ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

INSTITUTE OF TECHNOLOGY

ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

Study on Smart Grid System for Improvement of Power Distribution System Reliability Case Study: Addis Ababa District

By

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Approval by Board of Examiners

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DEDICATED

To

My mother: *Assefu Hadush Hailu*

Declaration

I, the undersigned, declare that this thesis is my original work, has not been Presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

Tesfay Gebreegziabher ____________________

Name Signature

Place: Addis Ababa

Date of Submission: ________________

This thesis has been submitted for examination with my approval as a university advisor.

Dr.-Ing. Getachew Biru _________________________

Advisor's Name Signature

Abstract

Unreliable power distribution reduces user power consumption, affects daily activity and drags modern life style. It impacts societal development and individuals' income. Basically, Power Distribution Reliability has been a major challenge in Addis Ababa city. It has incurred cost on customers and lowered product quality. In Addis, Customers have faced frequent interruption and utility has taken long time to alleviate it. Hence, it has to get amicable solution. Thus, the objective of the study is to assess the reliability of the current distribution system and suggest solutions of reliability improvement in smart grid environment.

Bella substation of Addis Ababa district, which has high rate of interruption, is selected as case study area. Bella substation's reliability is assessed based on data of two and half years from Ethiopian electric power corporation. To limit the scope of the study, feeder-02 of Bella substation is chosen for reliability improvement measures. Feeder-02 has SAIDI of 163.3 Hr./cust./yr and SAIFI of 184.9 Int./cust./yr. The reliability index values of feeder-02 are not within the ranges of bench marks of best practices and Ethiopia's reliability requirement. Bella substation also has SAIDI of 146.5 Hr./cust./yr. and SAIFI of 128.53 Int./cust./yr. Reliability indices of Bella substation show the substation is unreliable as compared to standard practices and Ethiopia's reliability requirement.

Distribution network reconfiguration capacity is enhanced by designing laterals using genetic algorithm optimization technique that can supply the feeder during contingencies. It's simulated in Mat Lab 2012. The design has considered energy serving capability and maximum customer reconnection possibility. An optimized lateral design solution is obtained that can supply 14550kVA out of 16085kVA and reconnects 10440 customers out of 11235 after reconfiguration, i.e. 90.46 % of the supply capacity and 92.92% of the total customers.

The same optimization algorithm is used to improve automation, reclosing and switching capacity of the feeder. A switch with automating equipment, a recloser, and three sectionalizing switches are integrated in the new design. SAIDI value of 98.33 hr. /cust.

/yr. and SAIFI of 56.025 int./cust./yr for the feeder-02 have been achieved. Reliability improvement by each new device is also calculated. Power restoration is boosted by integrating these devices. By integrating the sectionalizing /tie switches in the feeder, a minimum spanning tree (MST) for rapid restoration is attained using prim's algorithm in Mat Lab. For different fault points in the feeder, optimized kVA capacity is achieved and power loss is minimized. In average, SAIDI of 11.452 Hr./cust./yr., SAIFI of 12.966 int./cust./yr. and ASAI of 0.9986 have been achieved for network reconfiguration at various fault points.

Key words: Distribution Reliability, Smart Grid, Network Reconfiguration, GA optimization, Power Restoration, Prim's Algorithm

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List of Acronyms

CAIDI	Customer Average Interruption Duration Index
DG	Distributed Generation
DLOL	Distribution Line Overload
DPEF	Distribution Permanent Earth Fault
DPSC	Distribution Permanent Short Circuit
DTEF	Distribution Temporary Earth Fault
DTSC	Distribution Temporary Short Circuit
EEPCO	Ethiopian Electric Power Corporation
FDIR	Fault Detection Isolation and Reconfiguration
GA	Genetic Algorithm
IED	Intelligent Electronic Device
ITS	Information Technology System
KVA	Kilo Voltage Ampere
LDC	Load Duration Curve
MST	Minimum Spanning Tree
MVA	Mega Voltage Ampere
PLC	Programmable Logic Controller
PMU	Phase Measurement Unit
RCU	Remote Control Unit
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SG	Smart Grid
SOL	System Overload

CHAPTER ONE

INTRODUCTION

1.1 Introduction to Smart Grid

In the perspective of its customer attractiveness and effective power delivery, the distribution network is the main point of interest to work research on. Especially where competitive market exists, distribution reliability takes high concern to satisfy the user and keep power quality issues within limits.

In Addis Ababa city, achieving Power distribution reliability has been very challenging issue due to various shortcomings of legacy distribution network: Radial distribution system is vulnerable to faults, supply and demand imbalance occurs, aging of system equipment and time taking fault locating mechanism .Such vulnerability of the system to disturbance has caused frustration in daily activity of the customer. Unpredictable and non-programmed power outage, and long outage duration has affected customer electricity consumption patterns. Hence, the reliability issue is still the basic challenge for power utility to meet the customers need. Upgrading of the legacy distribution system to smart distribution system to alleviate existing problems is the proposed solution of this paper. Being reliability one of the core advantages of smart grid system, its implementation makes visible change in the system's reliable power delivery and operation. Implementation of smart distribution is not one step work but continual improvement. The aim of this paper is to study some of the features of smart grid to step up the legacy distribution system with an incremental step towards the smart distribution.

1.1.1 What's smart grid?

When the issues of power delivery and customer based reliable system is raised, the need for modern power grid comes to a point of recall. The term "smart grid" or ''intelligent grid'' or" secured smart grid'' comes from the clue showing that the system achieves the degree of high power quality and reliability in stable working mode. Though many literatures define it in different ways, the ideas the definitions convey is how the smart grid is very stable, efficient and reliable system. In more compact explanation; the smart grid is a power grid in electrical system that is self-healing, resilient and digitally controlled that has high immunity to disturbances and stable operating limits to assure reliable power delivery to customers. It's different in that it has high degree of versatility to dimensions of electric system efficiency and protection during disturbance. Its ability to retain its normal operating state after self-healing process makes it a very reliable power grid of the modern time.

R.E. Brown, [69], States the smart grid as "It is combining time-based prices with the technologies that can be set by users to automatically control their use and self-production, lowering their power costs and offering other benefits such as increased reliability to the system as a whole. It's the strong combination of information technology and electrical power systems." Basically the smart grid is an electrical network of digitally controlled devices that help to facilitate electrical pricing and power delivery to customers with two way communication between customer and the utility.[69] Also explains the smart grid as follows "Smart grids are electricity networks that can intelligently integrate the behavior and actions of all users connected to it—generators, consumers, and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies."

Additionally, [73] defines the smart grid as " The smart grid is an advanced digital two - way power flow power system capable of self - healing, and adaptive, resilient, and sustainable, with foresight for prediction under different uncertainties. It is equipped for interoperability with present and future standards of components, devices, and systems that are cyber - secured against malicious attack".

So generally defining it's digitally controlled electrical network which addresses basic issues of reliability, stability and efficiency that accomplishes these tasks with the use of smart technologies (smart metering, automation, distributed resources, etc.) and bi-directional communication between utility and the consumer.

Concisely, the smart grid is an electrical power network equipped with digital communication that achieves modern level of system protection, customer reliability satisfactions and integrated smart technologies optimized for high profile power delivery.

It‘s a grid of collection of information of resources and automatic system control is made for an adaptive power delivery and customer awareness from the utility.

1.1.2 Benefits of Smart Grid

Along with many different advantages, the smart grid provides multi-dimensional asset. It meets the international requirements both in environmental issues and clean interactive energy approach suitable to competitive market and design extensions. In contained look into the benefits of smart grid, it provides [35], [36]:

Stability

Smart grid power distribution creates immune and self -healing system resilient to disturbances and effective rapid restoration after clearing disturbance. It meets the real time demand for the connected load with automatic system control and direct fault diagnosis. It takes actions to correct faults in hazard prevention and predictive solutions. It also ascertains system security from malwares and cyber-attack. The interconnectivity among system components enhances protection and fault detection and isolation for particularly identifying faulted lines and stabilizing the un-faulted part to remain in normal operating conditions.

Reliability

Smart grid assures few power outage events and short fault clearing time providing clear power with adequate distributed generation integration in the grid system. Even if permanent fault occurs, it ensures major area power supply and power outage happens in faulted area only. The platforms of smart grid enables distributed generation integration and storage systems that give greater power distribution reliability.

Efficiency

Reduced Energy loss, minimum peak hour energy demand and efficient power usage is attained with demand response from customers [72]. These assets are obtained with the use of technological innovations and effective management for proper energy usage and reengineering system equipment for compatibility and flexibility. The smart grid sets up optimizations of networks and cost minimization of expansion with application of smart technologies that can achieve maximum energy efficient mechanism and powers delivery with renewable energy backups for system stability and load balance.

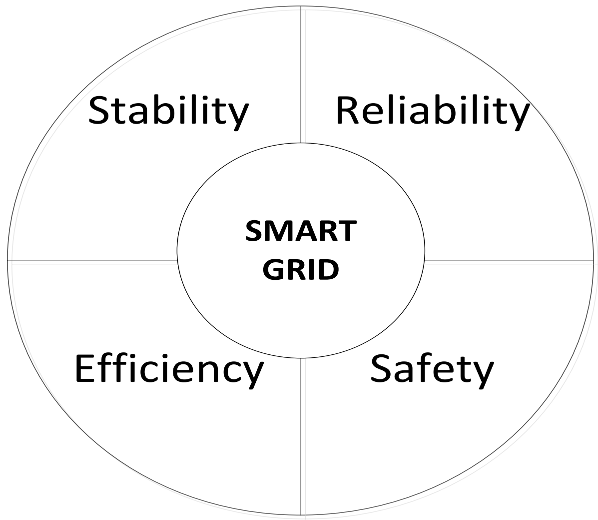


Figure 1.1 Diagram of basic benefits of smart grid with interlink between the benefits

Safety

Smart grid secures the wellbeing of the public from any electrical danger providing sophisticated fault isolating mechanism and power system protection. Every customer has way of communication with utility centers to advance safety and protection for appliances and public priority is given to ensure safe operation. This minimizes effects of human errors on the system and decrement risks of life of individuals.

1.1.3 Traditional Power Grid versus Smart Grid

The smart grid has much distinguishing benefits over the traditional Grid advancing into new level of power transmission and distribution. The aspects of handling uncertainties, failure prediction and automatic system control make easier power restoration. Data acquisition, and information transfer and gathering attain level of stability with digital bi-directional communication among system interconnectivity while legacy distribution operates in the level of electromechanical devices and analog communication [35], [68].

The smart grid is most sophisticated and dependable system as compared to contemporary distribution system grids. It has various very important aspects for stable power distribution system with future expandability of distribution network. Table 1.1 tries to show some of the few but not all differing points between the recent smart grid and the legacy distribution system. The smart grid answers the question of reliability, which is the concern of this thesis, with high priority to customers enabling rapid restoration reconnecting as many customers as possible.

Table 1.1 Comparison between legacy distributions and smart grid

Traditional grid	**Smart grid**
One way communication	Two way communication
Consumers are not informed	Active consumer participation
Slow response to power quality	Power quality a priority
Manual restoration	Rapid restoration
Failure and black outs	Adaptive and islanding
Centralized generation	Distributed generation
Prevention for further fault	Rapid solution to faults
Limited customers	Many customers given priority
Vulnerable to attacks	More or less secured from attacks

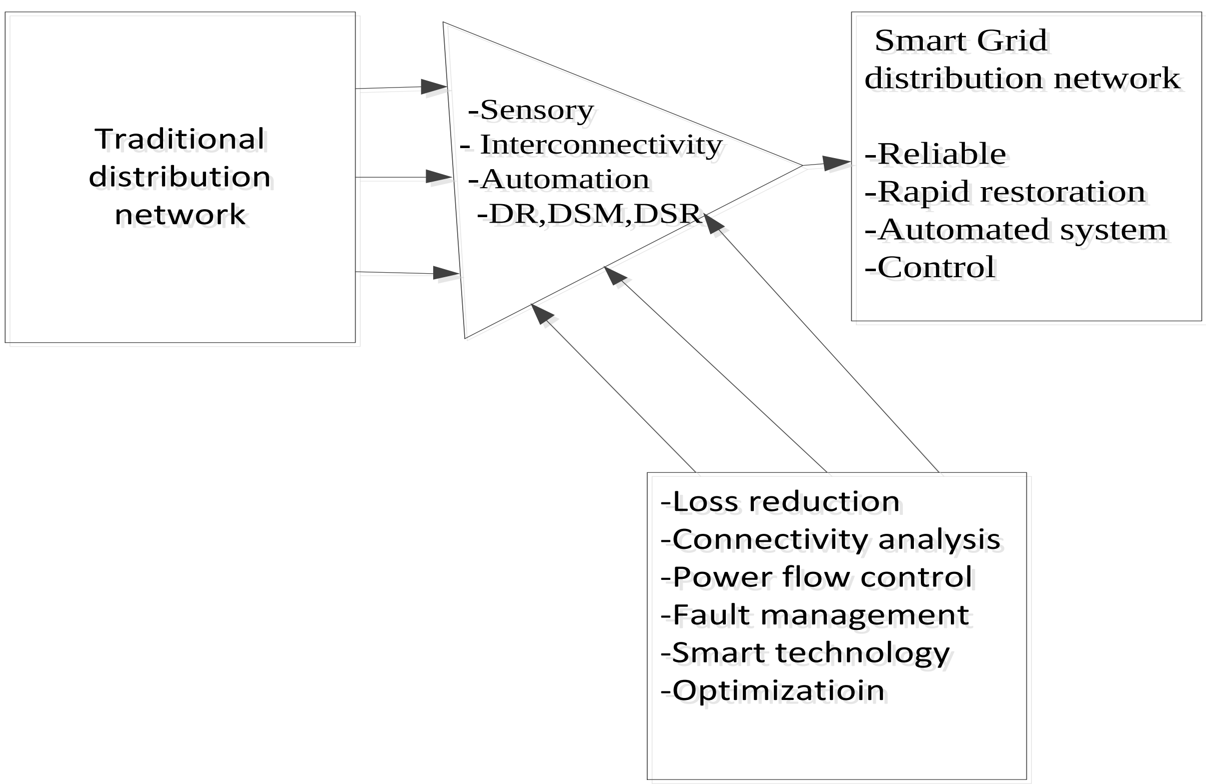


Figure 1.2 Basic features in transition from legacy distribution to smart distribution

1.1.4 Why Smart Grid?

The need for smart grid does not only lie in the fact that modern society crave to have change in life style. But the smart grid distribution network has great advantage to offer what the traditional grid lacks. The smart grid provides ways of data management for business process in distribution networks, customer choice of supply, optimization of network infrastructure, reliable and quality supply. The basic advantages of smart grid over current distribution and transmission legacies and other power system grids are [68]:

- Availability of power boosted with digital and IT system
- Improved power distribution reliability and quality
- Demand side response system control and effective use of energy storage
- Customer side deployment of smart metering and communication with utility
- Good handling of uncertainties and assessing optimal solutions
- Inclusion of renewable energy resources in the system grid
- Distribution automation for rapid restoration after service outage
- Efficient power usage causing less impact on the environment.
- Quick maintenance and operation enabling system rapid restoration

1.2 Features of Smart Grid

The smart grid has features that increase the asset of its implementation. These features accomplish the smart grid aims in satisfying customers' desire and system resilience. Among the many are the following [35], [68]:

Smart Metering: - are devices providing information about energy consumption of customer appliances. Smart metering helps the system to react to the customer power consumption and give awareness to the consumer. Smart metering helps the utility forecast its load dynamics and make use of data obtained from these devices to achieve power balance.

Distribution Automation: - Automation helps the system to rapidly restore power line after fault clearing from control centers. The fault detection, isolation and network configuration capability of distribution network improves system reliability and ensures short interruption duration.

Demand Side Management: - This feature enables the utility to modify its energy supply and cost management by giving awareness of energy effective use in the customer side. It achieves system energy balance by introducing automated and bidirectional power flow. This is done by deployment of smart meters and efficient appliances in home buildings. Awareness of time of energy use in the customer side attains clean environment, reliable generation and lower cost.

Communication: - Smart Grid dynamic and interactive approach is proved with digital two way communication with end user taking action to the real time demand enabling smooth power exchange.

Integration of Distributed Generation Resources:- Penetration of distributed energy resources maintain distribution system balance during peak loads or fault occurrence that lead to islanding or working as virtual power plant, hence stabilizes the distribution system by injecting renewable power sources at point of proper interconnection.

Energy Storage Devices: - Smart Grid alleviates congestions in transmission and distribution system with the use of storage devices and storage systems. Battery storage, pumped storage in hydro system can do away with tension in power system with instant response.

