 1000 \left[\frac{1}{3296} + \frac{1}{\sqrt{20 \times 30000}} \left(1 + \frac{1}{1 + 3 \sqrt{\frac{20}{30000}}} \right) \right] = 2.86 \Omega$$

4.2.2 Calculation of Attainable Touch and Step Potential

Attainable touch voltage is a form of touch voltage. Attainable touch voltages represent the highest possible touch voltages that may be encountered within a substation's grounding system. Attainable touch voltage is the basis for designing a safe grounding system, both inside the substation and immediately outside. For the grounding system to be safe, the attainable touch voltage has to be less than the tolerable touch voltage. Otherwise, the substation ground grid design needs modification [6].

The attainable touch voltage can be calculated by Equation (4.26);

$$E_{attainabletouch} = \frac{\rho K_i K_m I_G}{L_m} \quad (4.26)$$

where:

I_G is Asymmetrical fault current (kA) = 64.310 kA

ρ is the resistivity of the earth (Ω/m) = 1000(Ω/m)

L_M is effective burial length (m)

K_m is a geometrical spacing factor

K_i is an irregularity factor

The geometrical spacing factor, K_m , for attainable touch voltage is calculated by Equation (4.27) [6];

$$K_m = \frac{1}{2\pi} \left[\ln \left[\frac{D^2}{16hd} + \frac{(d+2+h)}{8hd} - \frac{h}{4d} \right] \right] + \frac{K_{ii}}{k_h} \ln \left[\frac{8}{\pi(2n-1)} \right] \quad (4.27)$$

where:

D is spacing between parallel conductors (m) = 25 m

d is the diameter of grid conductors (m) = 14.4mm

h is the depth of ground grid conductors (m) = 0.5 m

K_{ii} is a corrective weighting factor adjusting for the effects of inner conductors on the corner mesh =1

K_h is corrective weighting factor adjusting for the effects of grid depth =1.225

n is the geometric factor

The corrective weighted factor K_h is calculated by Equation (4.28);

$$K_h = \sqrt{1 + \frac{h}{h_o}} \quad (4.28)$$

Where:

h_o Is grid reference depth ($h_o = 1$)

$$K_h = \sqrt{1 + \frac{0.5}{1}} = 1.225$$

For ground grids with ground rods along the perimeter and throughout the grid, as well as in the corners, the corrective weighting factor, $K_{ii} = 1$ [6].

The geometric factor n is calculated by Equation (4.29).

$$n = \frac{n_a n_b n_c n_d}{L_p} \quad (4.29)$$

where:

$$n_a = \frac{2 \times 3200}{700} = 9.14$$

$n_b = 1$ for square grids

$n_c = 1$ for square and rectangular grids

$n_d = 1$ for square, rectangular, and L-shaped grids

$$n = 7.75 \times 1 \times 1 \times 1 = 9.14$$

The irregularity factor K_i is used in conjunction with n and it is calculated in (4.27) [6].

$$\begin{aligned} K_i &= 0.644 \times 0.148 \times n \\ &= 0.664 \times 0.148 \times 9.14 = 0.89 \end{aligned}$$

$$K_m = \frac{1}{2\pi} \left[\ln \left[\frac{25^2}{16 \times 0.5 \times 0.0144} + \frac{(25 + 2 + 0.5)}{0.5 \times 8 \times 0.0144} - \frac{0.5}{4 \times 0.0144} \right] + \frac{1}{1.255} \ln \left[\frac{8}{\pi(2 \times 12.09 - 1)} \right] \right] = 1.38$$

For ground grids with ground rods along the perimeter and throughout the grid, as well as in the corners, the effective buried length L_M is calculated by Equation (4.30).

For ground grids with ground rods along the perimeter and throughout the grid, as well as in the corners, the effective buried length L_M is calculated by Equation (4.30) [6].

$$L_M = L_C \left[1.55 + 1.22 \left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}} \right) \right] L_R \quad (4.30)$$

where:

L_C is total length of conductor in the horizontal grid (m) = $(10 \times 200) + (8 \times 150) = 3200\text{m}$

L_P is peripheral length of grid (m) = $2(200+150) = 700\text{m}$

L_x is maximum length of grid in the x-direction (m) = $10 \times 200 = 2000\text{ m}$

L_y is maximum length of grid in the y-direction (m) = $8 \times 150 = 1200\text{ m}$

L_r is total length of each ground rods (m) = 3 m

L_R is total length of all ground rods (m) = $32 \times 3 = 96\text{ m}$

$$L_M = 3296 + \left[1.55 + 1.22 \left(\frac{3}{\sqrt{2000^2 + 1200^2}} \right) \right] 96 = 3349.43$$

$$E_{\text{attainable touch}} = \frac{1000 \times 64.31 \times 0.89 \times 1.38}{3349.43} = 23.58$$

If a grid system is designed for safe attainable touch voltages, the step voltages will be within tolerable limits. Step voltages are usually smaller than touch voltages because both feet are in series rather than parallel. Also, the body can tolerate higher currents through a foot-to-foot path because it doesn't pass through vital organs such as the heart. For the ground system to be safe, the attainable step voltage has to be less than the tolerable step voltage [6].

The attainable step voltage is calculated by Equation (4.31) ;

$$E_{attainable\ step} = \frac{\rho K_s K_i I_G}{L_S} \quad (4.31)$$

The effective buried conductor length L_S is calculated by equation (4.32) [6];

$$L_S = 0.75L_C + 0.85L_R \quad (4.32)$$

$$L_S = 0.75 \times 3200 + 0.85 \times 96 = 2481.6\ m$$

The steps factor K_S for the step voltage is calculated by Equation (4.33) [6];

$$K_s = \frac{1}{\pi} \left[\frac{1}{2h} + \frac{1}{D+h} + \frac{1}{D} (1 - 0.5^{n-2}) \right] \quad (4.33)$$

where:

D spacing between parallel conductors (m)

h depth of ground grid conductors (m)

n geometric factor composed of factors n_a , n_b , n_c , and n_d

$$K_s = \frac{1}{\pi} \left[\frac{1}{2 \times 0.5} + \frac{1}{25 + 0.5} + \frac{1}{25} (1 - 0.5^{9.14-2}) \right] = 0.34$$

Therefore, the attainable step voltage is

$$E_{attainable\ step} = \frac{1000 \times 0.34 \times 64.31 \times 0.86}{2481.6} = 7.57\ V$$

4.2.3 Calculation of Tolerable Touch and Step Potential

For a crushed rock surfacing layer (h_s) of 0.1m with surface layer resistivity of 3000 Ω -m, and with the soil resistivity of 1000 Ω -m, the reduction factor (C_S) can be calculated by equation (4.34) [6].

$$C_S = 1 - \frac{0.09 \left(1 - \frac{\rho}{\rho_s} \right)}{2h_s + 0.09} = 1 - \frac{0.09 \left(1 - \frac{1000}{3000} \right)}{2 \times 0.1 + 0.09} = 0.79 \quad (4.34)$$

The tolerable step and touch potentials are calculated by using Equations (4.35) and (4.36) respectively [6].

$$E_{tolerable\ step} = (1000 + 6 \times C_s \times \rho_s) \frac{0.116}{\sqrt{t_s}} \quad (4.35)$$

$$= (1000 + 6 \times 0.79 \times 3000) \frac{0.116}{\sqrt{0.5}} = 2496.82\ V$$

$$E_{tolerable\ touch} = (1000 + 1.5 C_s \rho_s) \frac{0.116}{\sqrt{t_s}} \quad (4.36)$$

$$E_{tolerable\ touch} = (1000 + 1.5 \times 0.79 \times 3000) \frac{0.116}{\sqrt{0.5}} = 747.24\ V$$

Once the attainable touch and step voltages are calculated, the results are compared with the tolerable touch and step voltages to see if the attainable touch and step voltage are below the tolerable.

$$\Rightarrow E_{Attainable\ touch} \ll E_{Tolerable\ touch}$$

$$\Rightarrow E_{Attainable\ step} \ll E_{Tolerable\ step}$$

- Since attainable touch voltage is less than the tolerable touch voltage and the attainable step voltage is less than the tolerable step voltage, therefore, the grounding system is safe.

4.3 Distribution Substation Layout

The drawing in Figure 4.4 of this section is drawn by using ETAP software and includes:

- A primary circuit which includes bus bars, transformers, and feeder lines
- Switching
- Functional Relaying
- Advanced Monitoring (Automation)
- Automatic meter reading (AMR)

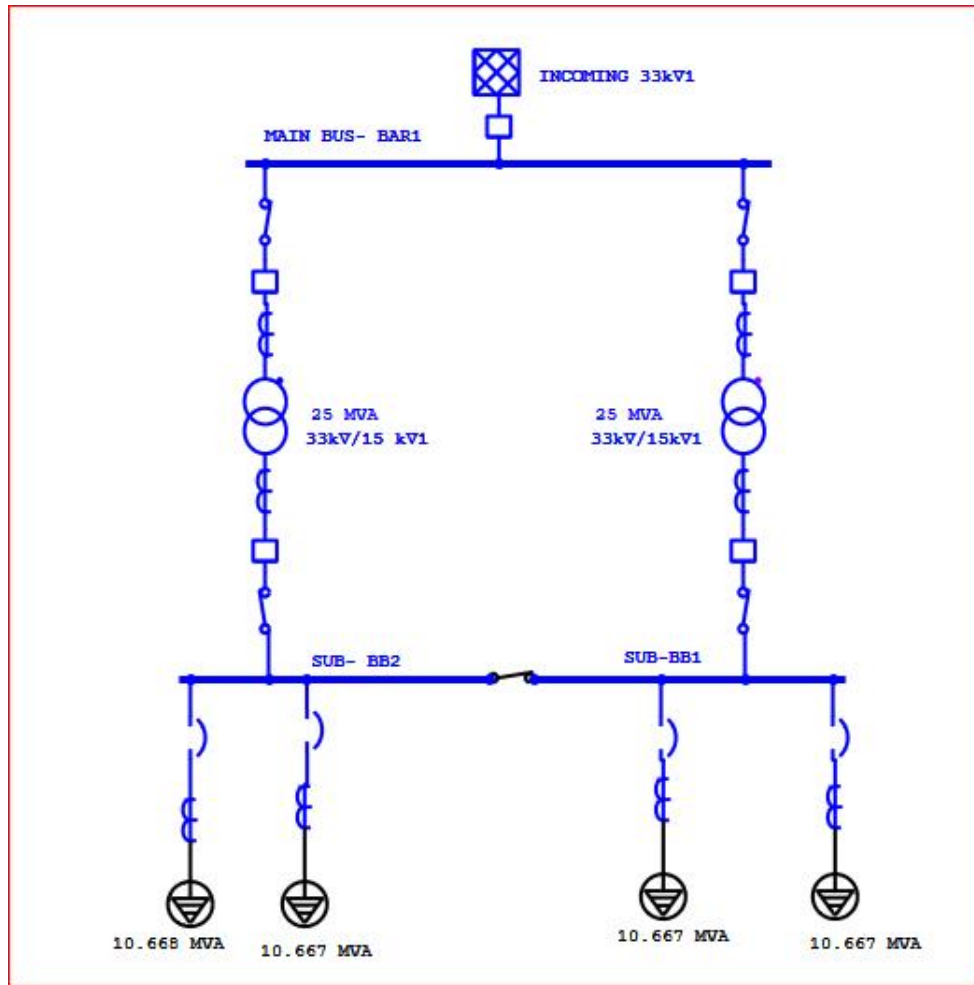


Figure 4.4 Complete single line diagram of the designed system

From figure 4.4, the feeders serving a particular ring main emanate from different bus sections which are in turn fed by different power transformers.

4.4 Optimization of the System through GA

This sub-topic presents a new genetic algorithm developed in this thesis for optimal power distribution network expansion planning. The algorithm finds the optimum (or near optimum) location and size of substations and feeders to minimize a cost function of the network, which represents capital (fixed costs) and operational costs (non-linear variable costs).

Most traditional optimization approaches are significantly different from genetic algorithms (GAs).