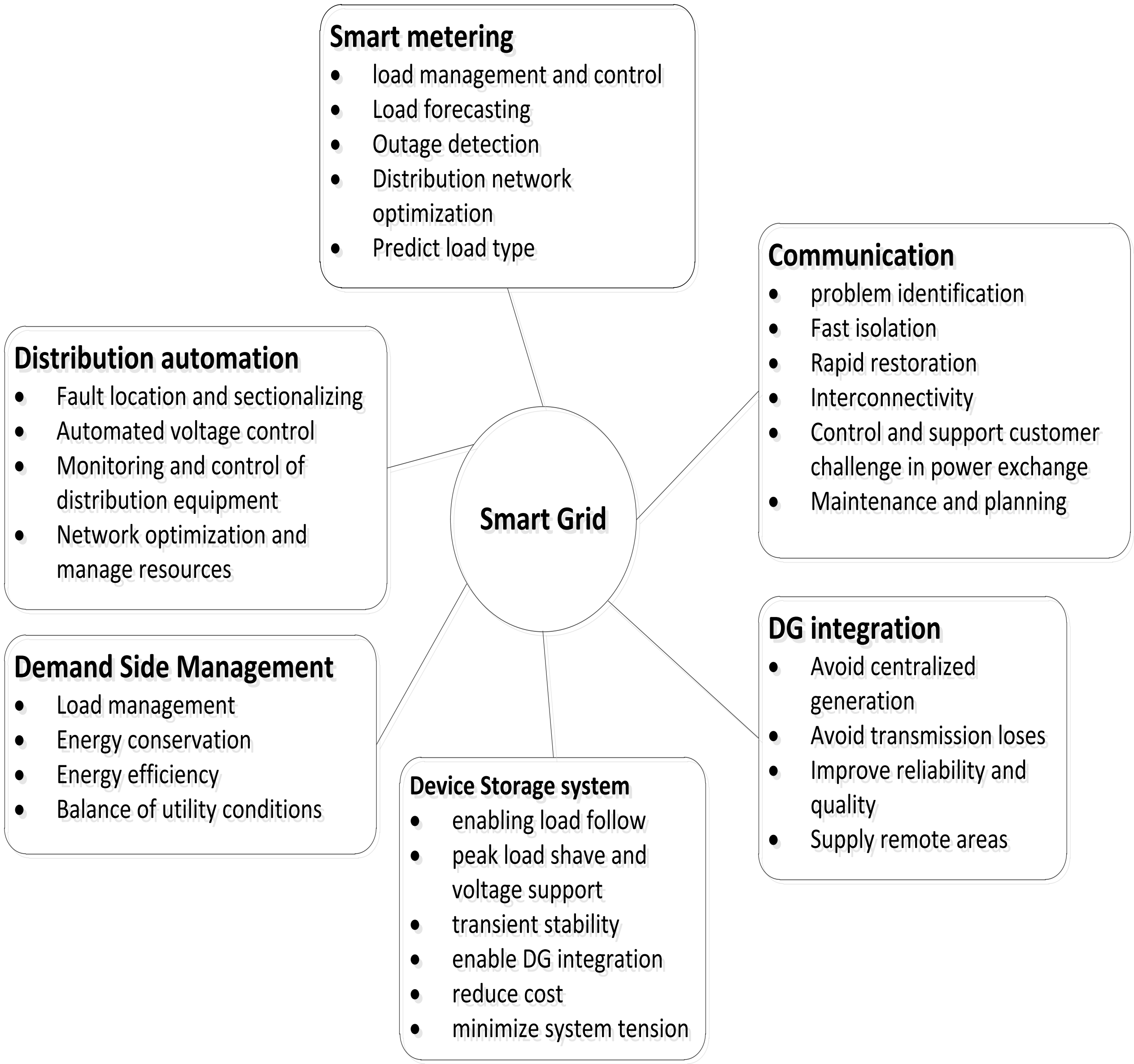


Figure 1.3 Features of smart grid with respective advantages and aspects

1.3 Distribution System Reliability

Though there is ambiguous definition between reliability and power quality, power interruptions are mostly the result of power quality issues. Power quality problems cause power outage. The outage depends on the hazard level of the problem. Under such circumstance, the distribution system has to able to identify the type of problem and its quick mitigation to maintain power availability. Power system reliability is the ability to deliver electricity to all points of power utilization within acceptable limits of power flow constraints. It's the capability of power system to supply customers with fewer interruption durations. Basically, distribution reliability is an added effect of system adequacy and system security. These two features determine power availability in distribution network and high probability of a load being energized [11], [68].

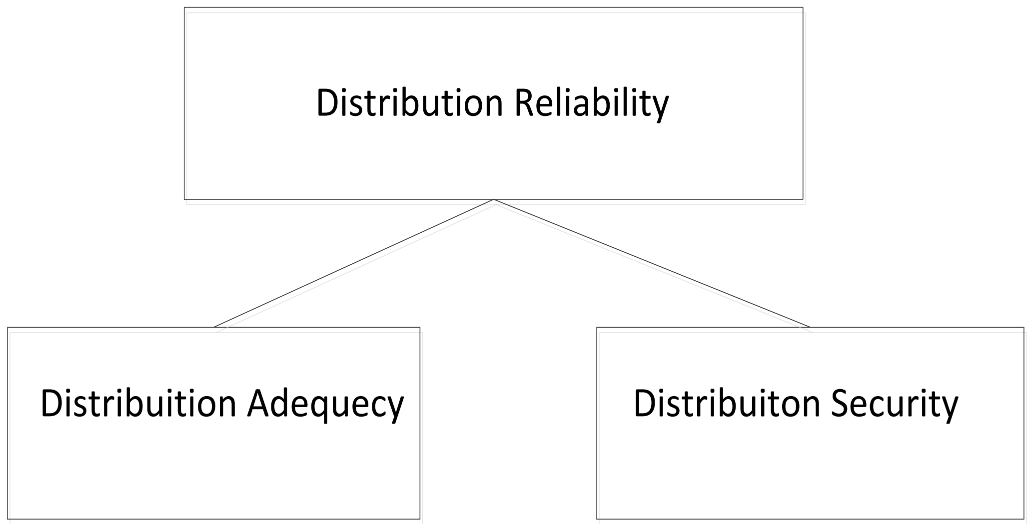


Figure 1.4 Distribution reliability and subdivisions [11]

Distribution reliability plays important role in bringing customer satisfaction and attain power delivery goals. Minimized number of interruptions and interruption duration increases public productivity and earns utility profit. In Ethiopia, the generation methods are hydropower systems and hence any un-served energy is being lost. Different contingencies in power system also bring about power failure and system outages in distribution networks. Unlike the smart grid, the traditional power system is vulnerable to various types of failure sources stating its lack of reliable power delivery. It's the sum of the different source of power failure that reliability of a system is defined by. Many of the outage in power system occurs due to faults at the end user level. Therefore, reliability measures must be taken in distribution system to keep connected load energized and customers' full power access.

1.3.1 Reliability Challenges in Power Distribution System

Various power system aspects affect the reliability of distribution system. Mainly it's very difficult to mathematically represent a failure source. Natural and human fault sources are stochastic and hard to model. Thus, Reliability issues and reliability measures to be taken become non-periodic. There are certain major conditions that influence power system reliability [71]. Some of the challenges of power system reliability are:

State Of System Equipment

Power availability in distribution system depends on the state of operation of system equipment. Any equipment failure results in power interruption. Failure rate modeling and repair time prediction is a very difficult task. Failure and repair rates of different equipment have different wear out curves and life time curves. Hence it's a challenge in estimating reliability of a system. Only general equipment operation assumption of failure rates, normal operation and wear out time can be modeled like that of bath- tub component life time curve, Fig. 1.5. This puts the composite system reliability have no uniform model and representation for all system components [11].

Loading Nature of Distribution Networks

Time varying load nature of distribution networks affects the aging rate of system equipment. Overloaded equipment are subjected to overheating and tensions. This decreases the life time of the equipment as a result of increased failure rates. Because of load increase, switching between systems connections are made which also puts equipment to increased switching rate; sparks, overheating occur. Therefore, system reliability is influenced by the loading variation of distribution networks.

Environmental Conditions

Environmental conditions such human errors, natural disasters make the prediction of reliability of a system difficult. Natural phenomenon increase aging of system component, equipment. Reliability of a system modeling at different Weather conditions influences the result of the analysis. Load forecasting issues face probabilistic nature which can lead to miscalculation. For this reason, system reliability is dependent to random modeling and non-concrete estimation of environmental conditions.

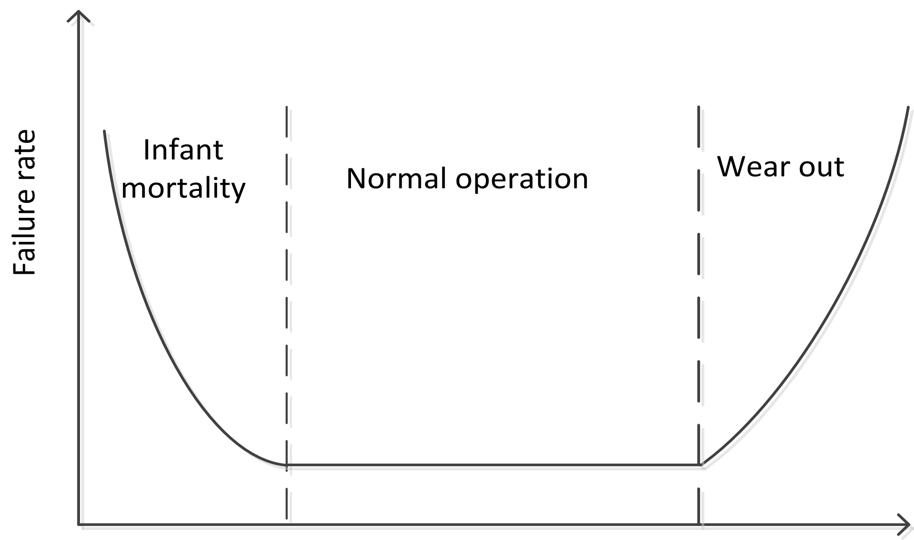


Figure 1.5 Bath-tub component's life [11]

Network structure

Radial networks are mostly vulnerable to failure and power outage. Any failure in system component results in entire power failure. Interconnectivity between distribution networks enables closing and opening of sectionalizing switches and ties switches. This switch also influences the reliability of a system as failure at some point in the network can lead to outage in other part of the network.

1.3.2 Distribution Reliability and the Smart Grid

Implementation of smart distribution system boosts distribution reliability. But its implementation doesn't come without change in distribution structure. One is Application of smart metering infrastructure; smart meters can be placed in the same location in existing meters. Hence distribution topology may not change but the real time demand pattern is same to the system load patterns enabling peak demand control. If peak demand can be controlled, feeder length, voltage level and line size can be changed. Another feature is distribution automation. Switching and protection capabilities of existing system components must be able to reach the flexibility and quick response to fault current and demand patterns of smart grid. System components shall be able to have easier communication and coordination to switching in system tie or sectionalizing switches for distribution network reconfiguration.

Under faulty conditions, Distributed generation integration must have capability of working as Electric Island. Because of lower correlation with load profile and source intermittency of DG systems, the system has to achieve automatic Voltage control and regulation capability in during connection and disconnection of DG. Interconnection of subsystems (distributed generation and distribution network) in the distribution system makes it complex to monitor and control. Hence the information technology and sensory systems impact in distribution system control takes high consideration. Strong communication among subsystem immune to attacks plays greater role for stable operation. Before deployment of smart technologies (smart meters, RCU, PMU…etc.), reliability effects and integration capabilities with traditional grid study has to be conducted.

1.4 Research Objectives and Methodology

1.4.1 Problem Definition

The distribution system is the core part of power system network which deliver power to the end user. It connects the customer to the power generation. Reliable power delivery plays a key role to profitability and customer satisfaction. Ethiopian electric power corporation has tried to improve the delivery mechanism and quality of supply. But the power distribution system in Addis Ababa city has remained inadequate to meet customer demand both in required reliability and reduced safety risks of the public. The power failure impacted, to varying degrees, a wide range of critical infrastructure like the industry, the business enterprises and for residential users. Low system reliability has led to increased outages resulting in more losses to business sectors. Reliability and consistency of electricity supply is critical to many industrial and service activities. Unreliable power supply does not only slows down or damages production or results in shut down of plant but also leads to equipment damage, additional maintenance and the industries' reputation for the quality of product. Power outage has resulted in customer stoppage of production and unavailability of lighting in the major areas of Ethiopia's cities. Achieving reliability of power supply in Addis Ababa has been a major challenge for the last many years and it will continue to be a challenge in the future, if an amicable solution is not found to the problem. How a reliable distribution system can be redesigned and reconfigured for optimal remedy is the main question this study tries to address. Therefore, the smart grid concept to achieve smart distribution system is studied for its implementation to alleviate this public problem.

1.4.2 Objective

The issue of distribution reliability is the main concern of the thesis. The study looks into the current system's reliability issues, challenges and possible effective improvement areas.

Main Objective

The main objective of this thesis is to identify and analyze the major problems of power distribution in Addis Ababa city and explore the implementation of smart-grid features for alleviating the existing distribution problems.

Specific Objectives

The specific objectives include:

- Evaluate the current state of power distribution system problems in Addis Ababa city.
- Evaluate various solution options for tackling the problems
- Identify solution ideas with smart grid environment and evaluate how it can foster distribution reliability in Addis Ababa district.
- Make simulations of smart grid model to evaluate improvements on the power supply system.
- Analyze reliability improvements of distribution system with smart grid model.
- Draw relevant conclusions and recommendations of the model

1.4.3 Methodology

The methodology of this thesis goes starting from the problem identification and reading helpful literatures. The problem identification is the first step towards solving the public problem. For this particular problem in power distribution reliability, the study goes through literature survey on smart grid reliability solution and come up with ideas of mitigating the problems. Feeder-02 of Bella substation is selected as case study area where interruption problems are highly pronounced. Data collection and analysis is done for the case study. Data obtained is organized such that it's easier to utilize it for distribution reliability implication. Then, the study stated the current situation of the distribution reliability from the data analysis and identified reliability solutions in smart grid environment. Proper algorithms are selected to analyze and test the identified reliability solutions. Feeders 02 of Bella substation AutoCAD drawings are redrawn in Microsoft Visio to visualize design options for reliability improvement. Finally, simulation for the identified solutions is made in Mat Lab m-file programming using genetic algorithm optimization and prim's algorithm graph theory.

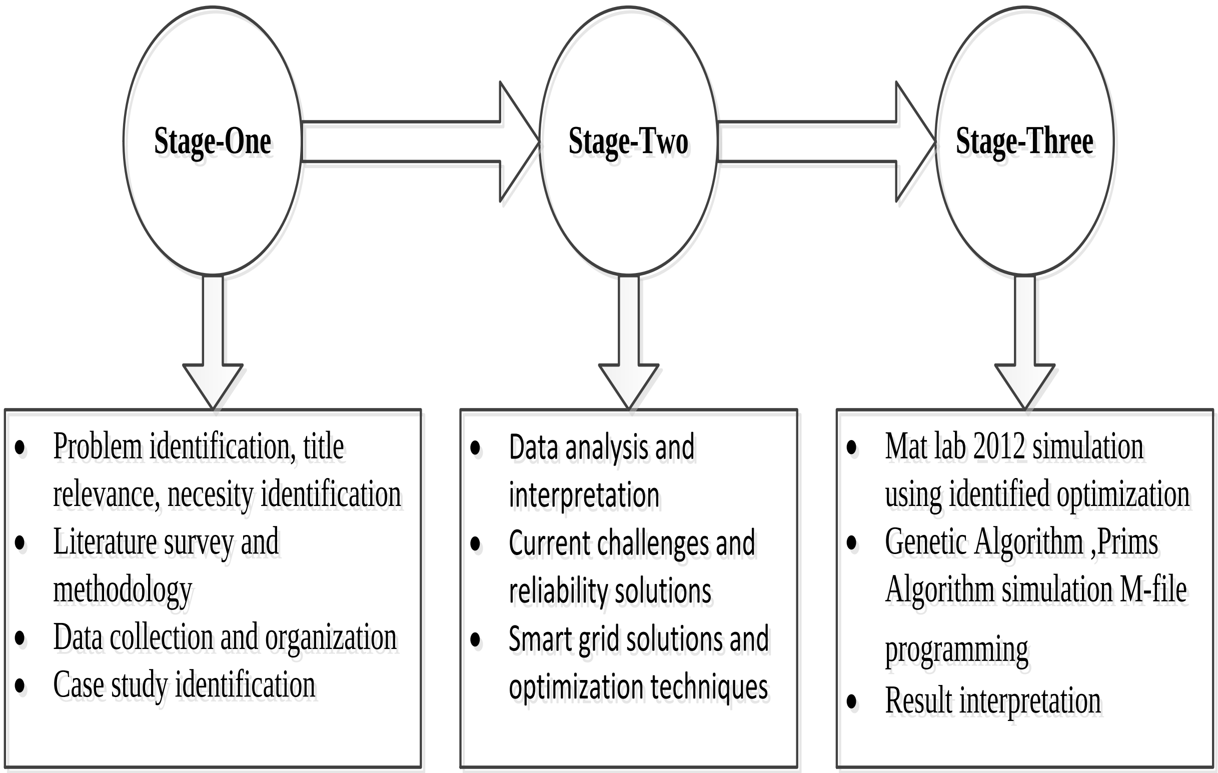


Figure 1.6 Approach and progress methodology of the thesis paper

1.4.4 Expected Outcomes of the Study

The study is expected to identify the current problems of distribution system in Addis Ababa district. The reliability of the Bella substation will be analyzed and conclusion will be derived based on the analysis. For reliability improvement, Alternative distribution networks (laterals) will be designed for Feeder-02 of Bella substation. Optimized locations for new switches installment will be achieved under reliability constraint. Simulation results for network reconfiguration, rapid restoration and effect of the new devices will be tested for reliability improvement. Reliability indices of the identified reliability improvement solutions will be evaluated.

1.5 Literature Review

1.5.1 Smart Grid On Distribution System

Smart grid system enables the use of alternative network lines during fault occurrence. Network reconfiguration is possible if alternative supplying lines exist. That is, during contingency, power supply will not be interrupted. The Design of such alternative distribution networks (laterals) and operation can be achieved using genetic algorithm, sequential feeder approach, etc. Points of connection for the laterals can also consider the inclusion of distributed generations. The DG systems help to maintain voltage levels of the distribution system. Optimal location to integrate DG to the distribution system needs proper consideration. With distributed generation (DG) penetration to stabilize distribution power flow, the point of DG interconnection and new topology designing can be simulated with sequential feeder approach. The overall effect of lateral networks and DG systems improve the reliability of the distribution system. But the study considers no DG penetration [5], [6].

For lateral design, the connectivity matrix of the feeder to feeder connection can be used. This matrix is applied to obtain optimum line connection under reliability constraints and voltage limits to achieve Network Reconfiguration and Rapid Restoration.

The smart grid resources such as renewable resources, storage devices, demand response and electric transportation have impact on the distribution network load profile. Ultimate (load duration curve) use of these resources reduces peak demand but the system will be operated near to peak demands overtime. This increases system's failure susceptibility. The congestion in grid interconnection with large number of line transfers reduces reliability margins. During failure, the system will be subjected to high tensions as it is almost operating at peak demand. At the ultimate level, Fig. 1.8, the fault correction time and tolerable error margins are very small leading to volatility of the system. Moreover, storage system, distributed resources are coordinated to achieve flat load profile almost near to the peak load demand which push maximum asset utilization [2], [3].

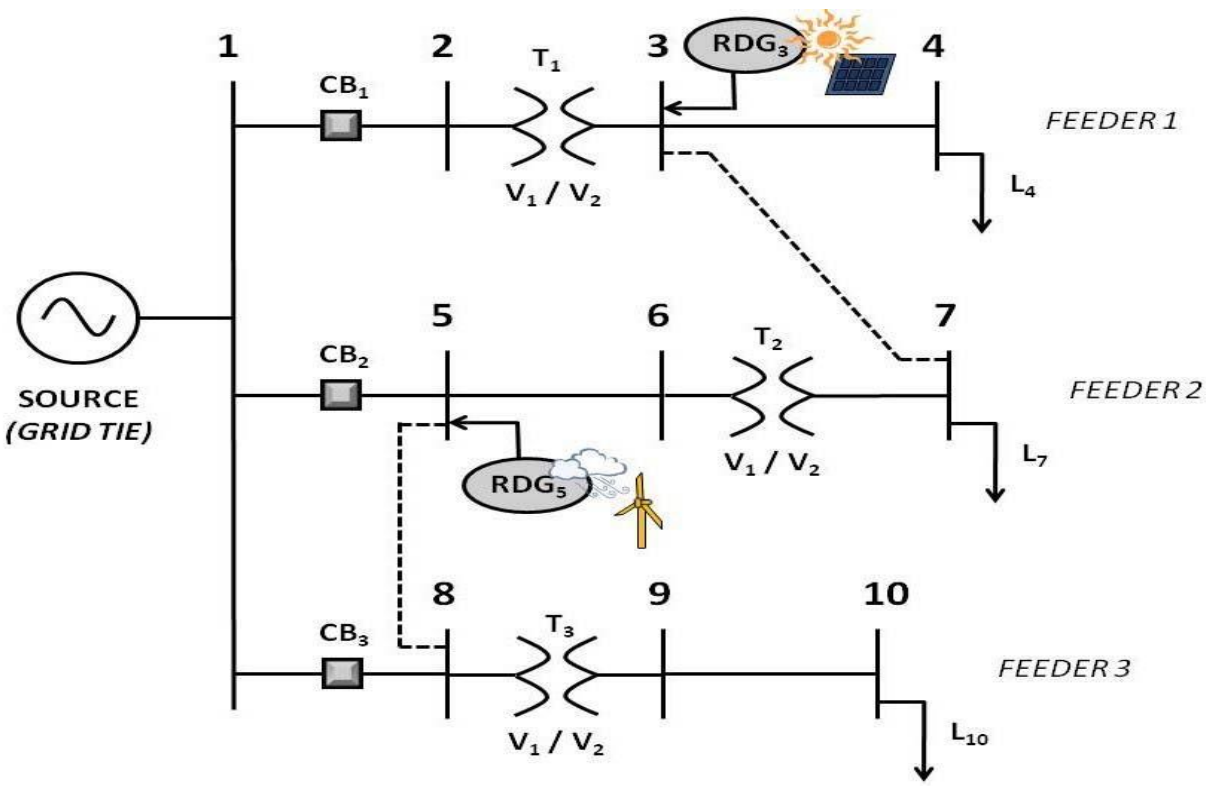


Figure 1.7 laterals designed using sequential feeder approach [5]

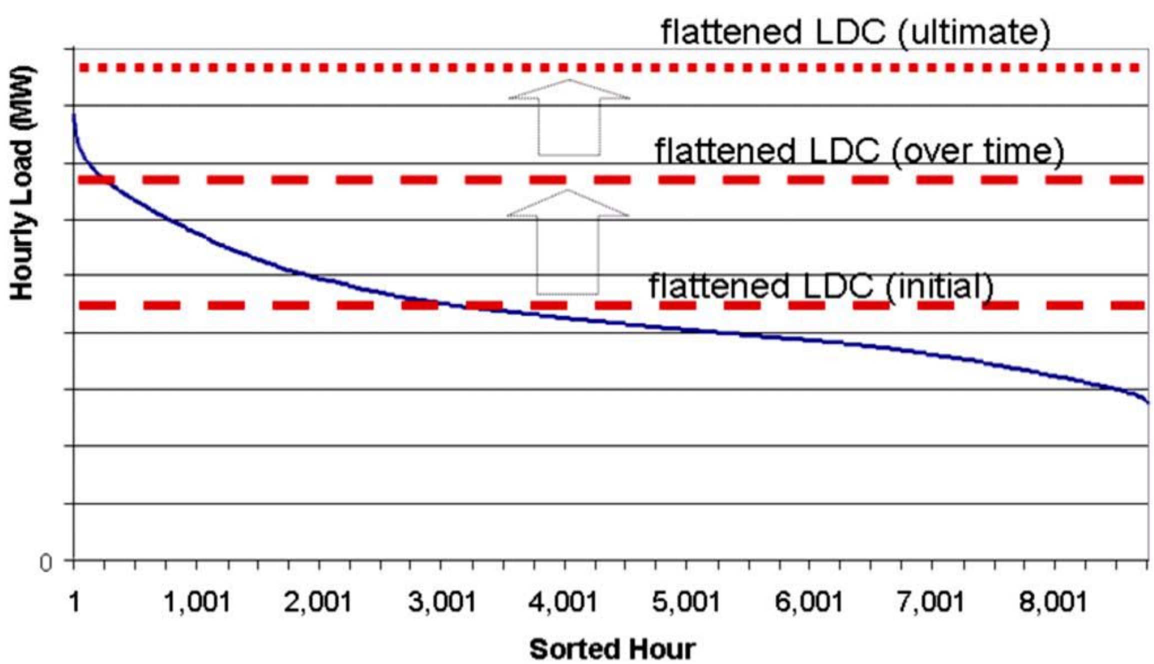


Figure 1.8 Ultimate reliability impacts of smart grid resources [3]

Though such kinds of effects occur, the reliability of distribution system is improved for sure with implementation of smart distribution system. Reliability modeling and analysis of the system can reveal how power exchange between utility and customer side is enhanced. Modeling of distribution system helps to undergo reliability analysis, risk analysis, contingency analysis and sensitivity analysis. Only reliability analysis is the concern of the study [69].

1.5.2 Reliability Analysis

A reliability data obtained from historical records conveys information about the system adequacy to supply power to customers. Reliability of distribution system can be expressed numerically using reliability indices: System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index (CAIDI) .These quantities reveal the sustained interruption frequency and duration of interruption on monthly basis or annual calculations. Moreover, reliability analysis can also be conducted using failure rates and outage duration of system components [15], [61]. The reliability data can be illustrated using geographical maps and histograms to have better visualization of distribution portions with good or bad outage experience [69].

SAIDI and SAIFI are the best known reliability measures [6]. They are calculated to display general reliability characteristics of a distribution system.

$$\mathrm{SAIDI} = \frac{\text{Total duration of all interruptions}}{\text{Total number of delivery points monitored}} = \frac{\sum_i U_i N_i}{\sum_i N_i} \qquad (1.1)$$

$$\mathrm{SAIFI} = \frac{\text{Total number of interruptions}}{\text{Total number of delivery points monitored}} = \frac{\sum \lambda_i N_i}{\sum N_i} \qquad (1.2)$$

λ_i is average failure rate of load point i

U_i average annual outage time of load point i

N_i number of customers connected to load point i

But the problem with such reliability measures is that the load loss during outage is neglected. Moreover, a calculation of these indices is inconsistent. They don’t show particular reliability measure in a bus but the system. For same number of interruptions in two systems, the reliability of the systems is affected by the number of customers. The more the number of customers, the lesser the reliability numeric value it’s obtained. Reliability measurement is also conducted from customer point of view.

$$\text{CAIDI}=\frac{\text{sum of all interruption durations}}{\text{Total number of customer interruptions}}=\frac{\text{SAIDI}}{\text{SAIFI}} \tag{1.3}$$

$$\text{ASAI}=\frac{\text{customer hours service availability}}{\text{customer hours service demand}}=\frac{8760-SAIDI}{8760} \tag{1.4}$$

The CAIDI Shows for how long an interruption lasts. By increasing interruption frequency with short time duration, the reliability of system can be improved. CAIDI improvement doesn't necessarily indicate reliability improvement because the CAIDI value can be reduced by reducing the duration of interruption while frequency of interruption remains same. Hence the system's SAIFI value is unchanged. System reliability can also be evaluated from the available data of equipment failure rate and repair time.

SAIDI based distribution reliability spending enables cost-to-benefit analysis for outage duration minimization. However, reliability improvement program that uses SAIDI and SAIFI performance tests tend to areas with densely populated feeders. The reliability indices are calculated based on the number of customers the feeder supplies [69]. Therefore, reliability improvement measures tend to satisfy large number of customers. Feeders with large number of customers, although could have satisfactory reliability, are preferred for reliability projects than with few numbers of customers.

1.5.3 Reliability Improvement Methods

The main purpose of reliability data quantification and information extraction is to take reliability improvement measures. Reliability of distribution system can be improved by increasing distribution system protection, decreasing equipment failure, system automation, installment of reclosing and switching devices and system configuration. System automation improves short interruption duration. Restoration time of momentary outage event will be small. Hence the duration that an outage will last will be diminished. Similarly system configuration produces effective improvement in reliability. During occurrence of fault that lasts long, distribution system can be configured into set of network topologies. Distribution network will have alternative supplying network after reconfiguration. These topologies provide alternative path for power flow. Configuration can be important during maintenance and permanent fault event. During disconnection of a portion of distribution system for maintenance, existence of alternative way of supplying the customer enables reconfiguration, Fig. 1.7. Hence customers experience little outage time. Additionally, reclosing and switching devices provide patterns to help to localize fault points and disconnect faulted lines. This achieves pushing a fault event affect a few numbers of customers only. Sectionalizing devices also enable way of choosing supplying path during contingency. By changing status (ON/OFF) of sectionalizing switches, network reconfiguration is established. Such capability improves reliability by reducing duration and frequency of interruption. The study considers automation, installment of reclosing and switching devices and system reconfiguration for reliability improvement.

One of the methods of reliability enhancement is increase in level of protection of distribution system. Increase in protection device gives option of selective protection system; thus, any failure in some part of distribution network may not affect other part of distribution portion [69]. Selective automation of distribution system can also improve the reliability of distribution system by more than half by placing automatically controlled switch mid-way in the distribution system; any downstream fault away from the switch cannot affect customers in the upstream [12]. Hence improves the reliability by 50% for faults that occur in the downstream portion. This also is related with designing alternative power supplying laterals for emergency cases. As in Fig.1.9, any fault occurring between NO and NC can be cleared by opening the middle normally closed switch. Therefore, customers between NC and NC can be supplied by the nearby substation. Similarly, any fault between the normally closed switches can be isolated by opening the remotely controlled middle switch. Additionally remote controlled devices help to monitor and control distribution equipment.

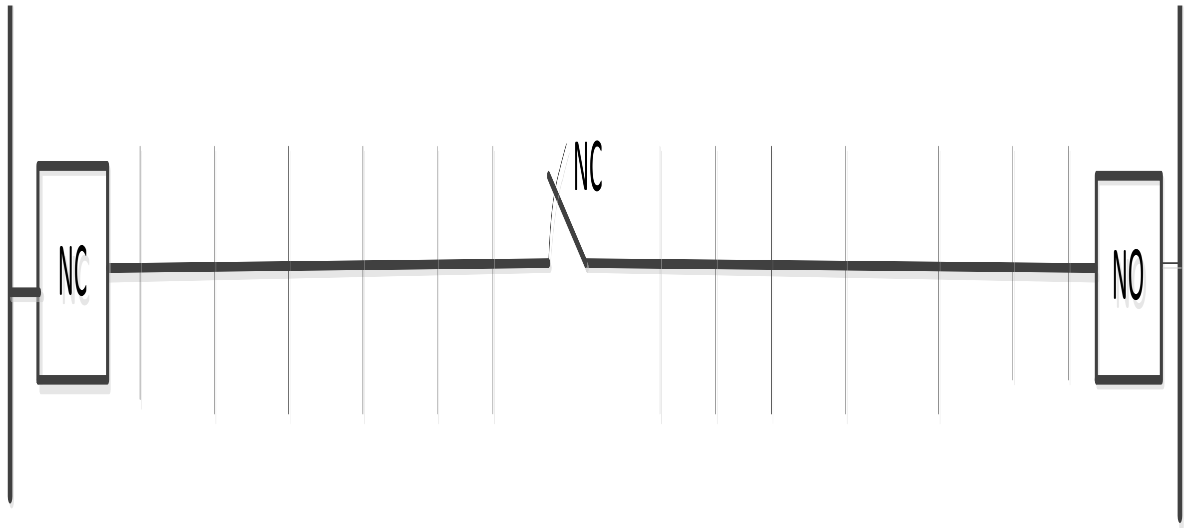


Figure 1.9 Fault clearing with remote controlled normally open/close switch. [12]

For momentary faults occurring in distribution system, installation of recloser in overhead lines can avoid sustained interruption by reconnecting line outages after self-clearing of the fault [4],[69]. The recloser, Fig.1.0, avoids long duration interruption due to momentary faults and if the fault persists, it ensures power delivery to upstream part of the feeder. The reclosing device helps faults to self-clear before affecting upstream customers. Placement of recloser prevents some customer from interruption due to fault occurring far from the substation. In radial distribution system, Fig.1.0, any fault occurring downstream of a recloser will not affect upstream customers, Hence improving reliability for specific customers.

As explained above, Network reconfiguration capability of a system enables customers' power access and reduction in un-served energy of the system. Sectionalizing and tie switch system option create power path searching alternative with the existing laterals. This improves supply reliability and power availability. It's also related to fault searching mechanism with remote control capability to identify which line to connect and disconnect. The resulting reconfigured network can have multi-objective function such as achieving maximized reliability and reduced power loss [22], [32].

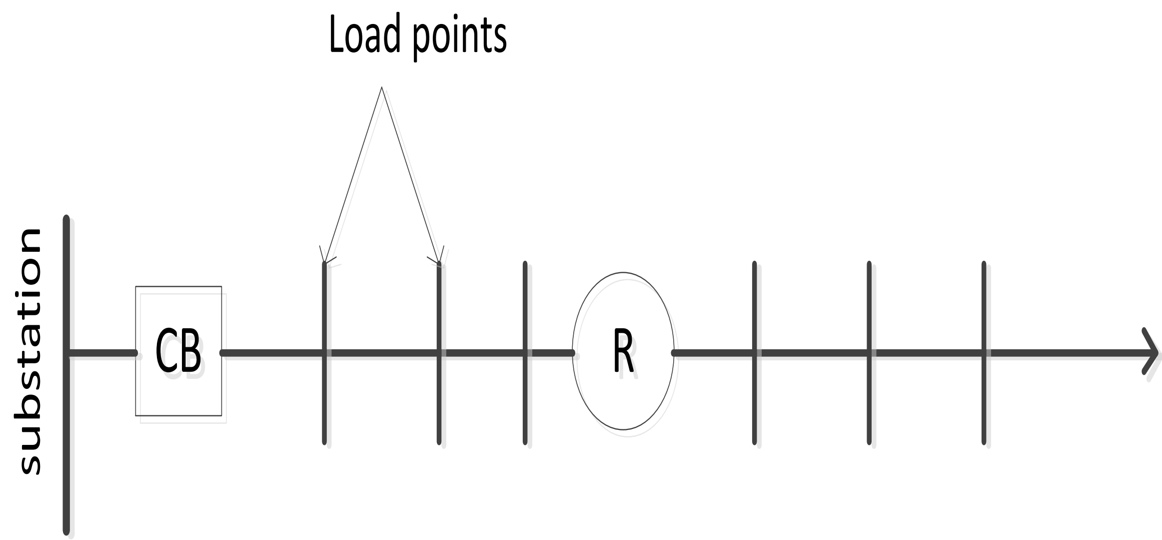


Figure 1.10 Recloser placement in midway of the distribution system: R- Recloser.