The following are the key distinct differences:

- Because genetic algorithms use the coding of decision variables rather than the variable itself, they may be used to solve issues with a high number of variables.
- As a result, they're perfect for solving combinatorial problems.
- Instead of working with a single solution, GAs deal with a population of solutions.
- As a result, GAs can simultaneously give several solutions in a single simulation run, allowing them to be utilized to identify Pareto-optimal solutions for multi-objective issues.
- GAs is capable of handling discontinuous, non-convex, and non-linear functions since they do not place any constraints on the objective function to be optimized.

Therefore, genetic algorithms are ideal algorithms for solving the distribution system planning problem, formulated either as a single-objective or as a multi-objective optimization problem.

The following factors were taken into account in the planning and selection of an appropriate location for the proposed ASTU substation.

1. Existing sub-transmission lines location; there were two lines, one to the north and the other on the northeastern side.
2. Load densities; the area with the highest load density was ascertained by using the GIS location as shown in Figure 4.5.
3. Closeness to load centers.
4. Feeder limitations; distance to the furthest load center was limited to 2km to ensure there was good voltage regulation, reduced line losses, and feeder costs.
5. Future loads are more likely to be concentrated around the student cafeteria, according to the load forecast.

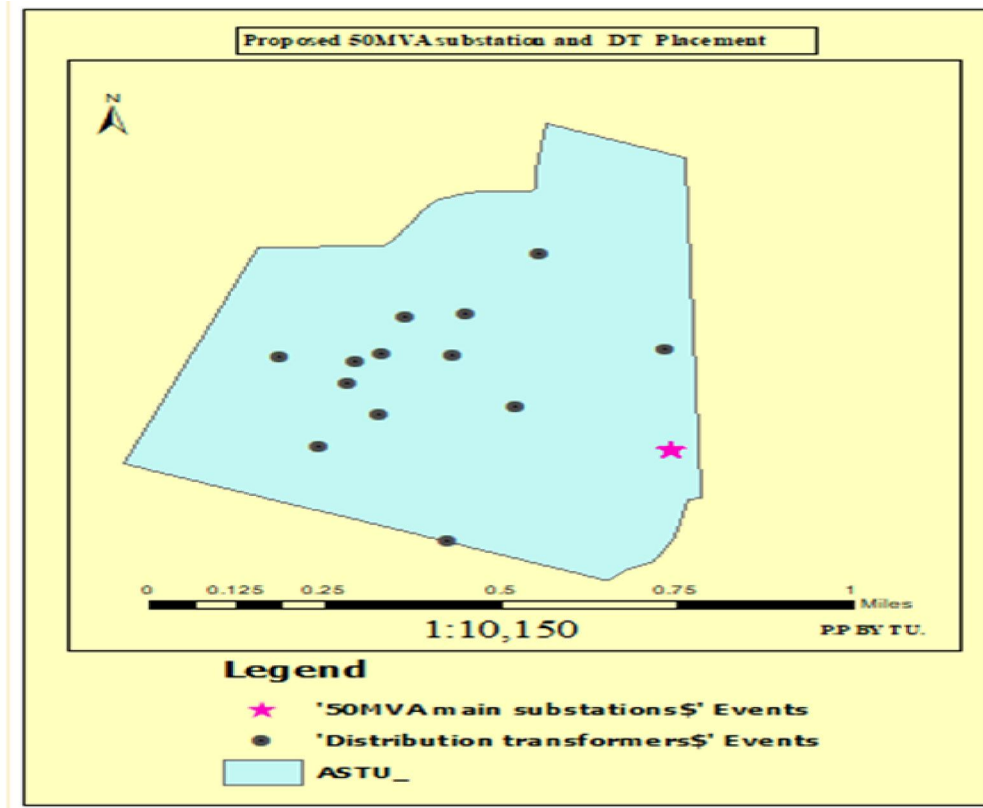


Figure 4.5 GIS Placement of ASTU substation site locations

Adama Science and Technology University has provided data for this thesis. Table 4.16 shows examples of load locations where latitude and longitude are calculated using GIS coordinates.

Table 4.16 Data of load location

S/No.	Latitude (X)	Longitude (Y)	Load (kW)
1	39.29	8.564	358.62
2	39.29	8.562	304.43
3	39.29	8.557	825.72
.	.	.	.
.	.	.	.
27	39.29	8.563	188.62
28	39.29	8.562	216.33

The coordinate is taken from Google Earth, so it must be converted to a degree decimal point. Before choosing the capacity of the transformer, firstly the database of the transformer must be fixed. Table 4.17 shows the specification and price of the distribution transformer.

Table 4.17 Specification and price of the selected size distribution transformer

Transformer Type (kVA)	Install Cost (\$)	Open-Circuit Losses (kW)	Short-Circuit Losses (kW)
50	807.9252077	0.19	1.1
100	1696.642936	0.32	1.75
200	3158.987562	0.5	2.35
315	4120.418559	0.85	4
630	7828.795262	1.3	6.5
800	12223.90839	1.6	8
1000	15108.20138	1.7	10.5
1250	20602.0928	2	12
1600	28087.51984	2.6	17

Table 4.18 shows an example of a transformer candidate's coordinates. The distance between the candidate and the load point must be calculated to calculate the voltage drop, losses, and investment cost of that network. This distance is calculated using the Euclidean formula [7]. As shown in Table 4.18, the calculated distances are saved in a matrix.

Table 4.18 Transformer load distance matrix

Load	Transformer			
	1	2	3	4
1	D11	D12	D13	D14
2	D21	D22	D23	D24
3	D31	D32	D33	D34
4	D41	D42	D43	D44

Table 4.19 Coordinate of transformer candidate

S/No.	Trans –Coordinates		Trans-Capacity (kVA)
	X	Y	
1	39.2905	8.5568	1250
2	39.2844	8.5605	630
.	.	.	.
.	.	.	.
17	39.295	8.5635	1000
18	39.2951	8.5635	630

4.4.1 The Processes of GA Optimization

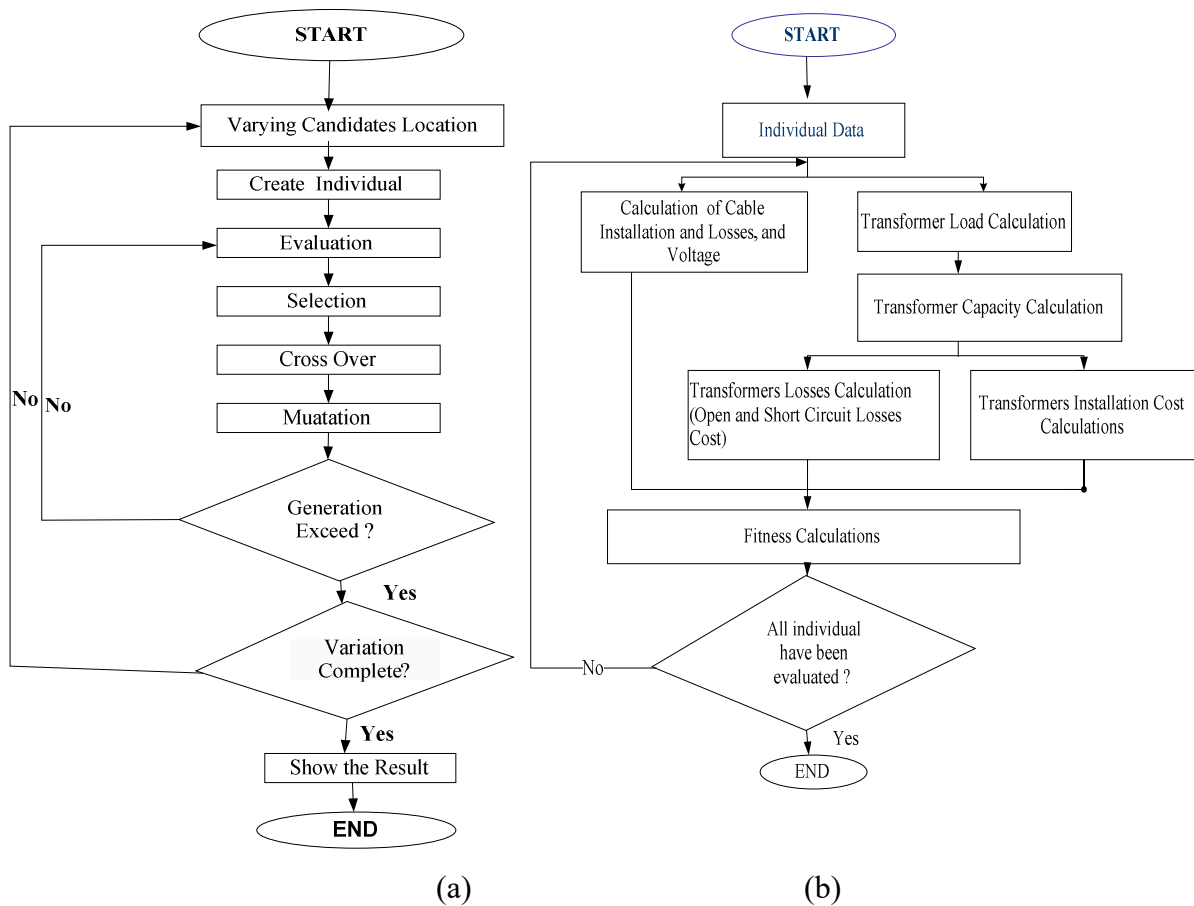


Figure 4.6 Optimization Process Flowchart (a) Overall Genetic Algorithm process (b) Fitness calculation process

A flowchart of the optimization process based on the GA method is shown in Fig.4.6 (a). From Fig. 4.6(a), the simulation is started by varying the location candidate of the

transformers. There are 18 location candidates with variations of the location candidates shown in table 4.20 below.

After varying the location candidate, the next step is creating the individual which represents the solution candidate. The example of the individuals is shown in Table 4.21. All of those individuals create many populations. In this case, the total number of individuals is 100 because the population is set to be 100. After creating all individuals, each must be evaluated its fitness score.

The flowchart of evaluation is shown in Fig. 4.6(b). The further step is the calculation of transformers load. In Table 4.21, the total loads connected to transformers 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 16 and 17 are calculated. Based on the total loads of each transformer, the capacity of the transformer can be determined. From the database, the transformers losses cost and transformers installation cost can also be calculated.

Table 4.20 Number of candidate transformer

Number of transformer candidates = 13																	
1	-	3	4	5	6	7	8	9	10	11	12	-	-	-	16	17	-

Table 4.21 Transformer-loads connection

load	transformer	load	transformer	load	transformer	load	transformer
1	12	8	10	15	8	22	16
2	5	9	4	16	5	23	5
3	1	10	17	17	7	24	6
4	8	11	6	18	3	25	9
5	10	12	4	19	5	26	10
6	12	13	3	20	5	27	10
7	11	14	16	21	5	28	10

The last step is fitness calculation as expressed by equation 4.37. All of the costs are combined to obtain the fitness which represents the total cost.

$$Fitness = F1 + F2 + F3 + F4 + F5 \quad (4.37)$$

where $F1$ = Transformer installation costs, $F2$ = cable installation costs, $F3$ = cable losses costs, $F4$ = open circuit losses costs, $F5$ = short circuit losses costs. If the voltage drop exceeds the limits, penalties scores should be added to the fitness score. By adding the penalties, this individual is expected not to be the best individual.

This algorithm is simulated on a very light and small network for simplicity. there are 28 load points in the simple network area (like a low voltage system) with 0.8 power factor and the available standard substation capacities in the inventory are 50MVA main substation and 630, 800 kVA, 1000 kVA, 1250 kVA, and 1600 kVA distribution transformers. Utility factor for planning purposes is considered equal to 0.8.

Finally, all of the above-mentioned design optimization parameters were fed into a genetic algorithm, yielding the desired results as we demanded to design an optimal substation. The following chapter of the thesis goes into greater detail about the output of the overall design result.

CHAPTER FIVE

RESULT AND DISCUSSION

In the following subsections, the proposed approach is truly tested on two different concerns: optimal location of the distribution transformer concerning the corresponding load center of the study area and medium voltage 33kV distribution substation design.

5.1 Reliability Analysis of Existing System and Switching Station of ASTU

When talking about the reliability of the incoming feeder of the ASTU from the Adama substation, it includes the reliability of each switching station R6_2. The 15kV incoming line three of the Adama substation has two switching stations one of these switching stations is R6-2 which feeds Adama science and technology university. The reliability index evaluation is mainly concerned with the reliability of the Adama Science and Technology University which is the study area of this thesis.

It is possible to show the reliability or unreliability of a given power distribution system, by using the most well-known two customer-based system reliability indexes. These system reliability indexes can be calculated using formulas given in Equations (3.2) and Equation (3.3). The feeders of the distribution system are radial so that total customers are considered as a single customer and the service demand hour is 8640 Hrs. based on the yearly collected data. Then results are tabulated in Table 5.1.

Table 5.1 Customer-based reliability indexes of ASTU distribution system

Feeder line	SAIFI (Fr/yr.)	SAIDI (Hr/yr.)	CAIDI (Hr/Fr)	ASAI (%)	ASUI (%)
L3	140	215.92	1.54	98.93	1.07

The existing Adama Science and Technology University system's average interruption frequency index is 140 fault/customer and the system's average interruption frequency index of 215.93 Hr/yr. The Adama science and technology university gets supply from feeder line-3 and switching station of R6-2 this feeder and switching station mostly affected by reliability problem.

5.2 Comparison of the Calculated Values of Reliability Indices of ASTU with Benchmark

The assessment of reliability indices for a power system network or of parts thereof is the assessment of the ability of that network to provide the connected customers with the electric energy of sufficient availability, as one aspect of power quality. Once we calculate the reliability indices then we have to compare them with the benchmark values of that network, in this case, the calculation results are compared with the benchmark value set by EEP and EEU to say the part of the network (the distribution system of ASTU) is reliable or not. And also the result is compared with standards of different countries by selecting the two most widely used reliability indices which are SAIFI and SAIDI values. Table 5.2, shows the comparison of the most commonly used reliability indices (SAIFI and SAIDI). Their calculated value of the particular year (2019/2020 GC.).

Table 5.2 Comparing the existing system reliability indexes of ASTU with different country standards

Country	Standard SAIFI value (int./year/customer)	Standard SAIDI value (int./year/customer)
USA	1.2	2.3
Europe	2.5	5.4
Sweden	1.2	2.5
Australia	2.3	3.3
Finland	5	6.9
Canada	3.4	6.9
Unite Kingdome	0.8	1.1
Ethiopia	20	25
ASTU	140	215.9

From the above reliability comparisons of the Adama Science and Technology University with different countries standards as represented in Table 5.1 the calculated values of the SAIFI and SAIDI values for ASTU is far from the standard value set by EEP and standard values of some other reference countries. This indicates that the distribution system of ASTU has serious reliability issues. As it has seen from the evaluation process ,the distribution system has the most common reliability problems are overloading of the distribution system and sitting of the station. So, it needs a mechanisms to overcome the reliability problems, one of such major mechanisms is designing an optimal location of the distribution substation to mitigate the

power reliability problem and to solve the overloading problems which will be discussed in the following subtopic of optimization.

5.3 Simulation Result of the Designed Substation

The result of reliability analysis is obtained by performing similar procedures as it is done for the existing system in the ETAP software. These procedures are:

- ✓ Draw the one line diagram on the working plane of the software
- ✓ Specify the voltage and power levels for each component
- ✓ Enter the created stochastic models in each component
- ✓ Specify the type and operation characteristics of switching and protection devices
- ✓ Run the reliability assessment

The following figure 5.2 illustrates the new designed substation for ASTU. In the figure it is shown that the new designed system is one main bus bar with one transfer bus bar with bus sectionalizer arrangement and the feeders are half sectioned by sub bus bar. The main bus bar supply 33kV to two adjacent parallel connected power transformer and then the transformers step down 33 kV to 15 kV. The 15kV line connected to sub-bus bar which are connected by bus sectionalizer and circuit breakers to the nearby feeder to achieve high reliability. And all switching devices are changed by automatically operated circuit breakers, isolators and load switches.

5.4 The ETAP input data of the system simulation of a new ASTU distribution substation

The following reliability input data in Table 5.3 to 5.8 are inserted to ETAP software to design a new distribution substation that fulfill all the international standards and to achieve reliability of the system.

Table 5.3 Load point input data

<u>Load Input Data</u>										
Load					No. of	λA	Momentary	MTTR	Replacement	
ID	Type	Connected Bus ID	kW	Sector	Loads	f / yr	$\lambda A\%$	hour	Avail.	Time
									Yes/No	hour
load1	LumpLd	SUB- BB2	1920.24	Govt. & Inst.	12	0.0200	80.00	50.00	Yes	10.00
load2	LumpLd	SUB- BB2	960.00	Govt. & Inst.	20	0.0200	80.00	50.00	Yes	10.00
load3	LumpLd	SUB-BB1	3840.00	Govt. & Inst.	8	0.0200	80.00	50.00	Yes	10.00
load4	LumpLd	SUB-BB1	1920.00	Govt. & Inst.	3	0.0200	80.00	50.00	No	10.00

Table 5.4 Bus bar input data

<u>Bus Input Data</u>							
Bus		λA	Momentary	MTTR	Switch	Replacement	
ID	kV	f / yr	$\lambda A\%$	hour	hour	Avail.	Time
						Yes/No	hour
MAIN BUS- BAR1	33.000	0.0010	80.00	2.00	1.00	No	1.00
SUB- BB2	15.000	0.0010	80.00	2.00	1.00	Yes	1.00
SUB-BB1	15.000	0.0010	80.00	2.00	1.00	Yes	1.00

Table 5.5 Source input data

<u>Source Input Data</u>								
Source				λA	Momentary	MTTR	Switch	Replacement
ID	Type	Connected Bus ID		f / yr	$\lambda A\%$	hour	hour	Avail.
								Yes/No
INCOMING 33kV1	Power Grid	MAIN BUS- BAR1		0.6430	80.00	2.00	2.00	No
								Time
								hour

Table 5.6 Branch connection structures

<u>Branch Connections</u>			
CKT/Branch		Connected Bus ID	
ID	Type	From Bus	To Bus
33kV/15 kV1	2W XFMR	MAIN BUS- BAR1	SUB- BB2
33kV/15kV1	2W XFMR	MAIN BUS- BAR1	SUB-BB1

Table 5.7 Input data for branches

<u>Branch Input Data</u>							
Transformer		λ_A	λ_P	Momentary Rate	MTTR	Switch Time	Replacen Avail.
ID	Type	f / yr	f / yr	$\lambda_A\%$	hour	hour	Yes/No
33kV/15 kV1	2W XFMR	0.0036	0.0036	80.00	67.00	67.00	No
33kV/15kV1	2W XFMR	0.0041	0.0041	80.00	378.00	378.00	No

Table 5.8 Switching device technical data

<u>Switching Device Input Data</u>									
Switching Device			λ_A	λ_P	Momentary Rate	MTTR	Switch Time	Replacement Avail.	Time
ID	Type	Status	f / yr	f / yr	$\lambda_A\%$	hour	hour	Yes/No	hour
CB-MN	HVBreaker		0.0176	0.0264	80.00	44.50	44.50	No	1
CB81	HVBreaker		0.0176	0.0264	80.00	44.50	44.50	No	1
IS-4	Switch		0.0061	0.0061	80.00	50.10	50.10	Yes	1
CB21.	HVBreaker		0.0036	0.0054	80.00	62.40	62.40	Yes	
ISL9	Switch		0.0061	0.0061	80.00	50.10	50.10	Yes	1
CB80	HVBreaker		0.0176	0.0264	80.00	44.50	44.50	No	1
IS-2	Switch		0.0061	0.0061	80.00	50.10	50.10	No	1
CB22.	HVBreaker		0.0036	0.0054	80.00	62.40	62.40	Yes	
ISL8	Switch		0.0061	0.0061	80.00	50.10	50.10	Yes	1
Bus- tie	Switch		0.0061	0.0061	80.00	50.10	50.10	No	1
LV-CB16	LVBreker		0.0030	0.0045	80.00	50.00	50.00	No	1
LV-CB17	LVBreker		0.0096	0.0144	80.00	8.00	8.00	Yes	
LV-CB15	LVBreker		0.0030	0.0045	80.00	50.00	50.00	No	1
LV-CB14	LVBreker		0.0030	0.0045	80.00	50.00	50.00	No	1

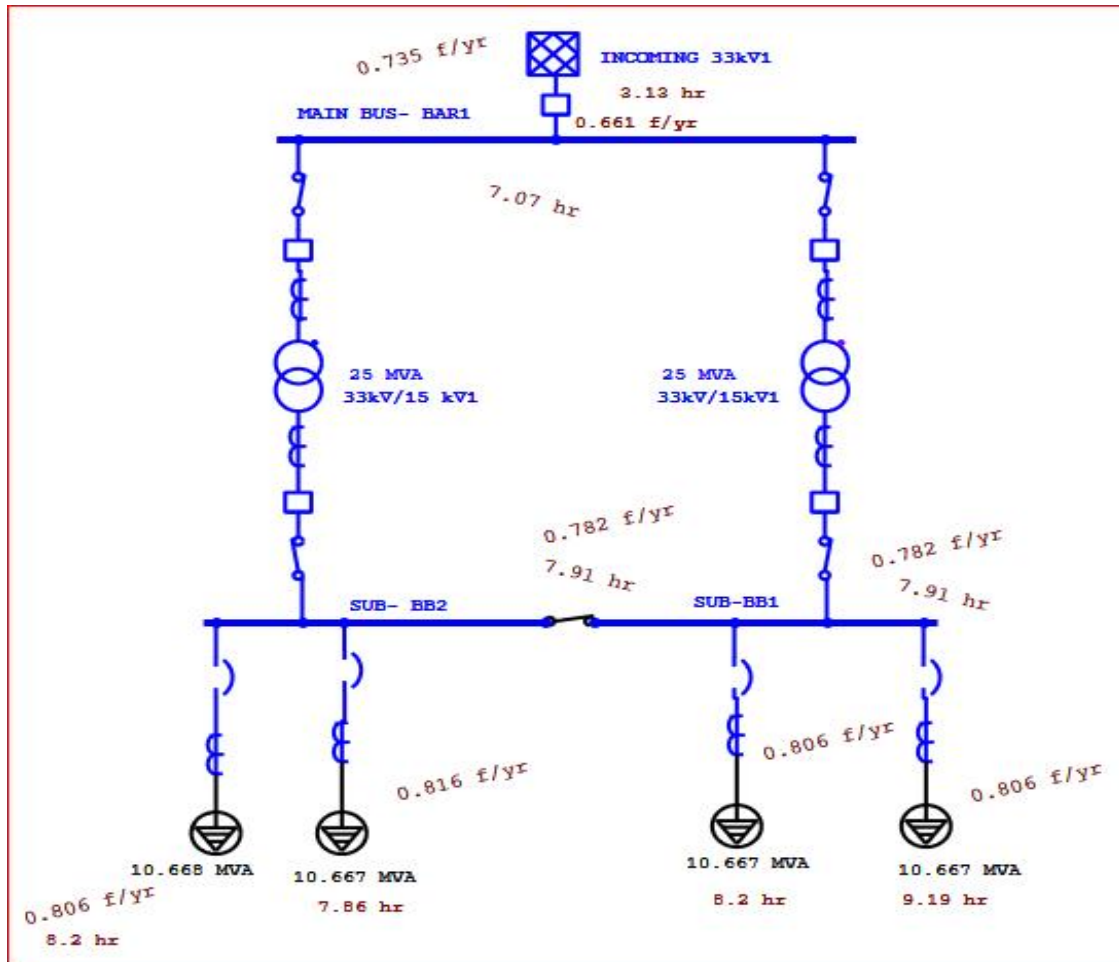


Figure 5.1 The layout of the new designed substation

The lay out single line diagram in Figure 5.1 in detail explains the reliability of the system and configuration of the new designed substation.

From the following outputs from Table 5.9 and Table 5.10 we can observe that the designed system gives an improved output of system reliability indices, load point reliability indices and energy reliability based indices. And these achievements are only by considering the primary system design.