1.5.4 Reliability Analysis Methods and Optimization

Depending on the complexity of distribution system, reliability can be analyzed in various methods. Fault tree analysis and Marko analysis method are two examples that have been used in reliability analysis for many years. The preference of one with respect to the other depends on how complex and time consuming the analysis could be [69], [26]. Although, the modeling types and different design complexities with recent technologies can take long computational time, these analysis methods are effective. For nature of system representation and type of analysis required, both discrete and continuous processes make the Markov analysis versatile. Probabilistic reliability assessment method is also another analysis based on the component modeling and failure assumption. Distribution systems components are modeled in a probability of the component be in maintenance, end of life, face active failure and passive failure. Data Population of distribution equipment are considered and aging patterns are assumed. The reliability is evaluated in cut set level. The different states of a component give rise to different value of reliability. By modeling each component, the reliability of the whole system can be analyzed [22].

1.5.4.1 Genetic Algorithm

Optimization is way of minimizing or maximizing objective function subjected to defined constraints. All solutions obtained with this method must be compounded to the constraints and objective function has to be computable. The target solution obtained in this situation is stated as optimal solution. Genetic algorithm (GA) is a technique of optimization based on natural selection of Darwin's theory of evolution. The theory lies in that selected initial population with member individuals (chromosomes) can give new population with better fitness and selectivity. These individuals (chromosomes) are represented either in double vector or binary string with single binary digit in the binary string representing the gene of the chromosome [19], [61], [62], [63]. The Genetic Algorithm is used in this study to locate optimal placement of new automating, reclosing and sectionalizing devices. It is also used to select points of optimal connection for alternative distribution network (lateral). GA has the following main components.

Representation: in a way that fits to the optimization problem, initial population can be represented either in double vector or binary string. In a binary string representation, an individual or chromosome is represented in string of binary digits, ones and zeros; a binary digit representing gene of a chromosome. The proper representation of initial population makes the optimization easier to run and reach optimal solution faster.

Selection: there are many ways to select individuals that advance to the next generation. Chromosomes can be selected based on ranking of the fitness value score or probability of selectivity among members in the population.

Recombination: parents from the initial population are selected to mate with other individuals of that population to get better individuals. In such process, every new generation gives better individuals to the next generation.

- ✓ Crossover Recombination

  Crossover recombination technique takes some genes of one parent (chromosome) and places on another parent's genes vice- versa to have new offspring. The new offspring will have a new type of chromosome taken from two parents. Crossover can be made at one or two point in the binary string of the chromosome.

- ✓ Mutation

  Alteration in the gene of a chromosome is made to have variety of individuals in population. Some binary values are changed from zero to one or one to zero to add evolving species to the next generation. The probability of mutation in a chromosome is assumed to be very small as many genes alteration in chromosome can kill the individual.

Fitness function: Fitness function is the objective function that's targeted to be minimized or maximized. The value of fitness function of individuals in the population determines its probability to advance to the next generation. Using crossover and mutation recombination techniques, individuals for the next population are reproduced from the initials population depending on set of selection criteria that meet the fitness function.

The Genetic Algorithm is effective type of combinational searching optimization. Each result in each step is related to the previous step which enables to reach optimum solution (global maxima or minima) in short run time. It's used in different application in distribution network optimization for reliability improvement measures. It's also used for optimization of capacitor placement, optimal power flow, maintenance scheduling, power transformer optimal design, power system planning, etc.

The genetic algorithm can be worked out using Mat Lab optimization tool. The GA tool helps to simulate the optimization problem by filling in problem parameters or Mat Lab m-file programming for a custom data input. The study uses genetic algorithm optimization to design alternative power supply network (lateral) for network reconfiguration.it also uses GA to automating distribution network and recloser placement in Bella substation distribution network for reliability improvement. The algorithm searches a location of automating devices placement where reliability of distribution network can be improved. It carries out such optimization under reliability constraints targets. Every line segment in the distribution line is treated as candidate for placement of automating device. By evaluating the reliability of the system for different locations, an optimal point is obtained.

1.5.4.2 Prim's Algorithm

Routing of distribution network to obtain the minimum routing path uses various types of algorithms. For power rapid restoration, these algorithms can be used to find minimum spanning tree in power path network. In the existence of many alternative routes to supply power, a path the gives short routing time is required. One it reduces power loss in the lines. The shorter the length of power lines the lower the loss in the lines. Secondly time of power restoration must be as small as customer can't be frustrated with the power outage. This is because during setting up the routing network, time for opening and closing of sectionalizing switches are carried out. This is in order to make sure no loop exists in the process.

Prim's algorithm is one of the methods of obtaining minimum spanning tree in graphic theory for undirected and connected graph [27]. It starts with one node and adds the cheapest line to that node, i.e. connects the line with minimum weight. The algorithm continues until all the nodes of the graph are connected to the tree. Consider Fig. 1.12 (a) undirected connected graph. Fig. 1.12 (b) is the minimum spanning tree of the graph. Take any node in Fig. (a) For starting point of routing, in this case node a is taken. Then add line with minimum weight. The line ae has weighed 2 minimum than af and it's connected to the MST. Then the destination node is node e. Similarly, line eb is connected to node e. at node b, the minimum node that can be connected is line bd. It has weight of 3 than lines bc and bf. So node d is reached. As the MST must contain all of the vertices of the connected graph, to connect node c, there are two ways. Either from node b or from node d. the MST goes for the minimum weight and line bc is lighter than line dc. Hence line bc is connected to the MST. Only one vertex is left, node f. there are three ways to go to node f. from node a, node b or node c. comparing the line weights from these nodes to node f, line af has minimum weight. In such a process, the MST is constructed as shown in Fig. 1.12 (b).

Lines Weights of connected graph in distribution network can be either the impedance or length of the distribution lines. For this case, data available for the substation case study are provided in terms of line lengths. Thus, line weights are length of distribution system per kilometers. Basically this computer algorithm has got applications in finding shortest path to supply power with minimum loss and high reliability. Its application to obtain method of reconfiguration to retrieve power line path to minimize amount of un-served energy and power access within minimal time has made it preferable in distribution network.

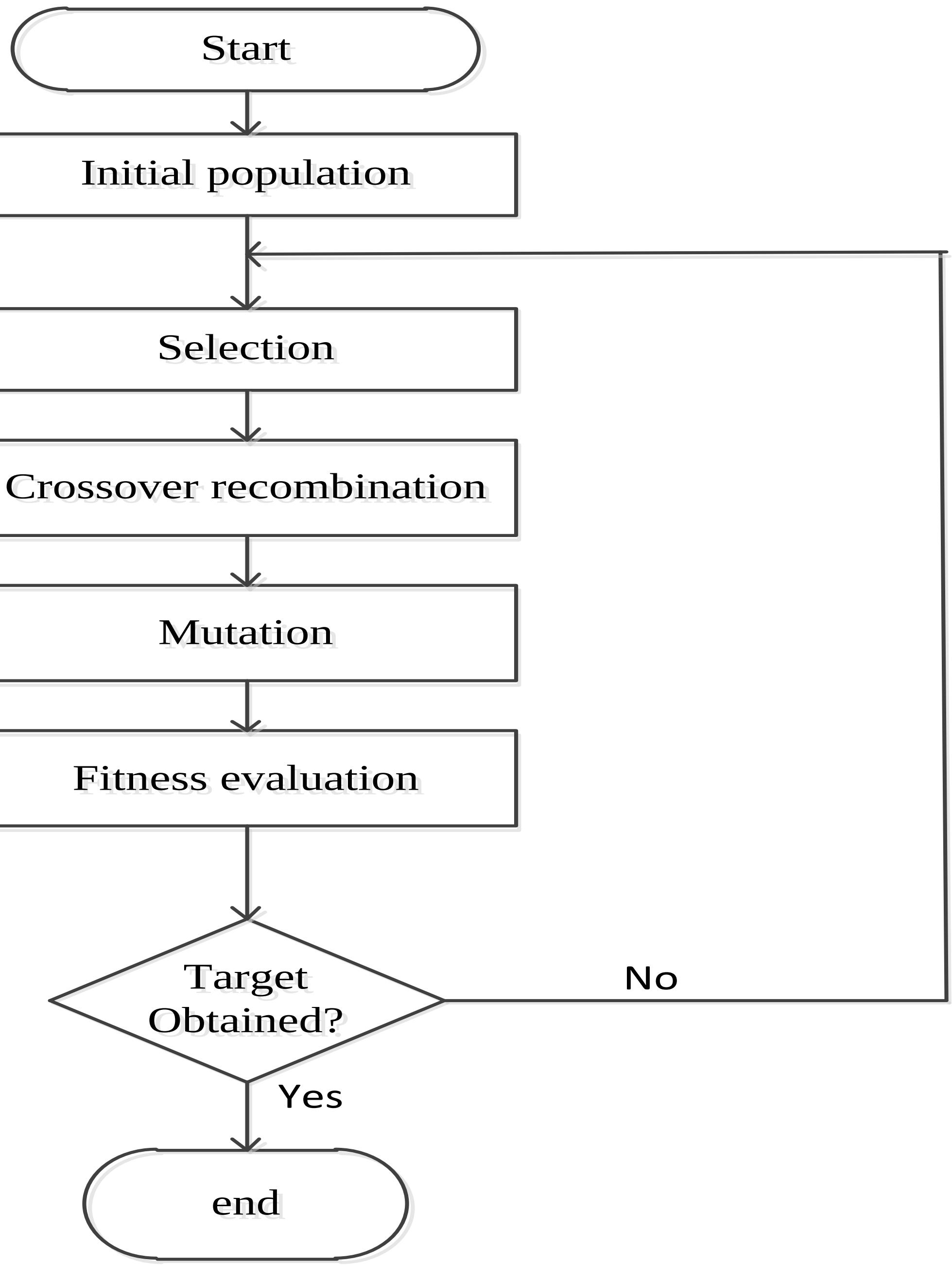
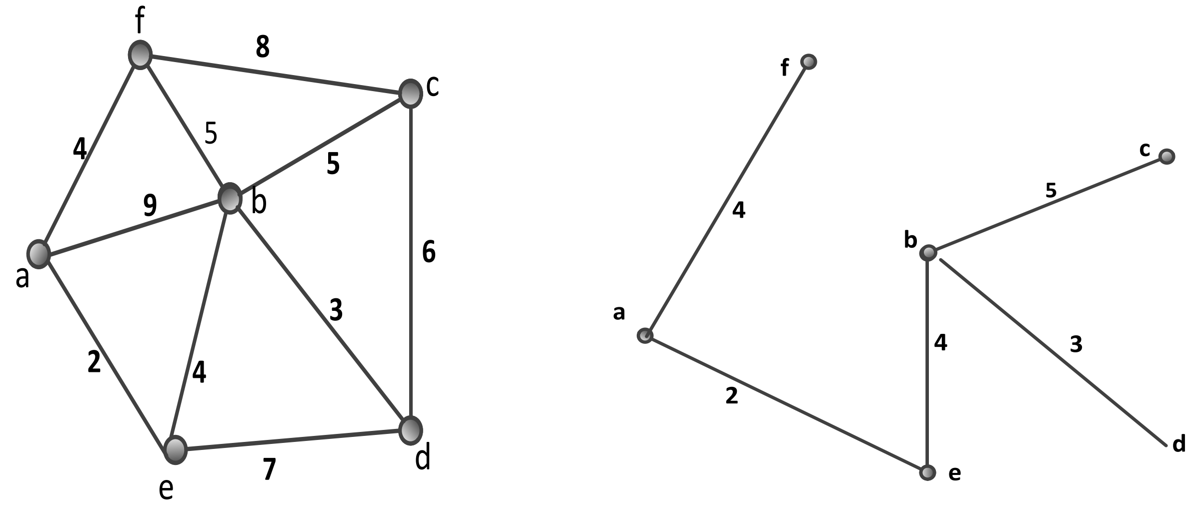


Figure 1.11 Flow chart of Genetic Algorithm Optimization technique



(a) (b)

Figure 1.12 Illustration of Prim's algorithm for finding minimum spanning tree: a).Shows original undirected connected graph system. b) Minimum spanning tree path found using prim's algorithm

CHAPTER TWO

CURRENT STATE OF POWER DISTRIBUTION SYSTEM

In Bella, Addis Ababa District

2.1 Introduction

Bella substation has five outgoing feeders. Out of these, Feeder-02 has the highest installed capacity. It has sectional connections to other feeder in the substation and to feeders in neighboring substation. The paper assesses reliability improvement measure taken on Feeder-02, which can bring fair improvement in reliability of both to the feeder and to Bella substation.

The AutoCAD drawing of Feeder-02 is redrawn in Microsoft Visio as shown in Fig. 2.1. This is done for ease of analysis. Fault point labeling and points affected by fault can be clearly visualized during analysis. From Fig. 2.1, each vertical line (node) along the straight line from left to right is the point of connection of step down transformer. The single arrow emerging from the nodes are the loads supplied by the transformers. The straight line (left to right) from node 1 to node 30 and branches connected to it are medium voltage lines. The feeder is radiated from the substation (node number 1). Sectionalizing switch and circuit breakers in the feeder are represented with the letter x. The circuit breakers in the fig. 2.1 are also labeled as CB to distinguish x whether it's switch or circuit breaker.

Feeder-02 of Bella substation is section ally connected to feeders in Bella and to feeders of nearby substations: Addis East, Cotebe-02, Bella-03 and Bella-05. The connection switch between feeders is also labeled as letter x. Power flow of the feeder goes from the substation point (node 1) to the branches of the radially distributed network.

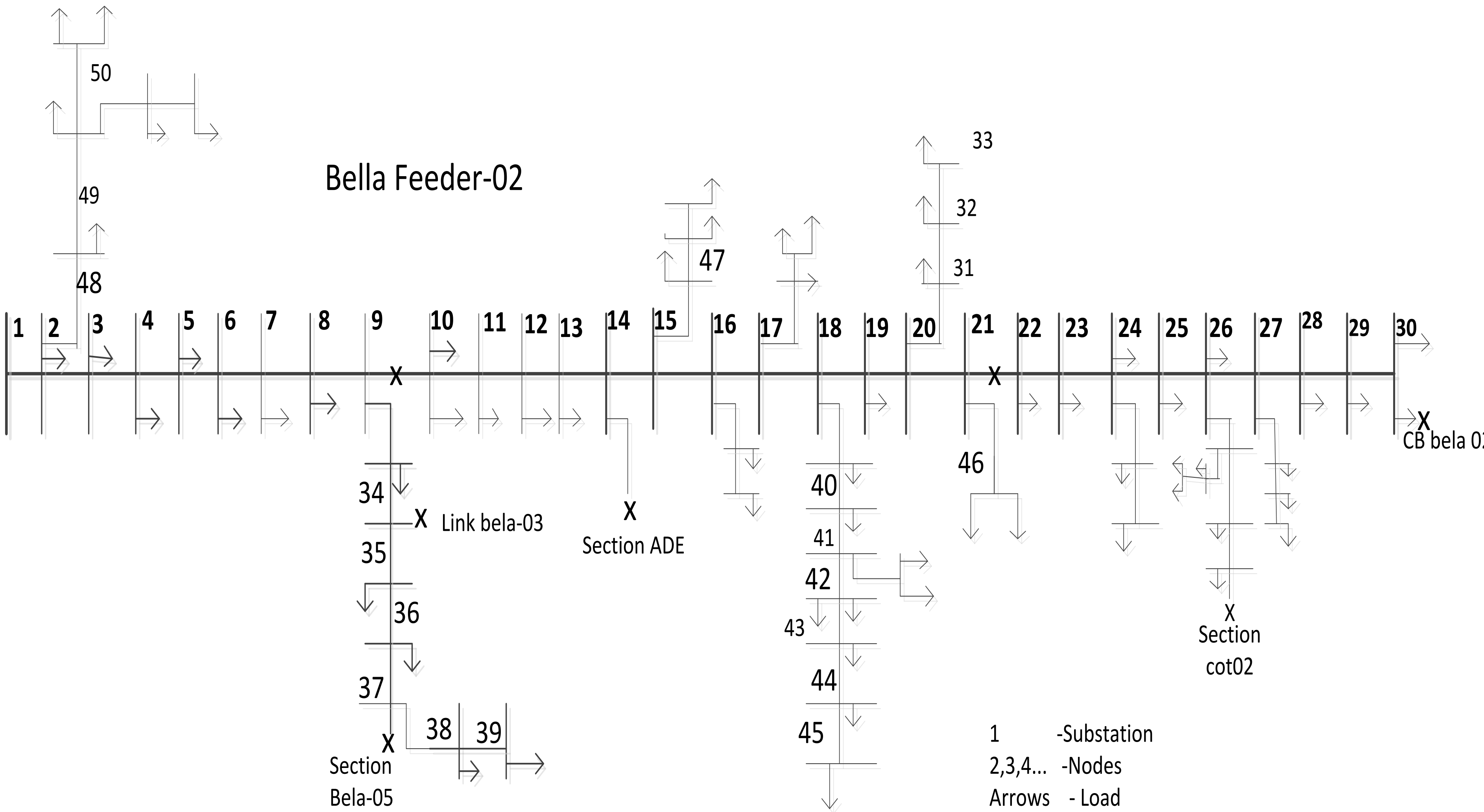


Figure 2.1 One line diagram of Bella substation feeder-02

2.2 Power Distribution study of Bella Substation

The current power distribution in Addis Ababa city is of radial distribution system type. Power is delivered to the customer from the utility in a straight forward fashion. There are no laterals and interconnection or mesh type network topology. Though radial power distribution system is less costly in terms of design and protection, it's vulnerable to disturbance hence less reliable. Because of its ease of operation, it has been very long applied in Addis Ababa city. But, the mesh or interconnected distribution is highly recommended to improve customer based reliability and power availability. From the different substations in Addis Ababa distribution system, Bella substation has a very high frequent interruption and lengthy interruption duration compared to other substations.