Table 5.9 The reliability output of a new designed substation of ASTU

Project: Distribution Substation Design			ETAP					
Location: ASTU			19.0.1C		Date: 25-02-2022			
Contract: TBA								
Engineer: Tarekegn Uta			Study Case: RA		Revision: Base			
Filename: New SSD					Config.: Normal			

Load Point Output Report								
ID	Bus Load	Connected Bus ID	Average Interrupting Rate	Average Outage Duration	Annual Outage Duration	EENS	ECOST	IEAR
			f / yr	hour	hr / yr	MWhr/ yr.	\$ / yr.	\$ / kW hr
MAINBB1	N/A		0.7354	7.07	5.2016	0.0000	0.00	0.000
SUB-BB2	N/A		0.7815	7.91	6.1830	17.8084	69552.93	3.906
SUB-BB1	N/A		0.7815	7.91	6.1830	139094.20	35.6139	3.906
load1	Govt. & Inst.	SUB-BB2	0.8060	8.20	6.6080	12.6889	49737.34	3.920
load2	Govt. & Inst.	SUB-BB2	0.8159	7.86	6.4118	6.1553	23912.61	3.885
load3	Govt. & Inst.	SUB-BB1	0.8060	8.20	6.6080	25.3746	99462.26	3.920
load4	Govt. & Inst.	SUB-BB1	0.8060	9.19	7.4080	14.2233	57212.22	4.022
Incoming33kV	None	MBB1	0.6606	3.13	2.0692	0.0000	0.00	0.000

Table 5.10 Summary of the reliability indexes of the new designed system

Project: Distribution Substation Design	ETAP	Date: 25-02-2022
Location: ASTU	19.0.1C	Revision: Base
Contract: TBA		Config.: Normal
Engineer: Tarekegn Uta	Study Case: RA	
Filename: New SSD		

SUMMARY

System Indexes

ACCI	174.48 kVA / customer
AENS	1.2424 MW hr / customer.yr
ALII	0.78 Pu (kVA)
ASAI	0.9993 Pu
ASUI	0.00071 Pu
CAIDI	7.912 hr / customer interruption
CTAIDI	6.183 hr / customer.yr
ECOST	208,647.20 \$ / yr.
EENS	53.422 MW hr / yr.
IEAR	3.906 \$ / kW hr
SAIDI	6.1830 hr / customer.yr
SAIFI	0.7815 f / customer.yr

ACCI	System Average Customer Curtailment Index
AENS	Average Energy Not Supplied
ALII	System Average Connected kVA Interrupted per kVA of Connected Load Served
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CTAIDI	System Customer Total Average Interruption Duration Index
ECOST	Expected Interruption Cost
EENS	Expected Energy Not Supplied
IEAR	Interruption Energy Assessment Rate
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index

5.5 Discussion of the reliability of the ASTU supply system

As it is explained above the simulation is done to check if the new designed substation can improve the reliability of the power supply system. This can be done by comparing the outputs of the simulation. This section takes some of the reliability indices such as System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), and Energy Not Supplied (ENS) to compare the new and existing substation and to check the benefit to both supplier and customer from the new system.

Table 5.11 Selected reliability indexes simulation results for comparison

System	SAIDI	SAIFI	EENS/ENS
	hr/customer .yr	fr/cust.yr.	MWh/yr
Existing System	140	215.92	745.56
New System	6.183	0.7815	53.422

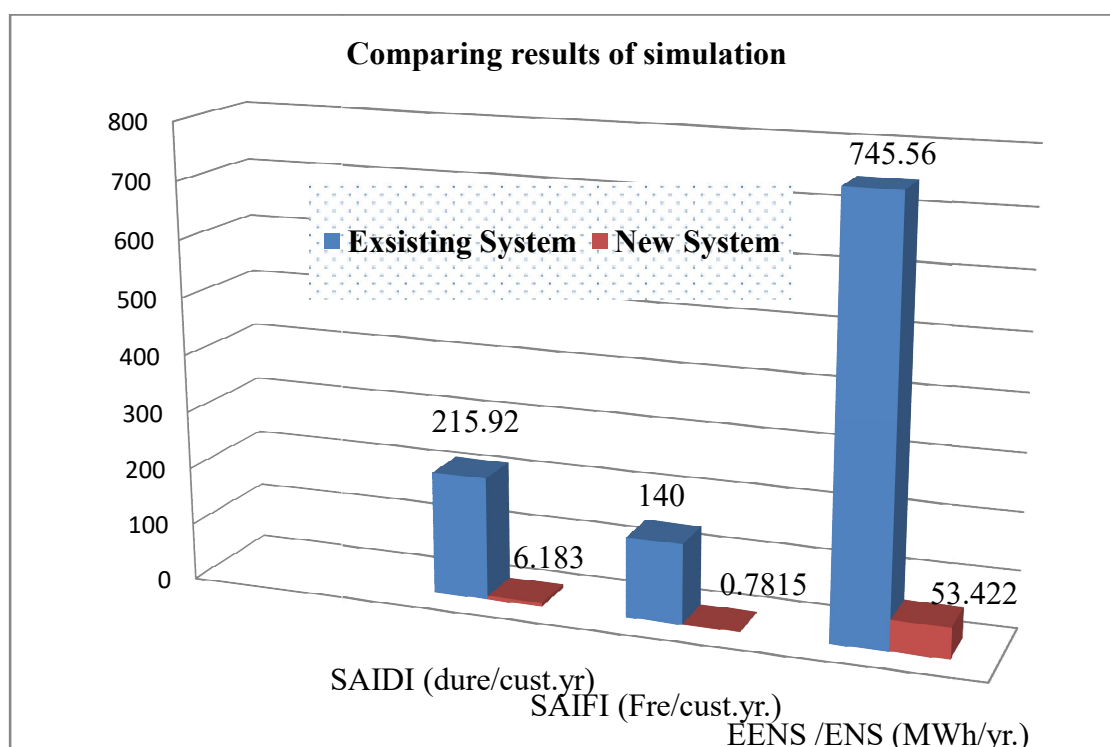


Figure 5.2 Comparing reliability indexes results of both system

5.6 Economic Analysis of the Existing and Designed System

Access to electricity supplies at a reasonable cost and quality levels has become a basic condition for development, economic growth, and welfare. The more developed societies are, the more vulnerable they are to electricity supply interruptions. This dependence on reliable electricity supplies implies that costs are associated with electricity supply interruptions.

The size of the economic losses due to interruptions depends largely on the composition of the customers that experience interruptions.

For industries, electricity supply interruption costs are strongly related to production losses and to costs involved in restoring production. In addition, interruptions also cause property damages and revenue losses for industries, commercial customers, and private individuals.

Wide-spread long-lasting blackouts put the vulnerable society to the test and involve extra expenses required to maintain tolerable living conditions. It is difficult to estimate the exact value interruption costs and economic losses since the properties of each customer are different.

Therefore, using the energy not supplied index (ENS) we can see how much Birr will be lost in the existing and the new substations. And we can compare the savings from these systems. Since the minimum value of the tariff is 0.273 Birr/kWh and the maximum value is 2.481 Birr/kWh then we can take the mean value of this to perform this analysis which is equal to 1.58 Birr/kWh.

The ENS of both systems is given in Table 5.11 and based on that, we can calculate the amount of money lost in both systems.

➤ For the existing system

$$\begin{aligned} ECOST &= ENS \times tariff & (5.1) \\ &= \left[\left(745.56 \left[\frac{MWh}{yr.} \right] \right) \times \left(\frac{1.58 \text{ birr}}{kWh} \right) \right] \\ &= \left[\left(745560 \frac{kWh}{yr.} \right) \times \left(1.58 \frac{\text{birr}}{kWh} \right) \right] \\ &= 1.18 \frac{\text{million birr}}{yr} \end{aligned}$$

➤ For the new system

$$\begin{aligned}
 ECOST &= ENS \times tariff \\
 &= \left[\left(53.422 \left[\frac{MWh}{yr.} \right] \right) \times \left(\frac{1.58 \text{ birr}}{kWh} \right) \right] \\
 &= \left[\left(53422 \frac{kWh}{yr.} \right) \times \left(1.58 \frac{\text{birr}}{kWh} \right) \right] \\
 &= 0.0844 \frac{\text{million birr}}{yr.}
 \end{aligned}$$

From this analysis we can see that the existing substation lost 1.18 million birr/yr. only because of the interruptions, and the designed substation can reduce this loss by 92.84% and the loss will be come 0.0844 million birr/yr.

5.6.1 Optimal location of the distribution transformers and load point

For the MV/LV substation number, location, and service area determination problem, a study system of 28 load points and 18 distribution transformer's geographical locations are being determined. Table C.6 in the Appendix contains data for the 28-load point system for the horizon year. For this design problem, the maximum utility factor of substations is assumed to be 80 percent. Table C.5 shows the possible conventional low voltage transformer and main substation transformer capacity and also the associated fixed costs. The load sites in the network are shown on the map of the study area in Fig.5.3 by using the X-Y coordinates of the geographical location of the load.

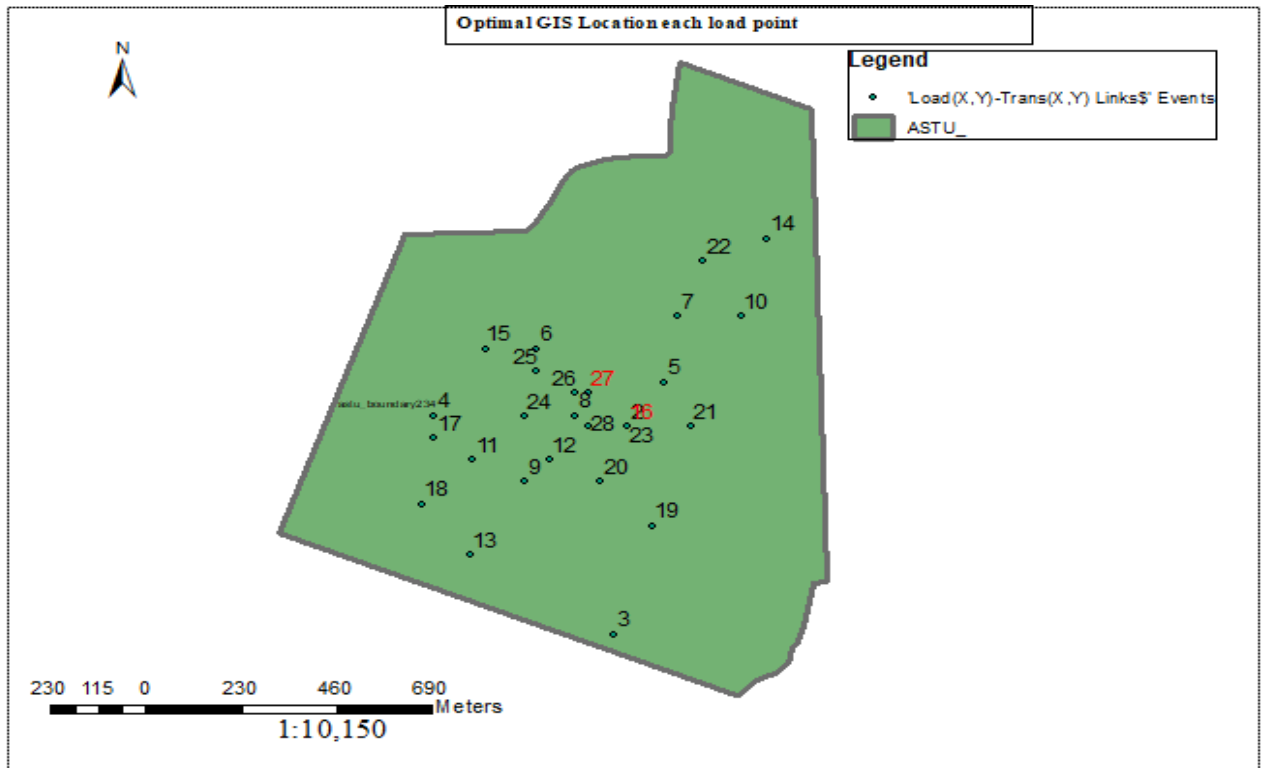


Figure 5.3 Geographical location of each load point of the study area

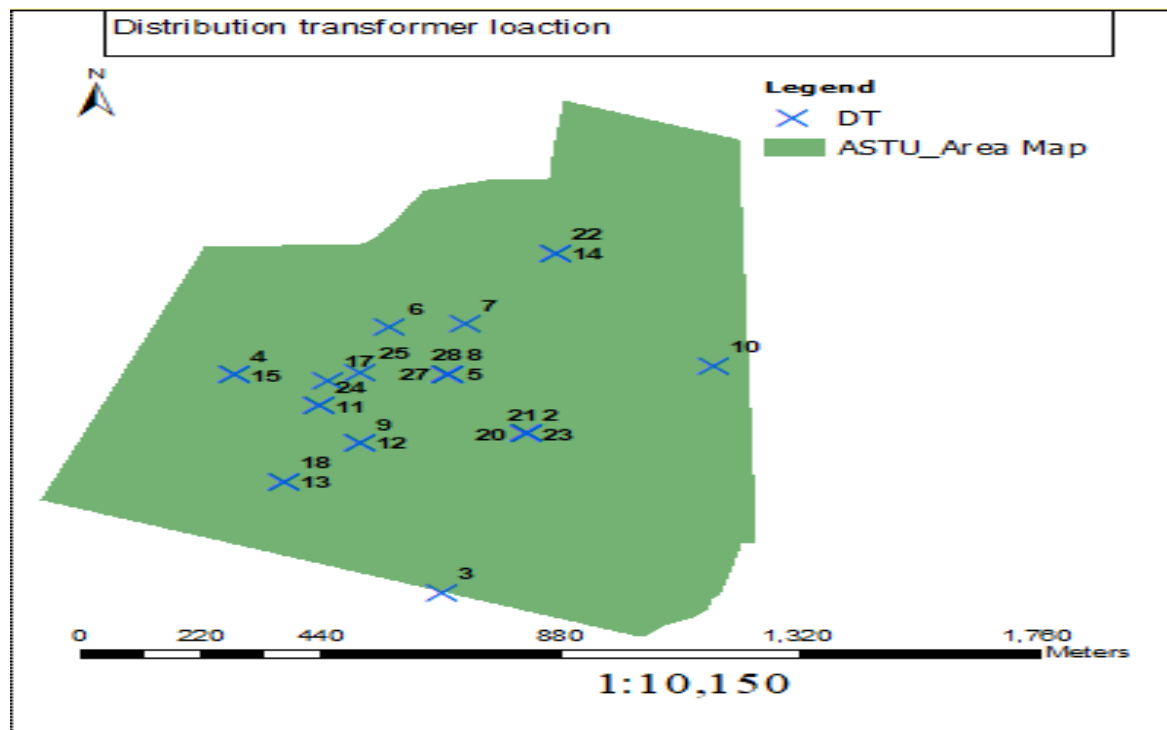


Figure 5.4 Geographical location of distribution transformer on the map of the study area

The distribution transformer location is determined by applying a genetic algorithm with a corresponding load point location. The above Figure 5.3 and Figure 5.4 show the geographical location of the load and current proposed distribution transformer location on the map of the study area. In Figure 5.3 above the small dots represents the load of that area and the number on it indicates the order name of the load point, whereas, in Figure 5.4, small 'x' symbols represent the location of the distribution transformer and the numbers indicate the corresponding load of the transformer that it supplies. The map of the study area is drawn by the ArcGIS software and locations of events taken from Google earth X-Y coordinates of the events which are recorded in the data Table C.1 and Table C.2. The output Table 5.12 of the developed software represents 13 distribution transformers that are selected to feed the existing loads and five distribution transformers are selected as sphere candidates. Table 5.12 below shows the sizes, capacities, and geographical location of the distribution transformer and the main 33kV substation both in one.

Table 5.12 Output of developed GA optimized size and location of distribution transformer

Existing 15kV supplying transformers					
Name of 15kV transformers	Trans - Coordinates		connected load Capacity(kW)	Proposed capacity(kVA)	Allocated load point
	X	Y			
DT-1	39.2905	8.5568	825.7168	1250	3
DT-2	39.2879	8.5601	888.8952	1250	13,18
DT-3	39.2892	8.5613	265.3863	630	9,12
DT-4	39.2919	8.5615	1348.3	1600	2,16,19,20,21,23
DT-5	39.2885	8.5624	260.2159	630	11,24
DT-6	39.2886	8.5631	463.6815	800	17
DT-7	39.2871	8.5633	557.7499	800	4,15
DT-8	39.2892	8.5633	229.9794	630	25
DT-9	39.2906	8.5633	2171.4	1600	5,8,26,27,28
DT-10	39.2909	8.5648	304.4332	630	7
DT-11	39.2897	8.5647	656.434	1000	1,6
DT-12	39.2924	8.5669	584.462	1000	22,14
DT-13	39.295	8.5635	692.7168	1000	10

Total		9249.371	12820	28
Chosen candidates 15 kV transformers				
Name of transformers	Trans - Coordinates		Proposed capacity(kVA)	Connected load
	X	Y		
New-1	39.2844	8.5605	630	to be allocated for the future
New-2	39.2898	8.566	630	to be allocated for the future
New-3	39.2912	8.5665	630	to be allocated for the future
New-4	39.2919	8.5669	630	to be allocated for the future
New-5	39.2951	8.5635	630	to be allocated for the future
Total		3150		

In detail, the information of each optimal location and size of distribution transformers are shown in Table 5.12. Even if, the connected load exceeds the capacity of the transformer. It is allowed because the customer is not always using the installed power at the maximum limit and not all customers experience peak loads at the same time. As the result of Table 5.12, for the active loads' location, the prepared capacity of distribution transformers indicated and for the new candidate load location, the new size of transformers are specified accordingly. For example transformer, two 630kVA and 0kW load capacity in above Table 5.12 indicates that, for the future load demand of the given area, 630kVA sized transformer is recommended.

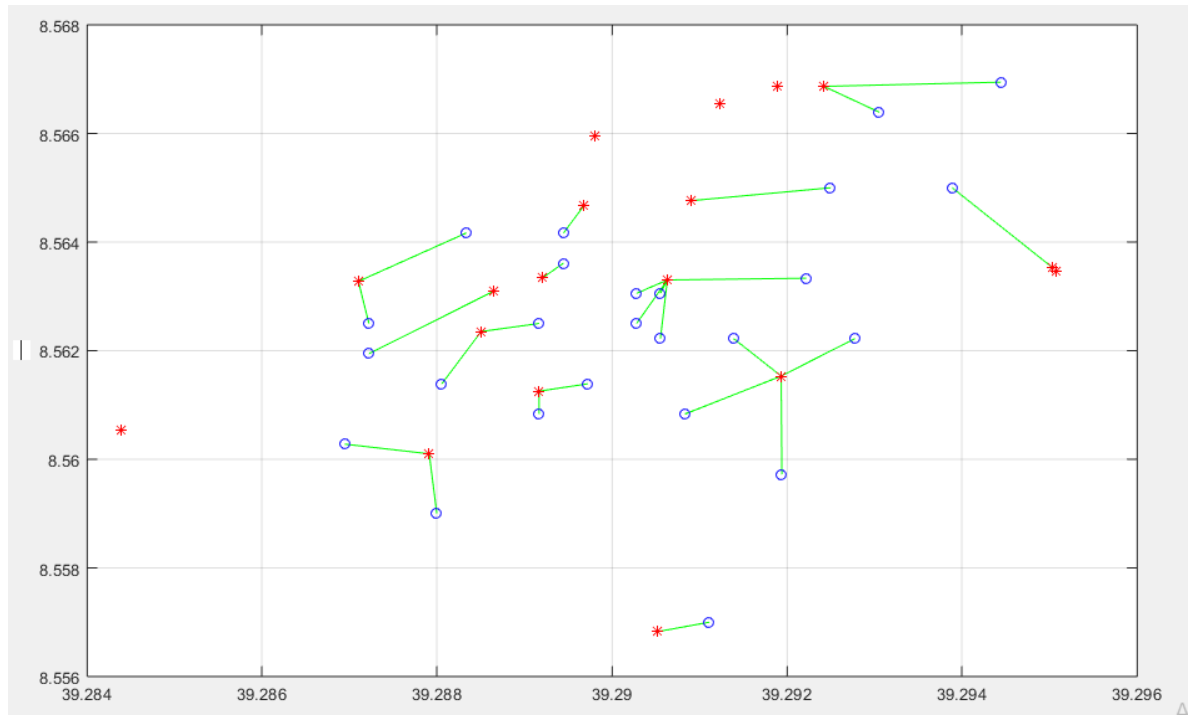


Figure 5.5 Optimal location and size of 28 load points with 18 distribution transformers obtained by applying GA

The simulation process is based on the flowchart of the methodology, as shown in chapter four in Fig. 4.6. The optimal result which is represented by the minimum fitness score was obtained in less than 300 generations. The simulation results of optimal location and sizing of distribution transformer are shown in Fig. 5.5 as depicted in Fig.5.5, the small dots represent the location of a load of customers. The adjacent customer loads are connected by low voltage networks which are represented by a green line to each of the centered small dots. This centered red star dot represents the location of the distribution transformer. The capacity of each distribution transformer for supplying the connected customer load is shown by the number around that centered small dot. From this simulation result, it can be seen that for supplying all of the customer loads in that area, it should be installed eighteen distribution transformers with the total capacity of the transformer is 15970 kVA and the total power of 9249.43kW.

5.6.2 The Main 33 kV Distribution Substation Capacity and Geographical Location

The distribution substation capacity is determined according to the maximum capacity of the load power demand of the study area, Table C.2 shows the maximum estimated peak load capacity of the area. And the substation was designed for the next 25 years so that the load growth mainly factories the design of the substation.

The simulation results of optimal location and sizing of 33kV distribution substation are shown in Fig.5.6 as depicted in Fig.5.6, the 'x' represents the location of the existing distribution transformer. The adjacent thirteen 15kV distribution transformers are connected by low voltage networks which are represented by a green line which are connected with the main 33kV distribution substation '*'. This centered red star dot represents the location of the proposed 33 kV distribution substation.