The Bella substation has five outgoing feeders. It works in 15kV voltage level in the secondary side of the substation transformer. The whole distribution system has a minimum power factor of 0.8. For comparison purpose, Table 2.1 illustrates capacities of the feeders of Bella substation. The Bella feeder-01 has least installed capacity containing eight node points as shown in Fig. 2.2. In all of feeder drawings, the numeric points representing the nodes and the outgoing line are drawn as uniformly sized conductors for analysis convenience. The drawings don't show any conductor size or type of conductor. For instance, the lines in Fig. 2.1 are uniform in thickness.

In this feeder, Fig. 2.2, there are 3 sectionalizing switches with no remote control mechanism. They are used to disconnect fault. For instance, any fault beyond node five will be cleared by the closest switch. The existing sectional interconnections of feeder 03 and Feeder-02 to other neighboring feeders are insufficient to set up different patterns of network reconfiguration.

Table 2.1 Feeder capacity in Bella substation: source EEPCO

Feeder name	Capacity (MVA)	Active power (MW)	Reactive power (MVAR)	No of transformers	No of customers
Bella 01	5.225	4.18	3.135	9	6400
Bella 02	16.085	12.868	9.651	66	11235
Bella 03	12.87	10.296	7.722	44	9213
Bella 04	10.495	8.396	6.297	44	8731
Bella 05	5.645	4.516	3.387	21	6522

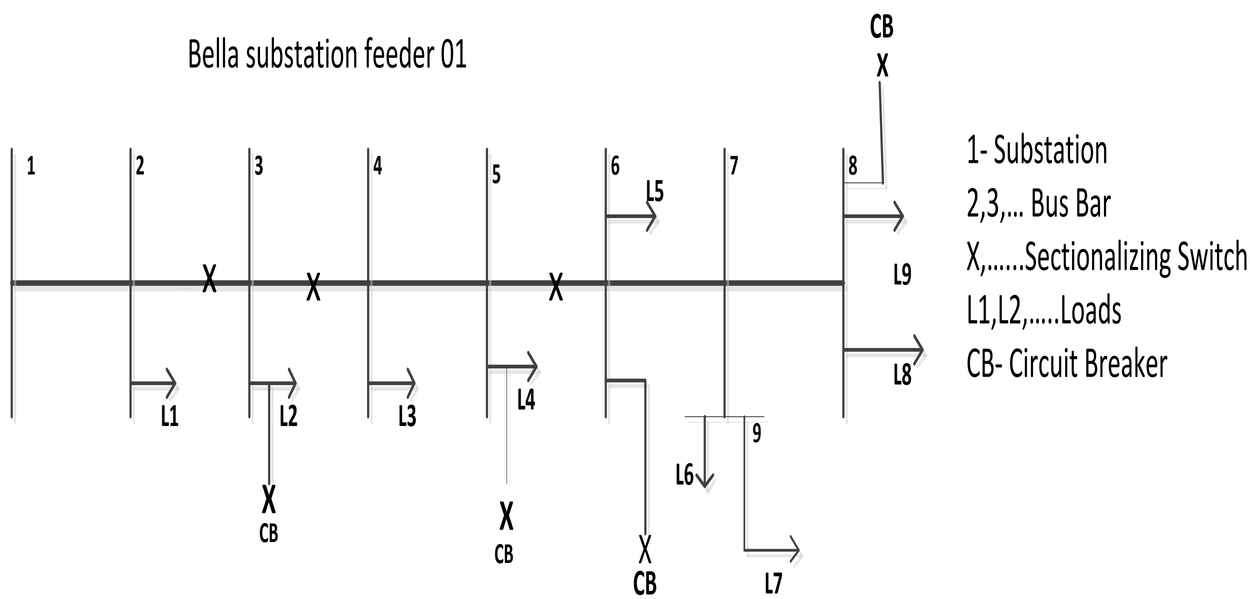


Figure 2.2 One line diagram of Bella substation feeder-01

But still these switches have not solved the issue of reliability and improved power availability. Moreover the sectionalizing switches interconnect one feeder to another feeder. In all of the feeders, there are no standby networks through which alternative power supply mechanism can be reconfigured. If any fault occurs, loads downstream of the fault remain de-energized until fault is cleared. During fault occurrence, because of no remote control mechanism and automated equipment, manual restoration is common practice which takes long time to re-energize disconnected lines.

Bella Feeder-02 has high installed MVA capacity as shown Table 2.1. The study assumes reliability improvement project undergone in Feeder-02 can improve reliability at the feeder level. Because the feeder is interconnected with neighboring feeders, the substation's reliability can also be improved. During fault in certain feeder, the substation power can be supplied to customers of that feeder through the sectional interconnection in different route or path.

This is done using network configuration and fault isolation mechanism. Additionally, out of the feeders in Bella, Feeder-02 has high frequency of interruption and it supplies the largest part of the energy from the substation. This is the reason why the reliability improvement study has focused on this feeder.

As it can be seen from Fig. 2.1, Bella Feeder-02 is connected using sectionalizing switch to Bella feeder 05 and feeder 03 at node point 37 and middle of node points 34 and 35 respectively. It has also a link to another substation to *COTEBE* Feeder-02 at network branch of node point 26 and at node 14 with *ADDIS EAST* substation. This interconnection has to be supported with adequacy and good reliability of Feeder-02, as any fault at Feeder-02 affects the other feeders as well. Making Feeder-02 distribution mechanisms smart enhances power availability in the feeders, as neighboring feeders can share power with this feeder during contingency. This improves definitely the substations reliability.

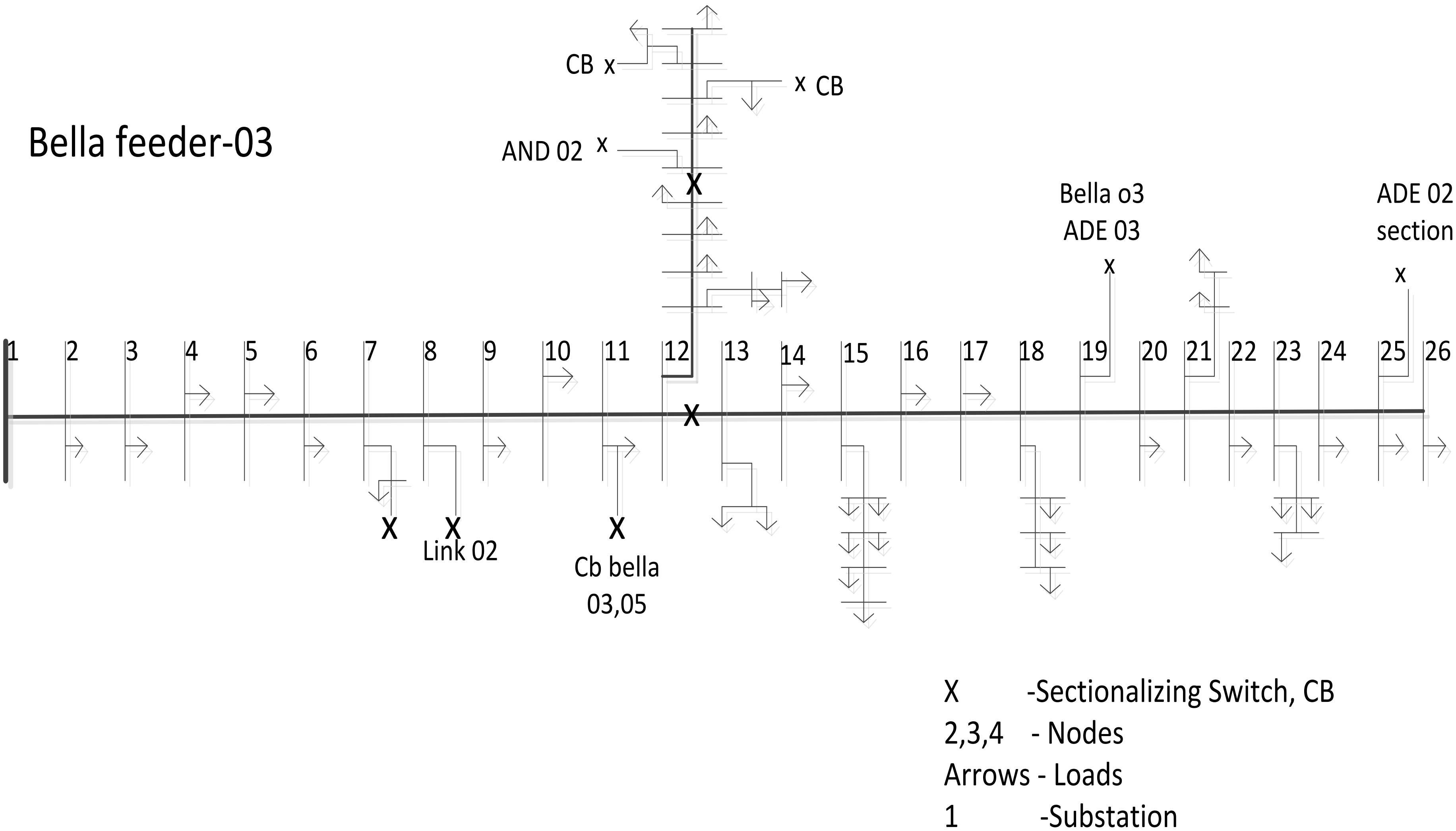


Figure 2.3 One line diagram of Bella substation feeder 03

2.3 Root Cause Analysis of Distribution System

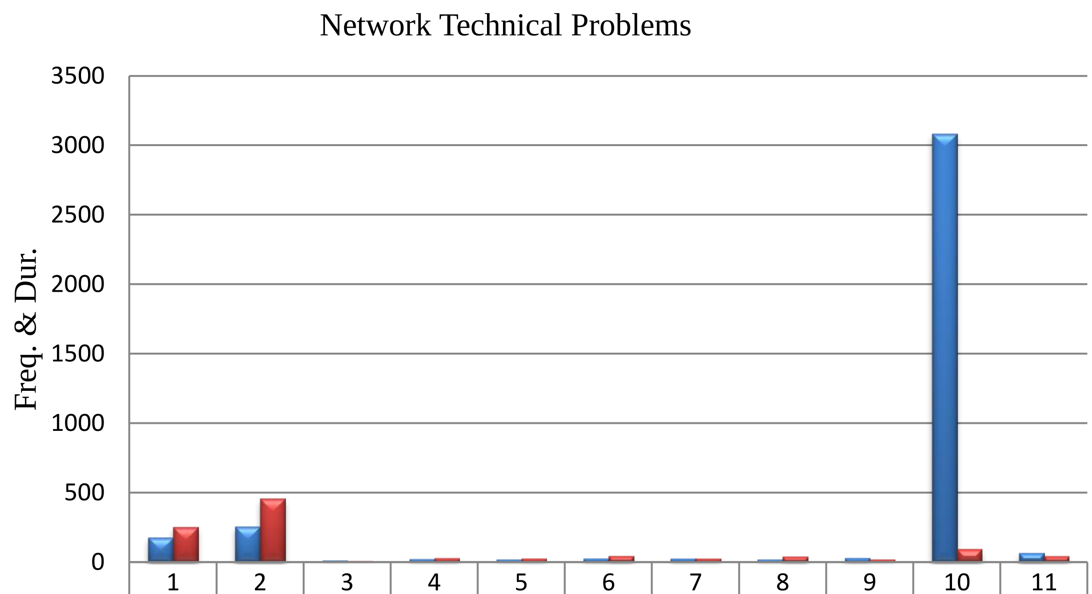
There are various problems faced with the existing Addis Ababa power distribution network. For this case study, Bella substation is selected due to the availability of load supply data. Similar to other substations, various faults occur in Bella substation that frequently cause interruption (momentary and sustained) .The causes of the interruptions are:

- ✓ Technical problems: - Technical problems are interruption causes that occur due to failure in distribution system components. They occur as result of distribution equipment failure. Outage or disconnections of lines by the operator for maintenance purpose are also technical cases. Technical problems occurred: transformer and arrestor explosion, loose lines on the supporting structures, oil leakage from transformer tank, aging of wood towers, and breaker failure to trip, etc.
- ✓ External causes: - Externals causes are other than technical problems or outages that occur due to failure of distribution components. They are result of natural phenomena or human errors on the distribution system from external. Wind, stormy rain, animals contacts of distribution lines, trees, lightning, and car accidents, etc.

According to the recorded statistics about the type of interruption sources occurring in Addis Ababa distribution network, network technical problem, external outage causes and interruption due to unknown causes have been recorded in frequency and duration of interruption. Unknown interruption causes have taken high record in 2010/11 both in frequency and the duration they took to be cleared. Unknown interruptions causes are causes of interruption that occurred but the system didn’t recognized what caused the interruption. The causes of interruption were not identified. These interruption causes were recorded as unknown source of interruption. Fig. 2.4, Fig. 2.5 and Fig. 2.6 indicate the causes and number of outages.

Similar problems were also observed in 2011/12 seven months record. External outage causes have imposed long interruption duration on distribution network in these months. Illustration for these sources is depicted in Table 2.3.

The x-axis of Fig. 2.4, Fig. 2.5 and Fig. 2.6 represents interruption causes according to the data in Appendix A. To increase readability, values of data points in the graphs are put along the numberings. For Fig. 2.4, the x axis numbers are representation of the types of causes listed below the graph. But for Fig. 2.5 and Fig. 2.6, the x- axis numbers are representations for causes listed in Table 2.2.



	1	2	3	4	5	6	7	8	9	10	11
Int. frequency	179	258	13	22	19	26	25	20	32	3084	66
Int.duration	252.52	456.99	8.64	27.6	26.88	45.59	24.55	40.46	18.44	93.93	41.6

Figure 2.4 Distribution Network technical problem graph: Data 2010/11

Note: x-axis numbers are interruption causes as listed below, duration is in hour.

1. Medium voltage lines contact each other due to wind

2. Medium voltage line cut off

3. aged tower broken due to stormy weather

4. Medium voltage underground cable burn

5. Aged tower broken and contact of cross arm and distribution line

6. Line disconnected from insulator string and contact to cross arm

7. Fire ignited due to transformer secondary side loose connection

8. Line outage due to oil leakage grounding of transformer

9. Feeder opens in switching station and time taken for fault tracing

10. Short circuit and earth fault line outages

11. High voltage line contact with street lighting line

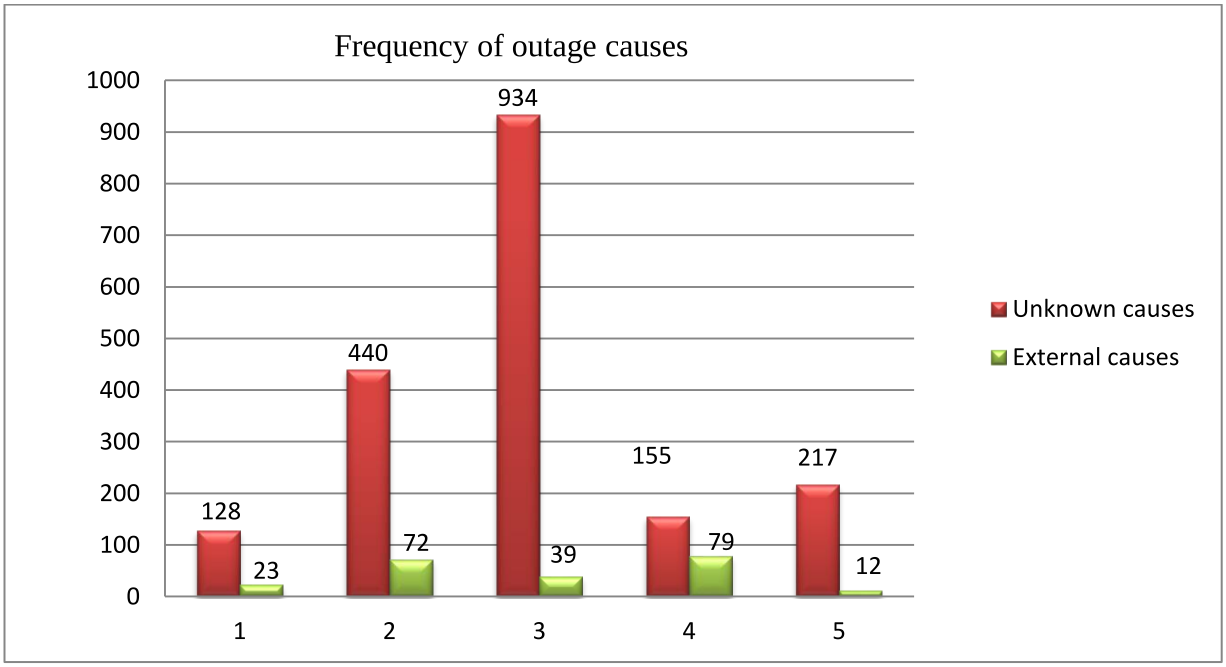


Figure 2.5 Distribution network outage causes frequency in 2010/11

Table 2.2 Cause of interruptions: 2010/11

Unknown causes	External causes
1. interrupted line during rain	1. car accident on medium voltage
2. substation breaker opens for unknown cause	2. tree falling on medium voltage
3. switching station breaker opens	3. explosion of arrestor due to lightening
4. tapped point disconnected and time taken for locating the fault	4. line short-circuit due to bird contacts
5. interrupted lines and then reconnected for unknown fault	5. Line faults due to windy rain