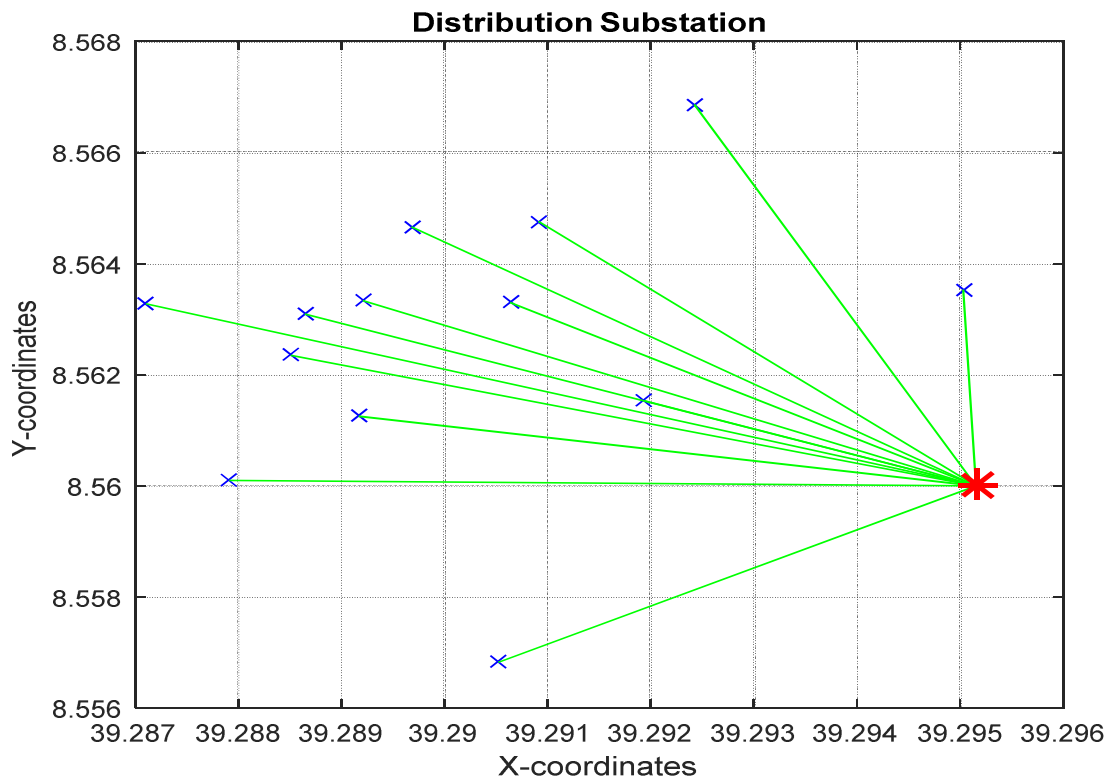


Figure 5.6 Output result of proposed distribution substation

Table 5.13 Numerical output of developed software

Existing 15kV Supplying distribution transformer					
Name of 15kV transformer	Trans -Coordinates		connected load Capacity (kW)	Proposed capacity (kVA)	Allocated load point
	X	Y			
DT-1	39.2905	8.5568	825.7168	1250	3
DT-2	39.2879	8.5601	888.8952	1250	13,18
DT-3	39.2892	8.5613	265.3863	630	9,12
DT-4	39.2919	8.5615	1348.3	1600	2,16,19,20,21,23
DT-5	39.2885	8.5624	260.2159	630	11,24
DT-6	39.2886	8.5631	463.6815	800	17
DT-7	39.2871	8.5633	557.7499	800	4,15
DT-8	39.2892	8.5633	229.9794	630	25
DT-9	39.2906	8.5633	2171.4	1600	5,8,26,27,28
DT-10	39.2909	8.5648	304.4332	630	7
DT-11	39.2897	8.5647	656.434	1000	1,6
DT-12	39.2924	8.5669	584.462	1000	22,14
DT-13	39.295	8.5635	692.7168	1000	10
Total			9249.371	12820	28
Chosen candidates 15 kV transformers					
Name of substation	Trans -Coordinates		Proposed capacity (kVA)	Connected load capacity (kW)	
	X	Y			
New-1	39.2844	8.5605	630	0	
New-2	39.2898	8.566	630	0	
New-3	39.2912	8.5665	630	0	
New-4	39.2919	8.5669	630	0	
New-5	39.2951	8.5635	630	0	
Chosen Candidates main 33/15 kV substation					
Name of substation	Substation - Coordinates		Proposed capacity (MVA)	Connected 15kV Substations (DT)	
	X	Y			
Main 33KV substation	39.2952	8.56	50	1,2,3,4,5,6, 7,8,9,10,11, 12,13	

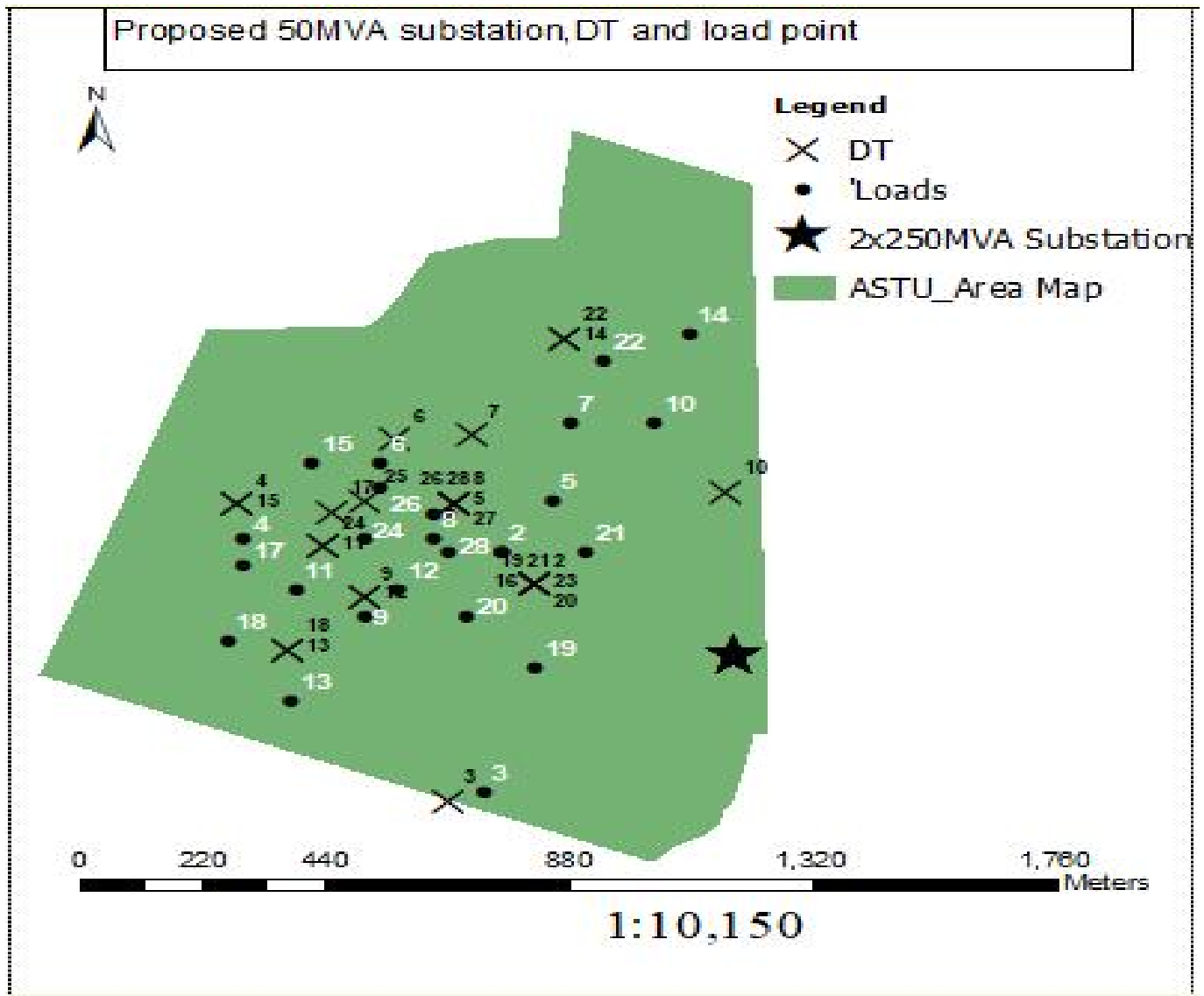


Figure 5.7 Geographical location of the main substation and corresponding distribution transformers

The optimal size and location of distribution transformers and corresponding load point show that the substation is obtained to build and supply the area. The proposed capacity of each existing distribution transformer to supply the connected customer load is 12820kVA the new future recommended transformers capacity of 3150kVA and the capacity of the main substation is 50MVA, with 0.8 as utility factors. It is placed that the (x-y) coordinates of the distribution substation are (39.295, 8.56) respectively.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The average frequency of interruptions on the existing system is 140 interruptions per customer per year, and the average duration of interruptions is 215.92 hours per customer per year. There is an extremely high unavailability of electric power in the distribution network. The power supply of the overall system is unavailable for 215.92 hours per year. There is also a loss of unsupplied energy due to both planned and non-momentary outages in the existing system. And also, the reliability of the ASTU power supply is very poor as compared to the international reliability indices and the reliability indices set by EEP. According to this, the low capacity, arrangement, aging of the substation equipment, poor training of scheduled maintenance and operation and lack of new technologies such as remotely controlled smart reclosers and circuit breakers are recognized as the main causes of the identified problems. Therefore, redesigning the existing system, changing the equipment arrangements so they can perform their operations in a more reliable way, replacing the aged manual switchgear devices, implementing substation automation, and developing awareness of scheduled substation maintenance and operation are given as the key solutions to solve the problems of the distribution system in this work. By implementing these, it improved the reliability of the power supply system from its current status.

In general, based on simulation results of reliability index values, the new designed substation achieved a 95.6% improvement in SAIFI value, a 99.6% improvement in SAIDI value, a 92.84% improvement in ENS value, and a 99.5% improvement in ASUI value. Since the new substations are arranged in a double bus bar manner and equipped with remotely controlled circuit breakers and switches, which are parts of the substation automation system. To address all of the aforementioned issues, this thesis proposed a new method for automatically determining the optimal size, location, and service area of substations in a power distribution system, which does not need the candidate substation sites. The genetic algorithm is used to solve the problem. This method is robust, has no restrictions, and may be used to MV/LV substation planning issues. In the case study, the network formed by the Genetic algorithm is sensitive to the geographic location of the load points, resulting in a near-optimum network

that can be improved by applying genetic algorithm operators. Because the encoding and decoding techniques, as well as the GA's operator implementation, change due to the usage of geographic location rather than specified pathways for distribution lines.

According to a survey of the literature on power substation location choices, one of the most important aims for researchers is cost reduction. This thesis study demonstrates the use of Geographical Information Systems (GIS) for system design, from substation location through feeder routing. The use of geographic information systems (GIS) to determine the location of load points and substations. Cost reductions can be realized by rerouting distribution lines using GIS-based technology to locate the shortest and most feasible new path. To achieve the lowest investment and operational costs, the optimal sizing and location of the distribution transformer problem at ASTU was addressed efficiently in fewer than 300 generations using Genetic Algorithms. To service all of the customer loads in the study area, 18 distribution transformers and one main distribution substation with a having a capacity of 15970 kVA and 50 MVA must be installed.

6.2 Recommendations

Due to time limitations, several sections of the thesis that are frequently critical in system design were not included.

As consequence, I recommended that further studies be conducted in the following areas:

- a. Substation control circuit wiring and schematics, as well as the civil design of the substation.
- b. A comprehensive cost analysis of the entire system.
- c. Further integrating the distribution system to improve reliability.
- d. System automation through remote, centralized control and monitoring using modern technologies such as SCADA.

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REFERENCES

- [1] Solomon Derby, “Study on Reliability Improvement of Adama City Power Supply Using Smart Grid Technology” Addis Ababa University Addis Ababa Institute of Technology School of Electrical and Computer Engineering, 2014.
- [2] LokeshPrakashManohar, “Reliability Assessment of a Power Grid With Customer Operated Chop Systems Using Monte Carlo Simulation”, University of Massachusetts, Amherst, 2009, Yeahitslokesh@Gmail.Com.
- [3] Hag-Kwen Kim,” Reliability Modeling and Evaluation in Aging Power Systems” a Thesis Submitted to the Office of Graduate Studies of Texas A&M University, August 2009.
- [4] Dinu-CălinSecui and Gabriel-ValentinBender,”Reliability Indices Assessment of Power Distribution Substations Considering the Load Transfer at the Consumers” University of Oradea, No.1, Oradea, Csecui@Uoradea.Ro, 2009.
- [5] M. Berende, H. Slootweg, J. Casteren, H. Dijk, ‘‘Advanced Reliability Assessment of A Distribution Network Objectifying of Proposals to Improve the Quality of Supply’’, 19thInternational Conference on Electricity Distribution, Vienna, 2007.
- [6] RUS Bulletin, ‘‘Design Guide for Rural Substations’’ United States Department of Utilities Service June 2001.
- [7] Michael J.Bio, ‘‘Bus/Switching Configurations’’ E.P. Breaux Electrical, Inc. Birmingham, Alabama Electric Power Engineering Handbook, Grigsby, L.L., ed., CRC Press, Boca Raton, FL, 2001.
- [8] Doeg Rodriguez Sanabria “Comparative Framework for Service Reliability in Electric Distribution Systems” MSc. Thesis, University of Puerto Rico, Mayaguez Campus, 2005.
- [9] Tempa Dorji, “Reliability Assessment of Distribution Systems, Including a Case Study on Wangdue Distribution System in Bhutan”, MSc. Thesis, Department of Electrical Power Engineering, Norwegian University of Science and Technology, 2009.

- [10] Gerd Kjolle, et al, an Analytical Approach for Distribution System Reliability Assessment, IEEE Transactions on Power Delivery, Vol. 7, No. 2, 2009.
- [11] "The Leading Electrical Power System Analysis & Operation Software ETAP - Operation Technology, Inc". The Silicon Review. Retrieved 2019-09-28.
- [12] BelalMohammadi, Ali Reza Seifi. "Optimal substation placement and feeder routing in distribution systemplanning using genetic algorithm." (Elixir), no. 37 (2011).
- [13] Jen-HaoTeng, "A Direct Approach for Distribution System Load Flow Solutions," IEEE Trans. Power Del. Vol. 18, No. 3, JULY 2003.
- [14] D. Hongwei, Y. Yixin, H. Chunhua, W. Chengshan, G. Shaoyun, X. Jian, Z. Yi, and X. Rui, "Optimal Planning of Distribution Substation Locations and Sizes-Models and Algorithm," Electrical Power & Energy Systems, Vol. 18, No. 6, pp. 353-357, 1996.
- [15] Z. Quan, S. Caixin, C. Guoqing, D. Qun and L. Ruijin, "GIS-Based Distribution System Spatial Load Forecasting and the Optimal Planning of Substation Location and Capacity," 0-7803-7459-2/02/© 2002 IEEE.
- [16] S. Sivanagaraju, N. Sreenivasulu, M. Vijayakumar, T. Ramana, "Optimal conductor selection for radial distribution systems," Electric Power Systems Research 63 (2002)
- [17] K. Adnan, "Optimal Location and Sizing of Distributed Generation, the Case Study of Adama Distribution System" MSc thesis submitted to Addis Abeba university: unpublished, 2015.
- [18] M.Girma, "Modeling of Grid Connected Solar, Wind and Fuel Cell Distributed Generation Units and Power Flow Controlling System for Interfacing" Addis Abeba: unpublished, 2018.
- [19] D. Solomon and B. Getachew, "Assessment of Power Reliability And Improvement Potential by Using Smart Reclosers," Journal of Ethiopian Electric Agency, vol. 31, 2014.

- [20] G. Adane, "Power Reliability Assessment of Adama Power Distribution System" MSc thesis submitted to Adama Science and Technology University: unpublished, 2019.
- [21] Malay Chintan Rahul Vishwas. "66/11 kV Distribution Substation Design." International Journal of Engineering Research & Technology Vol. 9 Issue 05, no. Issue 05, May-2020 (Vol. 9 Issue 05, May-2020): 540-543.
- [22] Nawaz, Mohammad Sharique. "Design and Construction of 33/11 kV Line & Substation." International Research Journal of Engineering and Technology Volume: 03, no. Issue: 07 | July-2016 (July-2016): 722-727.
- [23] Oyeleye, M. O. "Design of 11/0.415 kV Substation Using Applicable International Codes." Journal of Multidisciplinary Engineering Science Studies (JMESS), September - 2019: 2782-2789.
- [24] V. Parada, J. A. Ferland, M. Arias, and K. Daniels, "Optimization of Electrical Distribution Feeders Using Simulated Annealing," IEEE Transactions on Power Delivery, vol. 19, pp. 1135 - 1141, July 2004.
- [25] I. J. Ramirez-Rosado and J. L. Bernal-Agustin, "Genetic algorithms applied to the design of large power distribution systems," IEEE Transactions on Power Systems, vol. 13, pp. 696 - 703, May 1998.
- [26] I. J. Ramirez-Rosado and J. L. Bernal-Agustin, "Reliability and costs optimization for distribution networks expansion using an evolutionary algorithm," IEEE Transactions on Power Systems, vol. 16, pp. 111 - 118, February 2001.
- [27] H. Hashimi-Dezeki and H. Askarian-Abyanaeh, "Reliability optimization of electrical distribution systems using internal loops to minimize energy not-supplied (ENS)," Journal of Applied research and technology, 2015.
- [28] M. Gen and R. Cheng, "Genetic algorithms and engineering optimization." (Chichester: Wiley, 2000.) 2000.
- [29] Singh, Dr.Balwan. "Role of Geographical Information System (GIS) In Power Distribution in India." (IJSRST) Volume 4, no. Issue 2 (2018).

- [30] "Wikipedia, "encyclopedia, June 27, 2019. [Online]. Available: [Accessed 28 June 2021]. <https://en.wikipedia.org/wiki/Adama>.
- [31] M. Alramlawi, A. Gabash and P. Li, "Optimal operation strategy of a hybrid PVbattery system under grid scheduled blackouts," in In Proceedings of the IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe, Milan, 2017.
- [32] Palak Parikh, "Distribution System Automation" Ph.D. Scholar, Electrical and Computer Engineering Department, University of Western Ontario., 2011.
- [33] Turan Gonen, Electric power distribution system engineering, Copyright 1986 McGraw-Hill, Inc. California State University, Sacramento.
- [34] H.Lee Willis, Power distribution planning reference book, 2nd edition ABB, Inc. Raleigh, North Carolina, U.S.A.
- [35] Inna Baleva, Substation Grounding, Department of Electrical and Electronic Engineering, California State University, Sacramento, 2012.
- [36] Powertech, "Cables Facts and Figures" Aberdare, 2007.

APPENDIXES

Appendix A: Data of Reliability Analysis for the Distribution System

Table A.1: Annual frequency and duration of interruption of feeders

No.	Feeder	October 2019 to September 2020	
		Frequency of Interruption	Duration of Interruption(hr)
1	L1	145	377.49
2	L3	68	92.25
3	L4	101	165.91
4	L5	111	141.33
5	L6	111	213.77
6	L7	184	316.58
7	M1	160	395.68
8	M2	163	355.08
9	M3	202	405.50
10	M4	114	267.66
11	M5	66	152.58
	Total	1425	2883.82

Table A.2: Annual frequency and duration of interruption of switching station

Feeder	Switching Station	Frequency of Interruption	Duration of Interruption
LINE 7	R1-3	132	183.33
	R1-5	109	125.25
MOBILE 1	R2-2	26	42.75
	R2-3	158	150.85
	R2-5	61	75.83
LINE4	R3-2	100	104.58
	R3-3	48	70.50
MOBILI 6	R4-2	156	233.33
	R4-3	20	49.33
LINE 1	R5-2	24	19.25
	R5-3	63	37.25
LINE 3	R6-2	140	215.92
	R6-3	21	39.25
MOBILE 3	R7-2	16	10.58
	R7-3	49	36.42
MOBILE 5	R8-2	263	335.00
	R8-5	2	0.42
	AT-01	38	104.42

Table A.3: Electricity tariff Ethiopian Electric Utility (EEMU) Since December of 2019, [30]

Energy Tariff for Residential Consumer Category		
S/N	Block Range	Energy Tariff (Birr/kWh)
1	1st Block Up to 50 kWh	0.2730
2	2nd Block Up to 100 kWh	0.7670
3	3rd Block Up to 200 Kwh	1.6250
4	4th Block Up to 300 Kwh	2.0000
5	5th Block Up to 400 kWh	2.2000
6	6th Block Up to 500 kWh	2.4050
7	7 th Block kWh>500	2.4810
Energy Tariff Category for General, Industrial and Bulk Supply Consumers		
S/N	Categories	Energy Tariff (Birr/kWh)
1	General(Commercial)	2.1240
2	LV Industrial	1.5310
3	MV Industrial	1.1930
4	HV Industrial	0.9280
5	Bulk Supply	0.8870
6	A street light charge is taken as similar as general(commercial	2.1240

Table A.4: Interruption Data of Adama Substation From Switching Station and MV Equipment

No.	substation ion Name	substation Feeder Name	Feeder Name	Distribution												Frequen cy Of Intrrupti	Duration Of Intrruption
				DPEF		DPSC		DTEF		DTSC		DLOL		OP			
				F	D(Hr)	F	D(Hr)	F	D(Hr)	F	D(Hr)	F	D(Hr)	F	D(Hr)		
1	Adama Substation from switching station and mv equipment	LINE 7	R1-3	1	2.333	40	132.8313	2	0.4167	51	13.9994			38	33.7501	132	183.3305
2			R1-5	2	5.3334	33	78.2498	1	0.1667	26	11.083			47	30.4146	109	125.2475
3		MOBILE 1	R2-2	1	2.3333	7	19.1674	2	0.5	4	1			12	19.7497	26	42.7504
4			R2-3	4	1.3333	55	94.0813	9	2.4163	60	32.0157			30	22.3344	158	152.181
5			R2-5	2	1.2497	26	50.0007	2	0.4166	12	4.499			19	19.6667	61	75.8327
6		LINE4	R3-2	3	6.916	26	51.8327	2	1.0833	40	29.9162			29	14.8331	100	104.5813
7			R3-3	0	0	18	52.3326	1	0.25	19	6.5842			10	11.3341	48	70.5009
8		MOBILI 6	R4-2	3	8.25	62	190.2497	1	0.1667	61	25.0826			29	11.0828	156	234.8318
9			R4-3	0	0	8	45.75	0	0	2	0.7497			10	2.8336	20	49.3333
10		LINE 1	R5-2	1	0.0833	5	6.75	1	0.1667	6	0.9999			11	11.2504	24	19.2503
11			R5-3	2	7.5	8	13.3333	5	3.833	32	8.4993			16	4.0834	63	37.249
12		LINE 3	R6-4	0	0	5	31.0003	1	0.25	9	2.0835	1	2	5	3.9166	21	39.2504
13			R6-5	5	5.4997	72	156.5845	2	0.6663	31	15.6672	1	5.0833	29	32.998	140	216.499
14		MOBILE 3	R7-2	1	3.583	1	0.5			5	1.5834			9	4.9161	16	10.5825
15			R7-3	1	8.333	7	8.9167	1	0.583	23	8.9171			17	9.6655	49	36.4153
16		MOBILE 5	R8-2	12	23.9167	70	215.4989	15	3.166	113	53.9995			53	43.0011	263	339.5822
17			R8-5							1	0.0833			1	0.3333	2	0.4166
18			AT-01	14	69.2493	14	24.4996	4	8.0834	3	0.9166			3	1.667	38	104.4159
			sum	48	144.2474	457	1152.414	49	22.1647	498	217.6796	2	7.0833	368	277.8305	1426	1842.2506
														SAIFI	79.22222		
														SAIDI			102.35

Appendix B: Data for System Design

Table B.1: Installing power forecast for Adama Science and Technology University

Years	Forecasted Demand in (MW) peak	Forecasted Demand in (MVA)
2021	8.84	9.83
2022	10.08	10.41
2023	10.69	11.04
2024	11.33	11.70
2025	12.01	12.40
2026	12.73	13.15
2027	13.49	13.94
2028	14.30	14.77
2029	15.16	15.66
2030	16.07	16.60
2031	17.03	17.60
2032	18.05	18.65
2033	19.14	19.77
2034	20.28	20.96
2035	21.50	22.21
2036	22.79	23.55
2037	24.16	24.96
2038	25.61	26.46
2039	27.14	28.04
2040	28.77	29.73
2041	30.50	31.51
2042	32.33	33.40
2043	34.27	35.40
2044	36.33	37.53
2045	38.50	39.78

Table B.2: Hourly load in MW

Hour	Load	
00:00-01:00	0.50	
01:00-02:00	0.54	
02:00-03:00	0.54	
03:00-04:00	0.54	
04:00-05:00	0.54	
05:00-06:00	0.64	
06:00-07:00	2.10	
07:00-08:00	2.90	
08:00-09:00	2.61	
09:00-10:00	2.81	
10:00-11:00	2.81	
11:00-12:00	3.41	
12:00-13:00	3.11	
13:00-14:00	2.71	
14:00-15:00	3.05	
15:00-16:00	2.45	
16:00-17:00	1.55	
17:00-18:00	2.33	
18:00-19:00	1.69	
19:00-20:00	1.34	
20:00-21:00	0.54	
21:00-22:00	0.54	
22:00-23:00	0.54	
23:00-00:00	0.54	

Table B.3: Material constants Ref. IEEE Std. 80-2000[36]