NB. Fig. 2.5 and Fig. 2.6 x-axis numbers are according Table 2.2

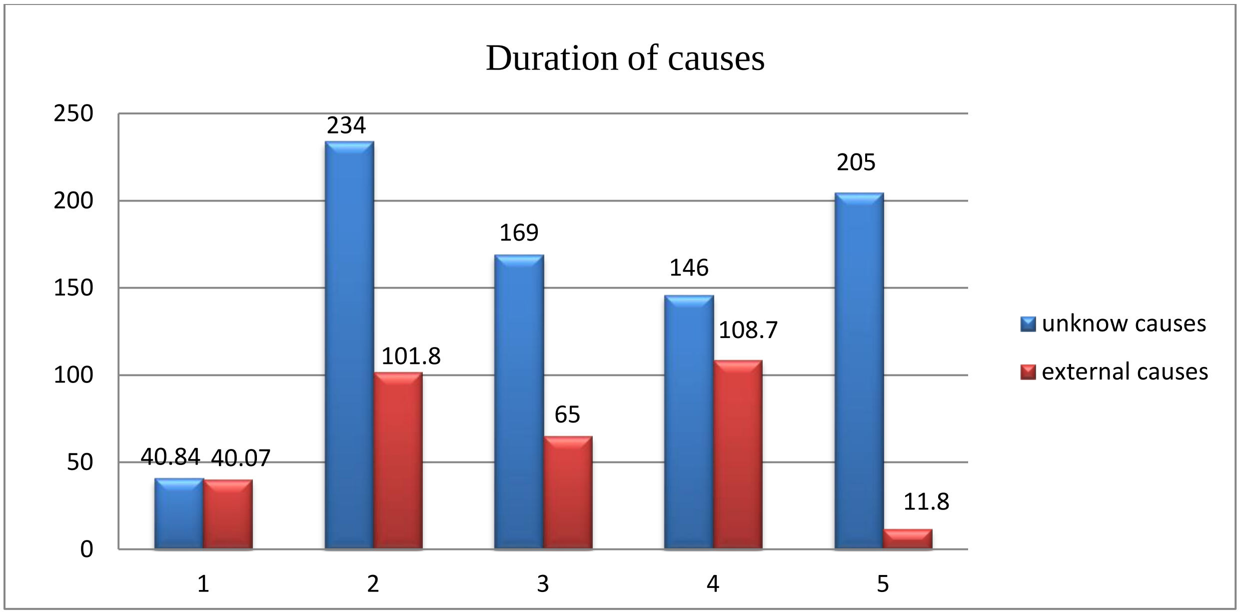


Figure 2.6 Interruption duration in hours for distribution network in 2010/11

The illustration of Fig. 2.4, Fig. 2.5 and Fig. 2.6 is to identify what the main causes of interruption are. Table 2.3 contains data of Bella distribution substation technical problems and external causes in frequency and duration. Technical problems are major causes of interruption in 2010/11. For example from network technical problem in 2010/11, power interruption due to breakage of aged tower occurred 13 times. The interruption caused 9 hours of power outage. However, in 2011/12, the same outage cause resulted in 21 interruptions and 25 hours power unavailability. Fire ignition due to loose connection in secondary side of transformer had caused 25 interruptions and nearly 25 hours electricity outage. In 2011/12 also, the same cause had resulted in 22 interruptions and 15 hours power outage. Providing means of mitigating technical problems can help significant reduction in power outages.

There are different causes of interruption in the distribution system. Some momentary faults are difficult to detect the type of faults and what caused them. The reason is the distribution system works in manual fault clearing and fault detection mechanisms are traditional. Types of faults are mentioned into the below categories during the fault clearing process.

Table 2.3 Bella Substation data: (in 2011/12 July -January)

	Distribution Outage Reason	Outage cause In Number	
		Freq.	Dur.(Hr.)
Network Technical Problem	1.Medium Voltage Lines Contact Due To Wind	82	153.7
	2.Medium Voltage Cut	271	527.95
	3.Aged Tower Broken Due To Heavy Rain	21	24.81
	4. Medium Voltage Underground Cable Explosion	24	36.91
	5. Aged Tower Broken And Contact Of '*Ganch*' And Distribution Line	21	70.93
	6.Fire ignited due to transformer secondary side loose connection	22	15.11
	7.Line outage due to oil leakage grounding of transformer	19	26.48
	8. Feeder opens in switching station and time taken for fault locating	871	93.41
	9. Short circuit and earth fault line outages	3149	148.96
	10. High voltage contact with street lighting line	17	40.96
	11. Medium voltage loose line fire ignition	5	9.57
	12.Sudden opening of circuit breaker and fault clearing	173	233.29
	13. Clamp loose and cut in tapping line	181	207.13
	14. Disconnected lines due to sudden increase in load	75	71.28
External Outage Source	1. Car accident on medium voltage line	41	53.21
	2. Tree falling on medium voltage line	57	124.82
	3. Explosion of arrestor due to lightening	14	56.71
	4. Line short-circuit due to bird contacts	48	98.86
	5. Interrupted lines due to stormy weather	92	48.56

Key: - Freq. = frequency, Dur. (Hr.) =duration (hour)

Distribution lines are also interrupted for maintenance purpose. The various forms of outages are tabulated in Appendix A. The main types of faults causing interruption in the current distribution system are:

- **Permanent Earth Fault (PEF)**

  This kind of fault is due to the distribution line or equipment getting in contact with the ground directly or indirectly. It's called permanent as it persists for long time after occurrence. An example of such interruption cause recorded is transformer oil leakage and connection to earthing wire. Transformer oil leakage formed internal fault in contact with earthing conductor. Distribution line in contact with trees happened as a result of untrimmed branches and cut distribution line lying against trees. Underground cable water leakage occurred and the time it took to locate the fault was long. Additionally, loose of distribution line from supporting structure and arrestor failure to clear fault took place. Aging of wood structure leaning to conductive substance and water flow to substation grounding that tripped circuit breaker of the substation and car accidents against tower resulted in interruption. Occasionally, Car accidents also caused interruption forming line to ground fault. Lines are cut by Lorries with hot line lying to ground.

- **Temporary Earth Fault (TEF)**

  Such faults happen frequently during rainy season because of the supporting steel structure gets in contact with distribution line and water leak to insulator cubs that results in interruption. Wind forces blow distribution lines against tree or/ and to each other. In Bella, high voltage lines and medium voltage lines are condensed in closely placed towers. Possibility of a line getting pushed or pulled to due to wind exists. Separation between lines gets close and forces of attraction /repulsion are created. This event produces contact with tree, metallic towers, etc. thereby creating contact to the earth. The term temporary is to indicate that the fault doesn't persist long. As result it causes circuit breaker to trip.

- **Permanent Short Circuit (PSC)**

  This type of fault most of the time is when two or more distribution lines come in contact with each other. Loose distribution lines fall onto nearby lines causing short circuit. It's due to untightened fixation of power lines to tower. Broken Wood towers lying on other lines result in tripping of circuit breaker. Especially the existence of HV and MV lines in close range of distance experience electric field forces. It narrows the air gap between the lines or nearby conductive elements. Broken tree branch touching two lines at the same time causes short circuit.

- **Temporary short circuit (TSC)**

  Contacts between distribution lines occur because of windy season. The lines contact and separate causing the breaker to trip. But these contacts do not stay long. It creates momentary short circuits. Similar event occurs during tree movement by wind creating contact with distribution lines. The tree touches two line same time forming line to line fault. Moreover, contact of birds dead on lines and stormy rain season caused interruption. Till rain stops some lines remain out of service. The rain pushes the dielectric strength of the air beyond limit thus forming corona. The circuit breaker trips as a result till the rains stops.

- **Distribution Line Overload (DLOL)**

  High tension on distribution line pushes disconnection of sections of power networks. Newly emerging small firms, business centers exist but still their power consumptions are unknown. The time of use of these firms causes demand imbalance. Circuit breaker trips to avoid damage on the line. The load dynamics causes line overcapacities. During public festivity, customer time of use is almost similar. Such high demand creates time shifting of supply by the dispatch center. For this reason, deliberate sectional disconnection of load points is under taken.

- **System overload (SOL)**

  This interruption type does not frequently occur and it's general to all substations. It's in distribution system level. Faults in some Generation plants cause power shortage to supply all loads. There has been a record of total blackout of system. Some generation plants faced technical problem and power access had been short. System overload also occurs due to imbalance of power demand and power generated during peak customer demand. In some seasons water levels of hydropower plant decrease and generating capacities are limited. Moreover system overload occurs as a result of poor load forecasting outcomes.

- **Aging**

  Power distribution equipment aging results in major customers' interruption as the whole supply line is interrupted. Main equipment: supporting towers, transformers and arrestors are vulnerable to aging. Aging mainly affected the supporting towers especially wooden towers. Tower roots immersed in ground lose mechanical strength due to water or soil moisture. The roots get putrefied. Especially towers in steep lands face erosion of the soil holding the roots. Land slide and chemical reaction of roots with soil softens hardness of the wood causing to fail. Rejuvenated equipment tends to fail for repeated event of temperature, overload and mechanical damage variations. Therefore, the life span of the equipment shortens. Temperature variations degrade tower strength. Power surges create sparks forcing Arrestors and circuit breaker to wear out. The same effects happen to transformers leading to frequent failure.

Interruption occurs for various reasons in addition to the above causes. During maintenance, power is interrupted to customer downstream of the point under maintenance. These customers will be affected till the maintenance process is finished. The reason is there is no alternative way to supply the downstream customers. Recently in some places, construction of roads has forced relocation of towers and the rebuilding process of the towers took so long time. Towers made from concrete had to be remade to get the power line to service. Additionally the distribution system is not automated. It works on a level of manual restoration. Fault locating techniques and manual fault clearing mechanism take long time. To exactly find the fault; some healthy lines are also disconnected for safety purpose.

Various types of causes result in earth fault, short circuit fault and loss of load. For instance, Wind caused contact of overhead lines with each other that resulted in locking out of circuit breaker and takes time for manual restoration. Distribution line contact with trees consequently tripped the circuit breaker. Another form of power outage is equipment failure. Cooling system oil leakage earthed a transformer, transformer fire ignition due to over Heating, explosion of underground cable and aging of cable carrying tower causing short circuit resulted in feeder line interruption. Loose line connection and loose arm connection to the tower have occurred frequently. The other problem for lengthy power outage was fault tracing due to breaker lock out in substation. Car accidents caused cutting of line cable and took long time for the line to be maintained and restored.

Another source of fault is external interference. Car accidents, water overflow to substation short circuiting bus bar, explosion of arrestor, dead bird short circuiting two lines, stormy rain that interrupted distribution line, substation breaker lock out and sectionalizing trial for long time are some of the human and natural faults happened as recorded data for 2010/11. The third sources of interruption are of unknown source. Breaker tripping for unknown source of fault, maintained lines for unidentified source of fault and false tripping of breakers in substation are some of them. Momentary interruptions also occur for unknown causes.

From Table 2.4, it can be said except permanent short circuit, the other fault types have shown decrease in frequency. Permanent short circuits had increased in 2010/11. But the duration it took was hugely reduced. Similarly in Table 2.5, although fair reduction in duration of interruption was observed in 2010/11, the total duration of interruption a faulted caused per annum was too high.

For more clarity in interruptions and causes of interruptions, data obtained is analyzed into sources (causes) of interruptions. The mostly prevalent and important categories are technical problems, external causes and unidentified causes. These parts are discussed in the previous section. The data is also analyzed by the type of faults which cause interruption. Table 2.4 and Table 2.5 show the frequency and duration of types of faults. This categorization enables to identify what reliability measures must be taken to improve power delivery reliability. Average values of frequencies and durations are assumed to conclude which fault has induced higher interruption in the system. Table 2.6 is average values of frequency and duration of interruption based on type of fault.

Table 2.4 Frequency of interruption of types of faults

Fault type	2009/10 G.C (2002-2003 E.C)	2010/11 G.C (2003-2004EC)	2011/12 G.C (July-Jan.) (2004-2005 E.C)
DPEF	1076	875	343
DPSC	1453	2263	888
DTEF	3728	2610	1131
DTSC	1270	1233	583
DLOL	40	8	15
Total	7567	6989	2960

Table 2.5 Duration of interruption of types of faults

Fault type	2009/10 G.C (2002-2003 E.C)	2010/11 G.C (2003-2004EC)	2011/12 G.C (July-Jan.) (2004-2005 E.C)
DPEF	1566.37	907.6	340.2
DPSC	2431.6	1901.3	860.9
DTEF	119.94	82.2	45.89
DTSC	67.21	43.5	25.52
DLOL	37.3	7.3	11.2
Total	4222.42	2941.9	1283.71

The contribution of each type of fault in the total interruption is depicted in Fig. 2.7. In terms of frequency of occurrence, temporary earth fault involved 43.5% of the average interruption in the distribution system. But the total average duration it contributed to power unavailability is very small.

On the other hand, 60.5 % of power unavailability was caused by permanent short circuit fault.it affected 25.5% interruptions. Loss of load (line overload) was not a big problem for power interruption. It comprises very small part in the interruption data, i.e., 0.33% of contribution in frequency and 0.62% of outage duration.

Table 2.6 Two years average interruption frequency and duration of fault types

Fault type	Fault frequency (Avg. freq.)	Fault duration (Avg. Hrs.)	Contribution in int. frequency (%)	Contribution in int. Duration (%)
DPEF	975.5	1236.985	13.40	34.53
DPSC	1858	2166.45	25.53	60.48
DTEF	3169	101.07	43.54	2.82
DTSC	1251.5	55.355	17.20	1.55
DLOL	24	22.3	0.33	0.62
Total	7278	3582.16	-	-

Key: - DPEF: Distribution Permanent Earth Fault, DPSC: Distribution Permanent Short Circuit, DTEF: Distribution Temporary Earth Fault, DTSC: Distribution Temporary Short Circuit, DLOL: Distribution Line OverLoad

As can be seen in Fig. 2.8, Earth fault and short circuit fault occurred frequently. The causes of interruptions are similar to causes of interruption in 2010/11. These faults mostly are caused by technical problems of the distributions system and forces from the environment. The external forces from the environment are man-made errors like car accidents, fire ignitions, etc. The numeric value labels in the graph shows repeated occurrence of fault and total sum of long duration time of power outage.

According to the data found from Ethiopian electric power corporation (EEPCO), power distribution system department in CASANCHIS branch, most of the faults that occurred, 2010/11, in the Bella distribution line are permanent short circuit and temporary short circuit faults as depicted in Fig. 2.8 All the interruption durations are treated as sustained interruption because of the recording is made on basis of frequency and for how long the interruption stays. It doesn't identify the momentary interruptions. Fig. 2.8 shows average value of frequency and duration for two years. Distribution Temporary earth fault (DTEF) occurs frequently but the power unavailability it caused is relatively low. In turn, permanent short circuit has imposed an average high duration and frequent of interruption.