Description	Material Conductivity (%)	α_r factor at 20°C (1/°C)	K_o at 0°C (0°C)	Fusing ^a temperature T_m (°C)	ρ_r at 20°C ($\mu\Omega\cdot\text{cm}$)	TCAP thermal capacity (J/cm ³ *°C)
Copper, annealed soft-drawn	100	0.00393	234	1083	1.72	3.42
Copper, commercial hard-drawn	97	0.00381	242	1084	1.78	3.42
Copper-clad steel wire	40	0.00378	245	1084	4.4	3.85
Copper-clad steel wire	30	0.00378	245	1084	5.86	3.85
Copper-clad steel rod ^b	20	0.00378	245	1084	8.62	3.85
Aluminum, EC grade	64	0.00403	228	657	2.86	2.56
Aluminum, 5005 alloy	53.5	0.00353	263	652	3.22	2.6
Aluminum, 6201 alloy	52.5	0.00347	2268	654	3.28	2.6
Aluminum-clad steel wire	20.3	0.0036	258	657	8.48	3.58
Steel-1020	10.8	0.0016	605	1510	15.9	3.28
Stainless-clad steel rod ^c	9.8	0.0016	605	1400	17.5	4.44
Zinc-coated steel rod	8.6	0.0032	293	419	20.1	3.93
Stainless steel, 304	2.4	0.0013	749	1400	72	4.03

Table B.4: Single Core Unarmored XLPE Insulated Pvc-sheathed 600/1000V Stranded Copper

[36]

Cable Size (mm ²)	Electrical Properties								Physical Properties		
	1ϕ Cable AC or DC			3ϕ Cable in Trefoil Formation				Impe dance (Ω/km)	Nominal Diameters		Nomi nal Mass (kg/km)
	Current Rating		Voltage Drop per Amp per mV (mV)	Current Rating			Voltage Drop per Amp per mV (mV)		D ₁ (mm)	D ₂ (mm)	
	Ground (A)	Air (A)		Ground (A)	Duct (A)	Air (A)					
25	118	126	1.75	127	111	112	1.52	0.8767	5.95	11.91	366
35	156	156	1.27	153	132	141	1.1	0.6356	7	12.96	469
50	186	191	0.95	180	155	172	0.82	0.4745	8.15	15.15	632
70	232	246	0.67	221	190	223	0.58	0.3356	9.79	16.57	880
95	281	300	0.5	265	226	273	0.43	0.25	11.54	19.04	1160
120	324	349	0.41	301	256	318	0.36	0.2054	12.96	20.24	1413
150	370	404	0.35	338	287	369	0.3	0.1734	14.39	22.07	1734
185	424	463	0.3	381	323	424	0.26	0.1499	16.1	24.08	2145
240	498	549	0.25	442	372	504	0.22	0.1268	18.71	27.81	2725
300	566	635	0.23	499	419	584	0.2	0.1131	21.45	30.75	3375
400	651	742	0.21	565	472	679	0.18	0.1028	24.3	34.1	4395
500	740	835	0.19	634	532	778	0.17	0.0963	26.51	37.17	5299
630	836	953	0.18	718	603	892	0.15	0.089	33.15	43.62	6965
800	931	1086	0.17	792	689	1020	0.15	0.0852	37.7	49	9118
1000	1041	1216	0.16	856	741	1149	0.14	0.0819	42.25	53.45	11050

Table B.5: Earthing mat design for substation aTable C. 1s per ANSI/IEEE Std. 80-1986 code

:Enter Your Details:			
Length of Area Occupied by Earthing Grid	la	200	mt
Width of Area Occupied by Earthing Grid	lb	150	mt
Fault level at Incoming Bus	fault	1000	MVA
Incoming Voltage	Vin	132	KV
Outgoing Voltage	Vout	33	KV
Soil Resistivity	q	1000	Ω -m
Resistance of Main Earthing Mat		0.5	Ω
Resistance of surface Material (Crushed Rock)	qs	3000	Ω -m
Thickness of Surface Material (Crushed Rock)	hs	0.1	mt
Depth of Earthing Grid Conductor	h	0.5	mt
Diameter of Earthing Grid Conductor	d	185	mm2
Reference Depth of Grid		0.5	mt
Area Occupied by Earthing Grid		30000	m2
Spacing between Parallel Conductor of Grid	D	20	mt
Duration of Fault (To determine Size of earthing Mat)	t	0.5	sec
Duration of Fault (To determine safe Step & Touch Poter t		0.5	sec
Margine Factor in Earthing Mat against corrossion and Rusting		100.00%	
Number of Adjacement Earthing Mat Conductor	nm	23	nos
Relaction Factor	K	-0.5	
Constant (KS)	Ks	0.262	
Constant (Ki)	Ki	4.612	
Number of Parallel Conductor in Longitudinal direction	na	10	
Number of Parallel Conductor in Transverse direction	nb	8	
No of Lighting Arrestors		2	
No of Transformers		2	
Decrement Factor for entire duration of Fault(to allow asymetrical of the Fault curemt wave)	Df	1.025	
Corrective projection factor according for the relative increase fault current during S/S life(Zero future system	Cp	0.79	
Ambient Temperature	Ta	40	0°C
Maximum allowable Temperature	Tm	1084	0°C
Temperature of Thermal Co-efficient of resistivity at 0°C	Ko	1.73	
Thermal Capacity Factor	TAC	3.8466	J/cm3/c
Thermal Co-efficient of resistivity at reference Temp of T &°	P	0.0038	

DESIGN OF EARTHING MAT			
Fault Current At Primary side	Ig	4374	Amp
Sizing of Earthing Conductor	A	15.34	mm2
Size of Earthing Conductor after considering Margine Factor	Final A	30.68	mm2
Standard Size of Earthing Rod (Round)		40	mm
Approximate Length of Earthing Mat Conductor	L	11017	mt
Reduction Factor	Cs	0.77	OR Enter Your Value 0.79
Tolerable Touch Potential	Etouch	747	Volts
Estimated Touch Potential	Esti(Etouch)	885	Volts
New Selection of Earthing Mat Conductor Length is OK			
Now New Length of Earthing Conductor	New L	18000	mt
New Estimated Touch Potential	Esti(Etouch)	542	Volts
Result : Size of Earthing Mat Conductor is OK which is			
Tolerable Step Potential	Estep	2496.8	Volts
Estimated Step Potential	Esti(Estep)	293.621	Volts
Estimated Step Voltage is Less than Tolerable Step Potential			
Station Ground Resistance	Rg	2.613	Ω
Earthing Grid Current	Ig	3542	Amp
Ground Potential Rise (GPA)	GPA	9255	Volts
No of Earthing Rod used in Earthing Mat			
No of Earthing Rod used at perimeter		36	Nos
Extra Earthing Rod used at 4 coners of Earthing Mat		16	Nos
Earth Electrode for Lighting Arrestors		4	Nos
Eath Electrode for Transformer		6	Nos
Control Room Earthing		2	Nos
Total Earthing Rods		64	Nos
Total Length of Earthing Mat Conductor			
Longitudinal direction		2000	mt
Transverse direction		1200	mt
Earthing Rod		192	mt
Total Length of Eartning Mat Conductor		3392	mt
Estimated Touch Potential		542	Volts
Estimated Step Potential		294	Volts
Estimated Length of Earthing Mat Conductor		18000	mt
No of Earthing Rod		64	Nos

Earthing Conductor	
Standard Dia of Conductor (mm)	
32	804
36	1018
40	1257
	0
	0
	0
	0
	0
	0
	0
	0

Appendix C: Data for optimization of System

Table C.1: The location of existing load point and estimated peak load demand

S/No.	Coordinates		Capacity
	X	Y	Load (kW)
1	39.29	8.564	358.62
2	39.29	8.562	304.43
3	39.29	8.557	825.72
4	39.29	8.563	465.72
5	39.29	8.563	721.44
6	39.29	8.564	297.82
7	39.29	8.565	304.43
8	39.29	8.563	419.34
9	39.29	8.561	85.87
10	39.29	8.565	692.72
11	39.29	8.561	134.84
12	39.29	8.561	179.52
13	39.29	8.559	340.83
14	39.29	8.567	387.16
15	39.29	8.562	463.68
16	39.29	8.562	236.56
17	39.29	8.564	92.03
18	39.29	8.560	548.06
19	39.29	8.560	343.85
20	39.29	8.561	87.48
21	39.29	8.562	243.22
22	39.29	8.566	197.30
23	39.29	8.562	132.78
24	39.29	8.563	125.37
25	39.29	8.564	229.98
26	39.29	8.563	625.72
27	39.29	8.563	188.62
28	39.29	8.562	216.33

Table C.2: Current transformer location and capacity

S/No.	Coordinates		Capacity
	X	Y	S (kVA)
1	39.29	8.557	315
2	39.28	8.561	315
3	39.29	8.560	315
4	39.29	8.561	630
5	39.29	8.562	315
6	39.29	8.562	50
7	39.29	8.563	630
8	39.29	8.563	630
9	39.29	8.563	800
10	39.29	8.563	800
11	39.29	8.565	630
12	39.29	8.565	630
13	39.29	8.566	100
14	39.29	8.567	630
15	39.29	8.567	200
16	39.29	8.567	630
17	39.30	8.564	315
18	39.30	8.563	630

Table C.3: Candidates new load point

S/No.	Coordinates	
	X	Y
1	39.29	8.558
2	39.30	8.557
3	39.29	8.564
4	39.29	8.565
5	39.29	8.564
6	39.29	8.562
7	39.29	8.560
8	39.29	8.560
9	39.29	8.563

Table C.4: Transformer types and installation cost and energy losses

S/No.	Transformers Types (kVA)	Install Costs	Open-Circuit Losses (kW)	Short-Circuit Losses (kW)
1	50	807.9252077	0.19	1.1
2	100	1696.642936	0.32	1.75
3	200	3158.987562	0.5	2.35
4	315	4120.418559	0.85	4
5	630	7828.795262	1.3	6.5
6	800	12223.90839	1.6	8
7	1000	15108.20138	1.7	10.5
8	1250	20602.0928	2	12
9	1600	28087.51984	2.6	17

Table C.5: Design-Constants

Design-Constants	
Power Factor	Utilization Factor (%)
0.9	80

Appendix D: Data of the result of simulation

Table D.1: Numerical results of the GA software

Existing 15kV DT					
Name of 15 kV DT	Trans - Coordinates		connected load Capacity(kW)	Proposed capacity(kVA)	Allocated load point
	X	Y			
Exsistng-1	39.2905	8.5568	825.7168	1250	3
Exsistng-2	39.2879	8.5601	888.8952	1250	13,18
Exsistng-3	39.2892	8.5613	265.3863	630	9,12
Exsistng-4	39.2919	8.5615	1348.3	1600	2,16,19,20,21,23
Exsistng-5	39.2885	8.5624	260.2159	630	11,24
Exsistng-6	39.2886	8.5631	463.6815	800	17
Exsistng-7	39.2871	8.5633	557.7499	800	4,15
Exsistng-8	39.2892	8.5633	229.9794	630	25
Exsistng-9	39.2906	8.5633	2171.4	1600	5,8,26,27,28
Exsistng-10	39.2909	8.5648	304.4332	630	7
Exsistng-11	39.2897	8.5647	656.434	1000	1,6
Exsistng-12	39.2924	8.5669	584.462	1000	22,14
Exsistng-13	39.295	8.5635	692.7168	1000	10
Total			9249.371	12820	28

Chosen Candidates 15 kV DT				
Name of Substation	Trans - Coordinates		Proposed capacity (kVA)	Connected load capacity (kW)
	X	Y		
New-1	39.2844	8.5605	630	0
New-2	39.2898	8.566	630	0
New-3	39.2912	8.5665	630	0
New-4	39.2919	8.5669	630	0
New-5	39.2951	8.5635	630	0
Chosen Candidates main 33/15 kV substation				
Name of Subsection	Substation - Coordinates		Proposed capacity(MVA)	Connected 15kV Substations (DT)
	X	Y		
Main 33 kV substation	39.2952	8.56	50	1,2,3,4,5,6,7,8,9,10,11,12,13