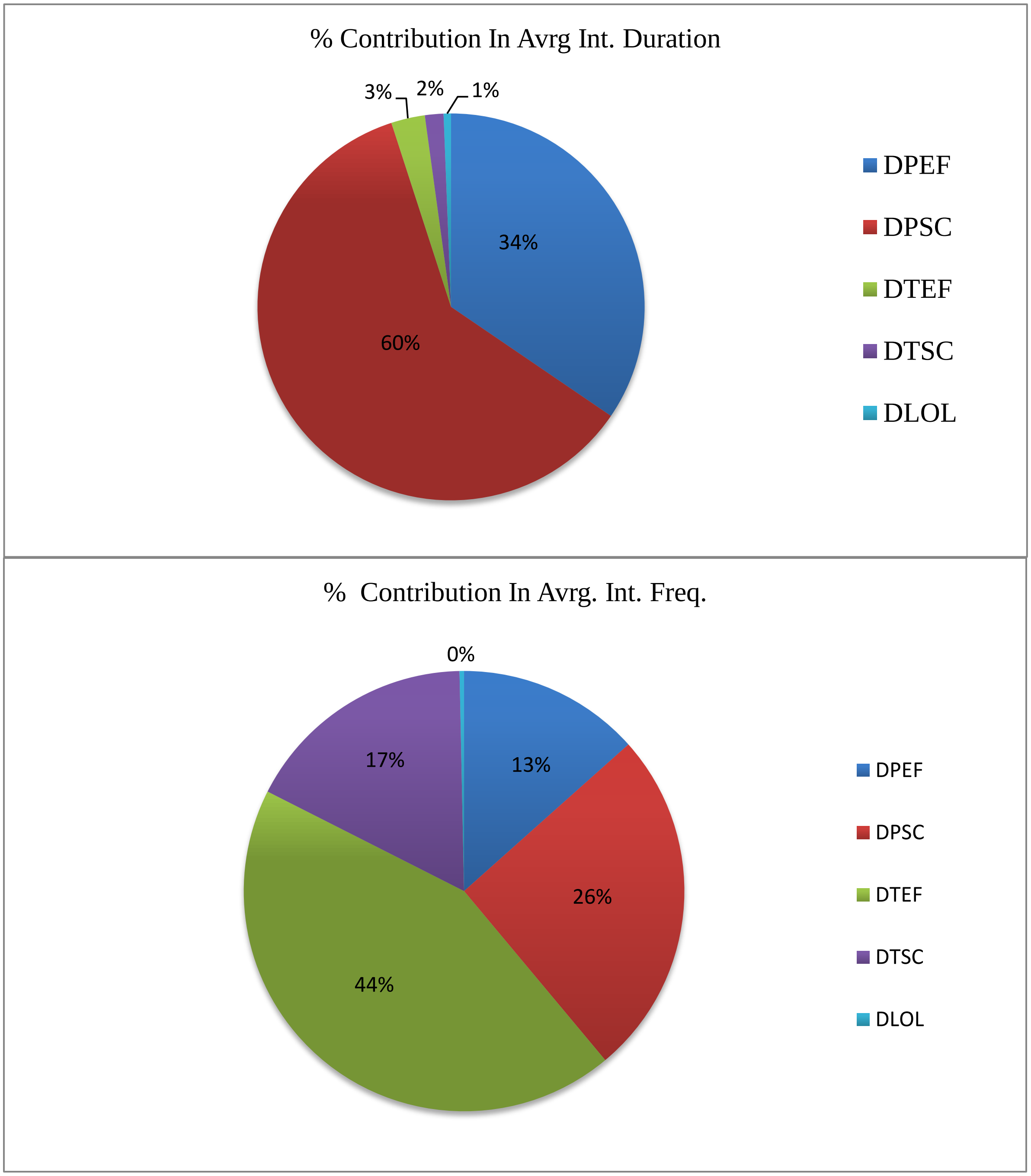


Figure 2.7 Percentage contributions of faults to total outage in Bella distribution system

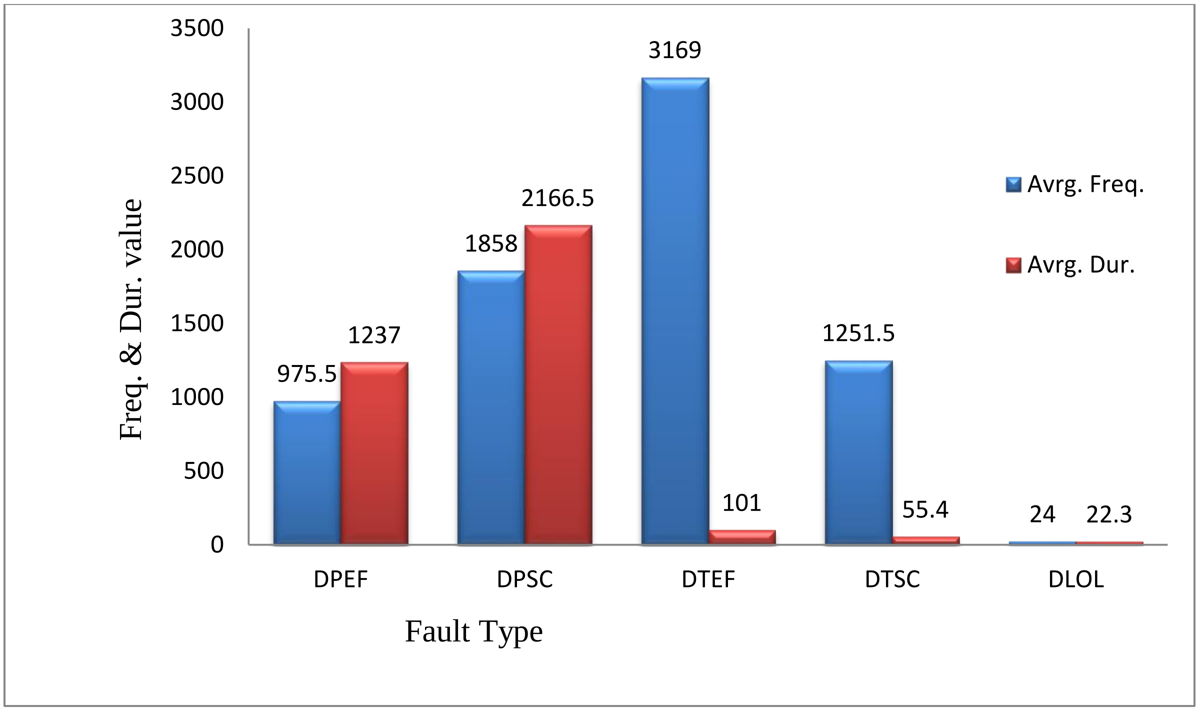


Figure 2.8 Frequency and Duration of occurrence of faults

2.4 Reliability Evaluation of Bella Substation

While calculating the reliability indices of Bella substation Feeder-02, only sustained interruption are considered. This is because the data obtained has only sustained interruptions in frequency and duration. The whole analysis is made only as system average indices of sustained interruptions. No momentary indices are considered. Additionally the interruption recording method is not only on basis of how many customers are affected by fault occurrence but also how many delivery points are monitored to clear the fault.

As discussed earlier, interruption causes can be technical problems in the distribution system. Interruptions also occur due to external causes. Table 2.7 and Table 2.8 show frequency and duration of sustained interruptions at Bella substation. In terms of frequency, high total number of outage is recorded in 2009/10 G.C (2002-2003 E.C) than the interruption occurred in the next two years. Feeder bella-02 has high interruption frequency in this year as in Table 2.8. But in term of duration; feeder 05 had high length of time of power outage. In the year 2009/10 G.C, Bella substation had frequent power interruption and the total duration of interruption of all the feeders in Bella was high as shown in Table

2.7. Both frequency and duration of interruption of Bella substation are reduced in 2010/11G.C by nearly 34.5% and 40% respectively.

Table 2.7 Duration (hours) of interruption of Bella substation

Feeder Name	2009/10 G.C (2002-2003 E.C)	2010/11 G.C (2003-2004EC)	2011/12 G.C (July-Jan.) (2004-2005 E.C)
Bella-01	125.3867	79.80333	38.37
Bella-02	189.7867	142.4	89.13
Bella-03	203.2567	112.2067	73.30
Bella-04	162.17	84.36	129.57
Bella-05	239.4433	131.3933	89.07
Substation's Total	920.0434	550.1633	419.44

Table 2.8 Frequency of interruption of Bella substation

Feeder Name	2009/10 G.C (2002-2003 E.C)	2010/11GC (2003-2004 E.C)	2011/12(July-Jan) (2004-2005 E.C)
Bella-01	105	76	50
Bella-02	261	135	81
Bella-03	160	103	55
Bella-04	134	85	68
Bella-05	140	125	80
Substation's Total	800	524	334

In average, feeder -02 of Bella substation has high outage frequency and duration. It has average 184.9 interruptions per year and average outage duration of 163.3 hours per year as shown in Table 2.9. The study has considered Feeder-02 of Bella substation for reliability improvement study in Addis Ababa distribution system. The assumption is that what works as reliability improvement to Feeder-02 of Bella substation can be replicated to other distribution systems.

Table 2.9 Average Frequency and Duration of interruption for Bella substation

Feeder Name	Average Interruption Frequency (Int./year)	Average Interruption Duration (Hours/year)
Bella-01	89.53488	94.40311
Bella-02	**184.8837**	**163.301**
Bella-03	123.2558	150.6835
Bella-04	111.2403	145.7752
Bella-05	133.7209	178.2584
Substation's Average	128.5271	146.4842

Int. /year: interruption per year

Reliability indices are calculated for each feeder of Bella substation per annum. Table 2.10 and Table 2.11 are reliability indices of Bella substation in 2009/10 and 2010/11 respectively. The reliability indices are calculated for sustained interruptions. The reliability indices are calculated using equations (1.1), (1.2), (1.3) and (1.4) and defined [69]:

SAIFI is a measure of how many sustained interruptions an average customer will experience over the course of a year. For a fixed number of customers, the only way to improve SAIFI is to reduce the number of sustained interruptions experienced by customers. The SAIFI values of Bella substation is shown in Table 2.12.

S**AIDI** is a measure of how many interruption hours an average customer will experience over the course of a year. For a fixed number of customers, SAIDI can be improved by reducing the number of interruptions or by reducing the duration of these interruptions. Since both of these reflect reliability improvements, a reduction in SAIDI indicates an improvement in reliability. The SAIDI value of Bella substation is obtained as in Table 2.12.

CAIDI is a measure of how long an average interruption lasts, and is used as a measure of utility response time to system contingencies. CAIDI can be improved by reducing the length of interruptions, but can also be reduced by increasing the number of short interruptions. Consequently, a reduction in CAIDI does not necessarily reflect an improvement in reliability. The CAIDI value of Bella substation is 1.139715 and that of feeder bella-02 is 0.8832.

ASAI is the customer-weighted availability of the system and provides the same information as SAIDI. Higher ASAI values reflect higher levels of system reliability, with most US utilities having ASAI greater than 0.999. Bella substation has 0.98328 ASAI value and Feeder-02 has 0.981358 ASAI value.

Table 2.10 Reliability indices of Bella substation in 2009/10 G.C

Feeder Name	SAIDI	SAIFI	CAIDI	ASAI
Bella-01	125.3867	105	1.194159	0.985686
Bella-02	189.7867	261	0.727152	0.978335
Bella-03	203.2567	160	1.270354	0.976797
Bella-04	162.17	134	1.210224	0.981487
Bella-05	239.4433	140	1.710309	0.972666
Substation	184.0	160	1.150054	0.978994

Key: SAIDI (Hr./cust./yr.), SAIFI (Int./cust./yr.), CAIDI (Hr./Int.) , Hr.=Hour, Int.=Interruption, cust.=customer ,yr.=Year,

Comparison of Reliability indices values of 2009/10 and 2010/111 are depicted in Fig.2.9 and Fig.2.10. Average duration of interruption per customer has shown reduction from 2009GC to 2011GC. In all feeders, the SAIDI value has greatly decreased in 2010/11 but still the SAIDI value is high as compared to bench marks shown in Table 2.14. Feeder-05 has high SAIDI value reduction in 2010/11 next to feeder-04. Both had SAIDI value decrease of 45% and 47.9% respectively. However Feeder-02 had little decrease in average duration of outage in these two years, Fig. 2.9.

But SAIFI value of Feeder-02 was much lower in 2011 than in 2009. The average number of interruption of Feeder-02 showed 48.3% decrease in 2011 while the SAIDI value was almost close to that of in 2009. All feeders had relatively lower SAIDI and SAIFI value in 2011 than the previous year, as shown Fig.2.10.

Table 2.12 shows average reliability indices, like CAIDI and ASAI. CAIDI and ASAI values are also calculated for all feeders. Feeder-02 has SAIDI of 163.3 (Hrs./cust./yr) and SAIFI of 184.89 (Int. / cust. /yr). These values are much higher than the SAIDI and SAIFI value of Bella substation, Table 2.12. Relative to other feeders, the duration an interruption lasts is low in feeder-02. It has CAIDI values of 0.883263. But it doesn't imply that Feeder-02 is reliable; the SAIFI and SAIDI values are not within standard practice.

Table 2.11 Reliability indices of Bella substation in 2010/11 G.C

Feeder Name	SAIDI	SAIFI	CAIDI	ASAI
Bella-01	79.80333	76	1.0500	0.99089
Bella-02	142.4	135	1.055	0.983744
Bella-03	112.2067	103	1.089	0.987191
Bella-04	84.36	85	0.992	0.99037
Bella-05	131.3933	125	1.0511	0.985001
Substation	110.0327	104.8	1.0499	0.987439

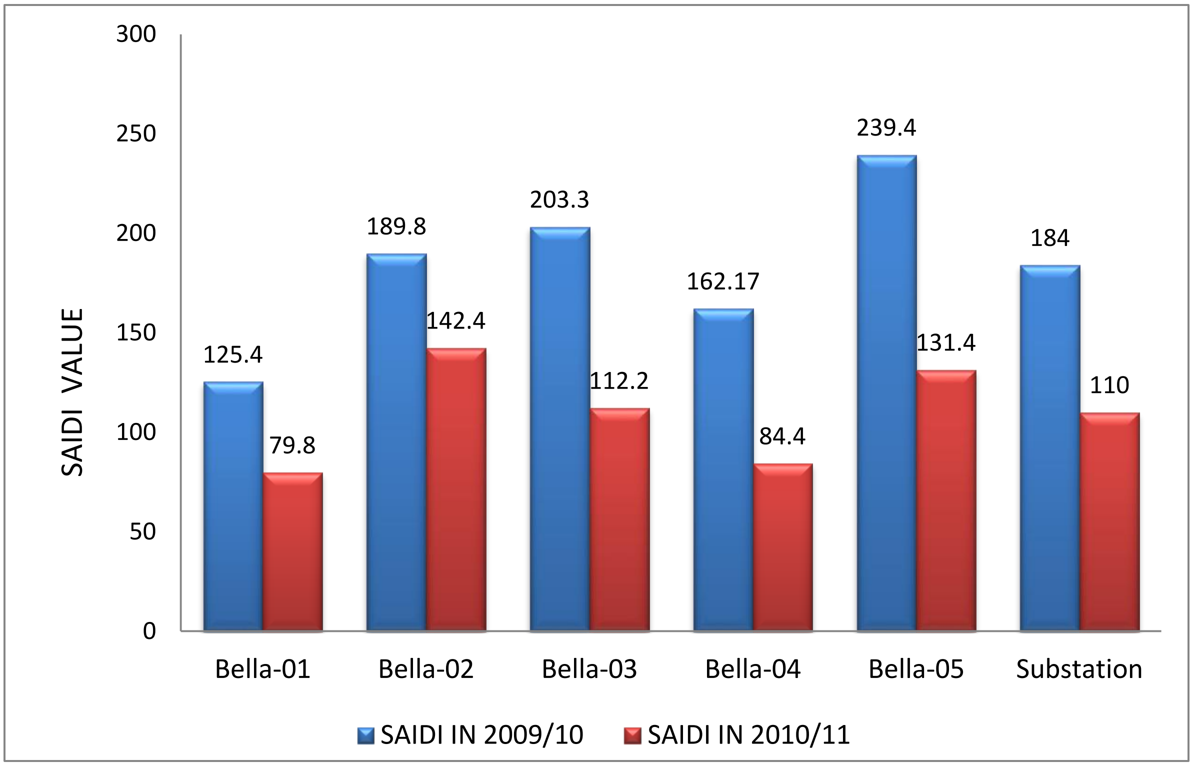


Figure 2.9 SAIDI values of each feeder of Bella substation (2009/10 G.C-2010/11G.C)

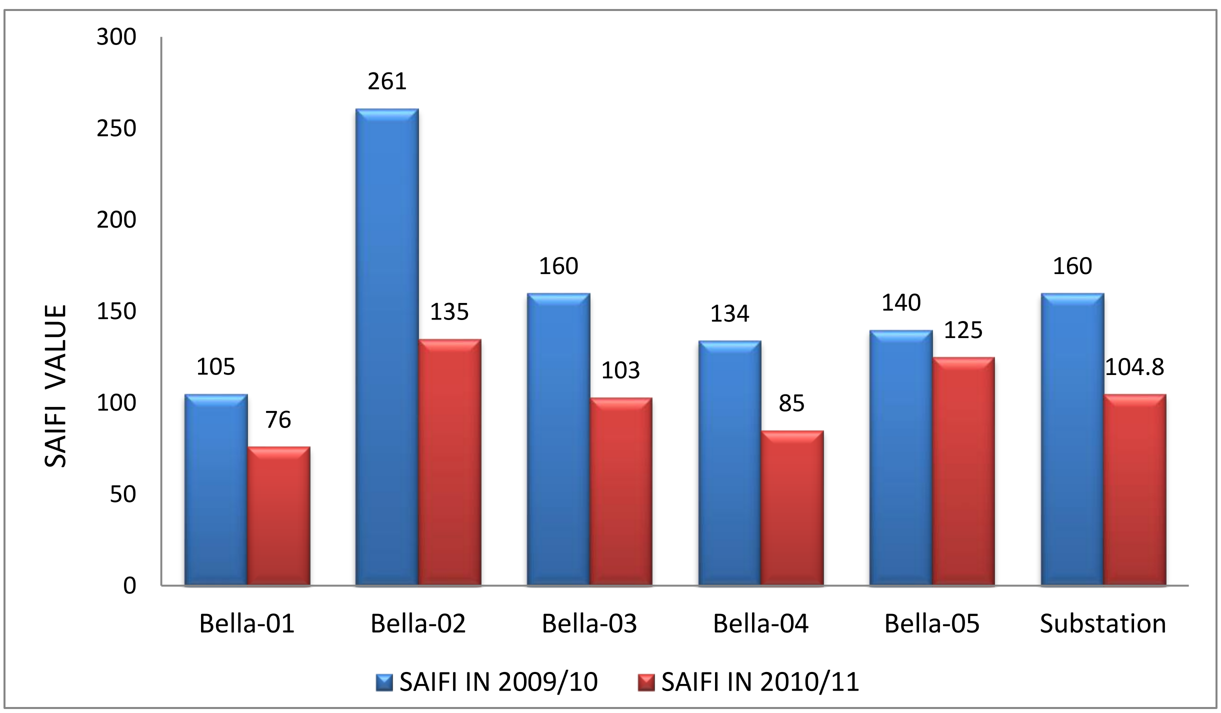


Figure 2.10 SAIFI values of each feeder of Bella substation (2009/10 G.C-2010/11G.C)

Table 2.12 Average Reliability Indices of Bella substation feeders

Feeder Name	SAIDI	SAIFI	CAIDI	ASAI
Bella-01	94.40311	89.53488	1.054372	0.989223
Bella-02	**163.301**	**184.8837**	**0.883263**	**0.981358**
Bella-03	150.6835	123.2558	1.222527	0.982799
Bella-04	145.7752	111.2403	1.310453	0.983359
Bella-05	178.2584	133.7209	1.333063	0.979651
Substation	**146.48424**	**128.52712**	**1.139715**	**0.98328**

SAIDI (Hr./cust. /yr.), SAIFI (Int./cust./yr.), CAIDI (Hr./Int.)

Table 2.13 Percentage comprison of feeders in SAIDI and SAIFI of Bella substation

Feeder name	% SAIDI	% SAIFI
Bella-01	13	14
Bella-02	**22**	**29**
Bella-03	21	19
Bella-04	20	17
Bella-05	24	21

2.5 Bench Marking and Comparison with Standard Practice

There are different recommended values of reliability standards. According to [83], Benchmarking Report on the Quality of Electricity Supply, 2008, the reliability indices values of five European countries is as shown in Table 2.14. Though the reliability reports of these countries doesn't show whether it's for urban or rural areas, the bench markings of performance in power reliability is recorded. These countries give high emphasis to power quality and reliability. Germany has highly reliable power delivery and it's within the mostly practiced target value of reliability indices [83].

According to Ethiopian Electric Agency, Average system standards for reliability in distribution system are set. Average interruption (planned and unplanned) frequency shall not exceed 20 interruption/customer/year and average interruption duration (planned and unplanned) shall not exceed 25hours/customer/year. The standard provided by Ethiopian Electric Agency (EEA) states any customer shall not face more than 20 hours per annum unplanned non –momentary interruptions duration and not more than 5 hours per annum planned interruption duration. For interruption frequency, any customer shall not face more than 15 non-momentary and unplanned interruptions and not more than 5 planned interruptions per annum. Bella substation’s SAIDI and SAIFI values are much beyond the Ethiopian and the International standards, shown in Table 2.14.

Table 2.14 Bench marking of standard practice of European countries

Country	SAIDI (Hr./cust./yr.)	SAIFI (Int./cust./yr.)
Austria	1.2	0.9
Denmark	0.4	0.5
France	1.03	1.0
Germany	0.383	0.5
Italy	0.967	2.2
Netherlands	0.55	0.3
Spain	1.733	2.2
UK	1.5	0.8
Ethiopia	**25**	**20**

There are different forms of reliability indices expression in power system. Reliability Indices can be expressed in terms of interruption per length of distribution line. They can be also expressed in terms of the energy supplied. They can be expressed in the number of monitored delivery points during fault occurrence as well.

Table 2.15 Target values for reliability indices [84]

Index	Target
SAIFI	1.0
SAIDI	1.0–1.5 h
CAIDI	1.0–1.5 h
ASAI	0.99983

For the two consecutive years, the average reliability indices of Feeder-02 are SAIDI=0.4152 int. /year and SAIFI=0.495hrs/year per monitored points. The analysis is made based on reliability indices formulas in equation (1.1), (1.2), (1.3), and (1.4). According to professionals and experts experience in fault clearing and maintenance in Ethiopian Electric Power Corporation distribution system department, assessed Delivery points feeder-02 has been approximated to 400 delivery points per year. Total delivery points include points assessed during fault location searching and points affected by the outage. Outage for maintenance and operation are considered in the monitored points of delivery.

General conclusion from the data analysis

1. Interruptions in Addis Ababa distribution network are mostly caused by distribution technical problems. Interruptions from outside or external causes have also contributed to the frequent power outage.
2. In the past three years, permanent earth fault and permanent short circuit faults have caused power outage substantially.
3. CAIDI values of all feeders in Bella are almost close to the standard practice. But this doesn’t show the feeders are reliable. Because the SAIFI, SAIDI and ASAI are not even close to the standard practice and bench marks.
4. Compared to reliability standards set by Ethiopian Electric Agency, Bella substation has reliability indices values far away from the required values. Out of feeders in Bella, Feeder-02 of Bella substation is the most unreliable.

5. Bella substation needs more reliability improvement to come to best practice. It needs amicable reliability solution to achieve standard and best practiced power reliability.

2.6 Solution Ideas For Reliability Improvement of The Existing System

A. Periodic Maintenance of Distribution Equipment

Periodic maintenance decreases interruption frequencies and duration of interruption. Distribution system main equipment shall be assessed periodically. Experts must predict probability of failure before the equipment fails. For instance, Transformer oil system and grounding can cause major outage in customers if not continuously monitored. Other main equipment such as arrestors, line tapping after being installed can experience failure. Periodic maintenance improves the failure rate and outage time. Predictive maintenance and planned maintenance can be carried out according to the criticality of the system failure. Precautious maintenance is done to equipment to prevent any failure occurring in the future. It's done by undertaking maintenance in continual basis.

Condition monitoring of distribution equipment can be predicted using potential failure graphs, Fig.2.13. Condition of equipment is the state or current working capability as compared to working in full operation without failure. Condition of distribution equipment is predicted from various available resources. Status of transformer and its working conditions is predicted from manufacturer information, experts experience and data recording of the transformer. Hence, distribution equipment shall be assessed for proper functionality to obtain level of reliability at normal operation. Maintenance actions must be carried out before failure event occurs. Planned maintenance overcomes the effect aging and probability of failure occurrence. Planned maintenance is required to reduce outage frequency and time.

B. Proper Load Forecasting Mechanism

Load forecasting is technique of predicting the load that will demand power from the utility. It can be conducted on daily, weekly and monthly basis. Proper load forecasting balances supply and demand. But poor load forecasting can result in load shifting and peak shaving. Customers can be subjected to such actions which diminishes the reliability of the system. Supply and demand imbalance can lead to disconnecting of specific customer from the distribution network. Peak power demand shall be within acceptable capacity of supply and load forecasting accuracy shall be maximized. That improves the normal operation of the system. Fussy systems, neural network and other load forecasting methods can be applied to achieve accuracy in prediction.

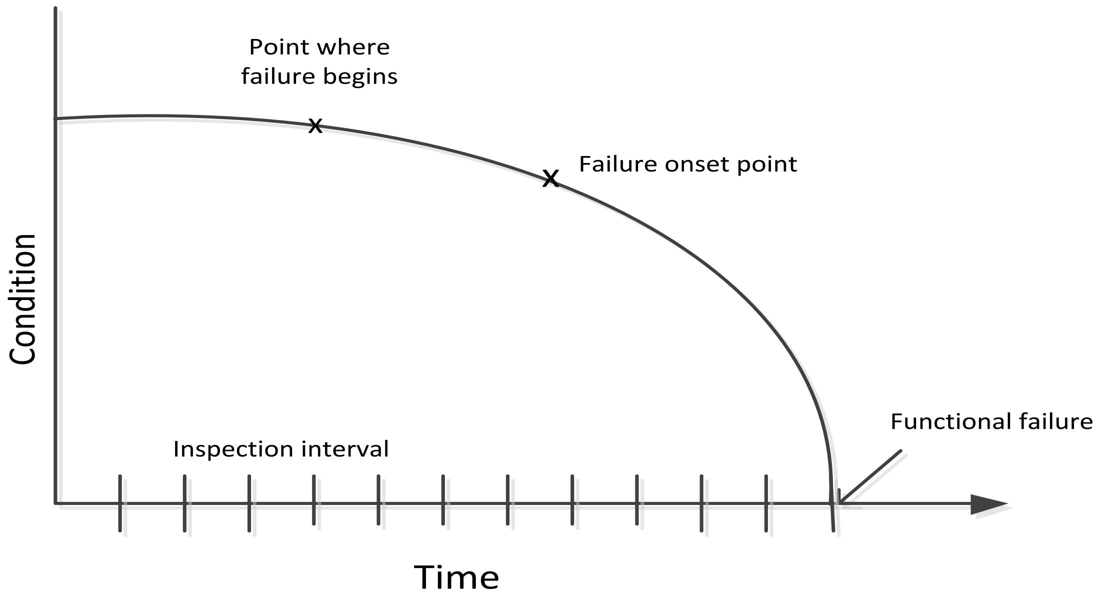


Figure 2.11 Potential failure diagram for predictive maintenance [65]

C. Repair versus Replacement of aged equipment

Electrical equipment wears out due to various aging causes. Insulation degradation, heating due to current flow, mechanical damage and corrosion from chemical reactions bring about shortening of equipment life time. Life extension and repair practice are preferable to replacing with new equipment. Damages on equipment have to be addressed by life extension programs. Life extension of distribution equipment must be carried out timely and on regular basis depending on condition of the equipment. Repair of equipment is more preferable to replacement of equipment in terms of cost and equipment durability. Replacement is done after ascertained data of failure frequency and operation incapability.

D. Technical Assessment Of Distribution System

Technical assessment of distribution network is done after fault event. Usually fault causes are identified after their occurrence. But the repetitive occurrence of fault causes shall not be allowed to happen. For instance, Falling line with trees and flooding into tower foundation has been recorded as technical problems in Bella substation. Tree trimming must be taken place to avoid contact with trees. To reduce outage due to falling down of wooden towers, tower rebuilding shall be practiced before failure. Additionally, clearing bird nets from towers reduces short circuit fault. Transformer connections and system configuration shall be assessed for better operation. Sectional connections between feeders shall be checked. Basically technical assessment reduces number of fault causes. It narrows fault cause margins. Outages due to network technical problems will be minimized.

E. Upgrade existing distribution system

The existing distribution network is radially operated. The radial distribution system is vulnerable to faults though less costly to deploy. For reliability improvement, an interconnected system has options of supplying isolated area and energizes rest of the system while the faulty part is under maintenance. That as a result increases the served energy of the system and reliability of customer service. New development in distribution system features shall be implemented to increase system flexibility and quick response to faults. Capacity of interconnection among system components and working as electrical island must be practiced to reduce mass outage. Upgrade of distribution system to level of modern grid integration enables monitoring, real time demand response of the system. Feeder-02 capabilities are limited to protection with circuit breaker and switching with few sectionalizing switches although interconnection with neighboring feeders. That limits the system's reliability and dimensions to stand up to the customer need. Therefore, the existing radial distribution system shall be upgraded to interconnection or mesh network system to increase reliability and alternative path during contingency.

CHAPTER THREE

SOLUTION OPTIONS WITH SMART GRID ENVIRONMENT

3.1 Smart Technologies

Smart grid uses technologies that have high performance in communication with control centers. They are remotely controlled. This feature has high importance in automation. The smart distribution is an evolution towards smarter power distribution with high flexibility towards controllability, monitoring and protection. The smart distribution approach enhances better power availability. It enables distribution system interconnection for central decision making. This is possible by the use of smart technologies. The smart technology devices are superior in performance of communicating with system equipment, working reliably and making logical decisions in power system. An example of smart technology is Intelligent Electronic Device (IED). Intelligent Electronic Devices are smart devices used in automation, data communication and system control.

Intelligent Electronic Device (IED)

The intelligent electronic device is one of the smart technologies that have achieved high application in power system protection, monitoring and control. Unlike the traditional devices such as remote control unit (RCU) and the general purpose programmable logic controller (PLC), they can adapt to the working environment [39]. They have adaptation to the working principle of devices and components in the system. Intelligent Electronic Devices are that experts in all of the system working state and status of all system components even before they are integrated to the system. This is because expertise and special knowledge used during their development. Their design sophistications enable pre-informed working principles of distribution equipment. They have quickest adaptation to working environment and easier communication to system components. IDEs have special capability in data processing and interpretation. They are devices applied in data acquisition and decision making from the data obtained. They communicate with high technologies and take logical decisions. Intelligent Electronic devices (IEDs) communicate with SCADA systems and also with each other. The action taking capability and effectiveness in the required task makes the IED superior in performance than the traditional devices used in protection, monitoring and control. IEDs boost the automation and remote capability of distribution system.

The IEDs have more application in information communication and the system automation of the smart grid, i.e. they can be informed and organized with formation of small database Through which they bi-communicate with control centers. Protocols and communication channels make the IED capable of Information exchange between operators, engineers, computers and controllers, and other IED engaged in similar function in the power system.

Phase Measurement Unit

Distribution system deployment of Phase Measurement Unit (PMU) improves voltage level information. It helps to balance the phase voltages. Additionally, the use of sensory information on voltage levels makes control and operation easier. Applications of phase measurement units improve transmission and distribution health status and monitoring and the sensory information data provide way of reducing lengthy outage and boost reliable power delivery [35]. Occurrence of mechanical damages in networks is assessed using data obtained from sensors. Such evolution in modern grid features facilitates the real time development of system energy supply performance and better power consumption profitability.

Automatic Sectionalizer

Automatic Sectionalizer is manually or remotely operable load break devices located on a feeder. They operate with added intelligence from IEDS. Automated sectionalizer helped with IEDs counts number of over current events. When over current events reach predefined count value, the automatic sectionalizer disconnects faulted phase or opens upstream side circuit breaker. They are applied as part of Fault Detection Isolation and Reconfiguration (FDIR).

Smart Recloser

Smart Recloser is equipment that trips during overcurrent events. Not only under over current conditions but also they are used to isolate loads in a feeder under normal conditions. Like that of automatic sectionalizer, they are remotely operable with the help of Intelligent Electronic Devices (IEDs). Line Smart recloser is used to isolate fault in some part of feeder while the rest part of the feeder remains energized. Smart Recloser can be coordinated to substation circuit breaker to isolate fault on a feeder.

Sectionalizing and Tie Switch

Sectionalizing switches are basically used to make or break loads under normal conditions. They are used for immediate restoration of power to healthy part of distribution system. Similarly, the tie switch is normally open switch applied for network reconfiguration. In case of power failure, distribution network is routed to alternative power supplying path by the use of Tie switches. Both sectionalizing and tie switches are applied in primary distribution network to reduce power interruption. The sectionalizing and Tie switches can improve the SAIDI and CAIDI of a feeder.

3.2 Distribution Automation as Base Line For Smart Grid

Because of the advancement in technology, energy dispatch systems are controlled from one point by monitoring the status of remote controlled devices that can feed the operator information of distribution networks. Automation of distribution, reclosing and switching capabilities improve the time duration an interruption lasts. If a fault persists for long time, auto-sectionalizing and auto-isolation of fault is carried out using switching and sectionalizing capabilities. For the set piece development of automation and auto sectionalizing possibility of the current distribution system to smart grid environment, the distribution automation has substantial advantage. Automating a single switch at some part of a feeder improves reliability of specific customers. The automated switch avoids interruptions of customers due to faults in down streams of the switch. It being automated means momentary fault can’t cause sustained outage and the switch can be operated from control centers. Installment of new devices for automation is important. Automating equipment and reclosing mechanism sustain the power distributing ways. Automation in distribution for this case is done either in the existing switch or placing new switch on optimized location and connecting automating devices with it. They are different methods to create interconnection and redesigning of distribution system for automating options. Sequential feeder approach can be used to optimize the problem though the algorithm does not guarantee optimality [5]. The sequential feeder approach, for feeder to feeder connection; a new connection is conceived in each iteration that can result in maximum benefit (maximize reliability, minimize cost and loss) for that iteration. If a topology does not yield the target benefit, the solution is discarded. In such a way, all options are tested but for high number of interconnections, the solution does not grantee optimality. Because there is no relation between the solutions and it can't assure the benefits are ultimate maximum. But instead, genetic algorithm is used in this paper because of its effective combinational searching and better solution.

Placement of automating device is done using genetic algorithm assuming the line segments of the system as chromosomes of the algorithm. For each location, the feeder's reliability indices are evaluated to insure improvement in reliability. Reliability improvement in this section is assumed to be achieved by installment of suitable device from either of automating equipment, recloser or switch. The reliability of candidates is evaluated according to equations (1.1) and (1.2).

Figure 3.1 is flow chart algorithm showing the incorporation of the model in the Mat Lab module. The algorithm starts by obtaining lines in mutual effect. Mutual effect lines are segment of a feeder where any fault occurrence in some part the feeder affects customers of other mutually connected segments. Then, the algorithm puts devices in candidate segments. Reliability indices are calculated for the whole feeder with the new devices in the candidate segments. The resulting Reliability indices are compared to target reliability indices. The cost minimization process continues by placing either of automating equipment, recloser or sectionalizing switch as long as SAIFI and SAIDI are within target limits. There are fifty candidate segments for device placement. Optimization of Reliability improvement with lower total cost of devices is simulated within reliability constraints. If the resulting SAIFI and SAIDI violate target limits, a new location for placement of devices is tested for better solution. If relocating of the devices does not improve the reliability, the type of devices is interchanged. By varying the type of devices installed under the required reliability, the cost of installment is also minimized. In such a process, optimal solution of new device placement location is achieved. This flow chart algorithm is written into Mat Lab programming code and simulated as shown in Appendix E.

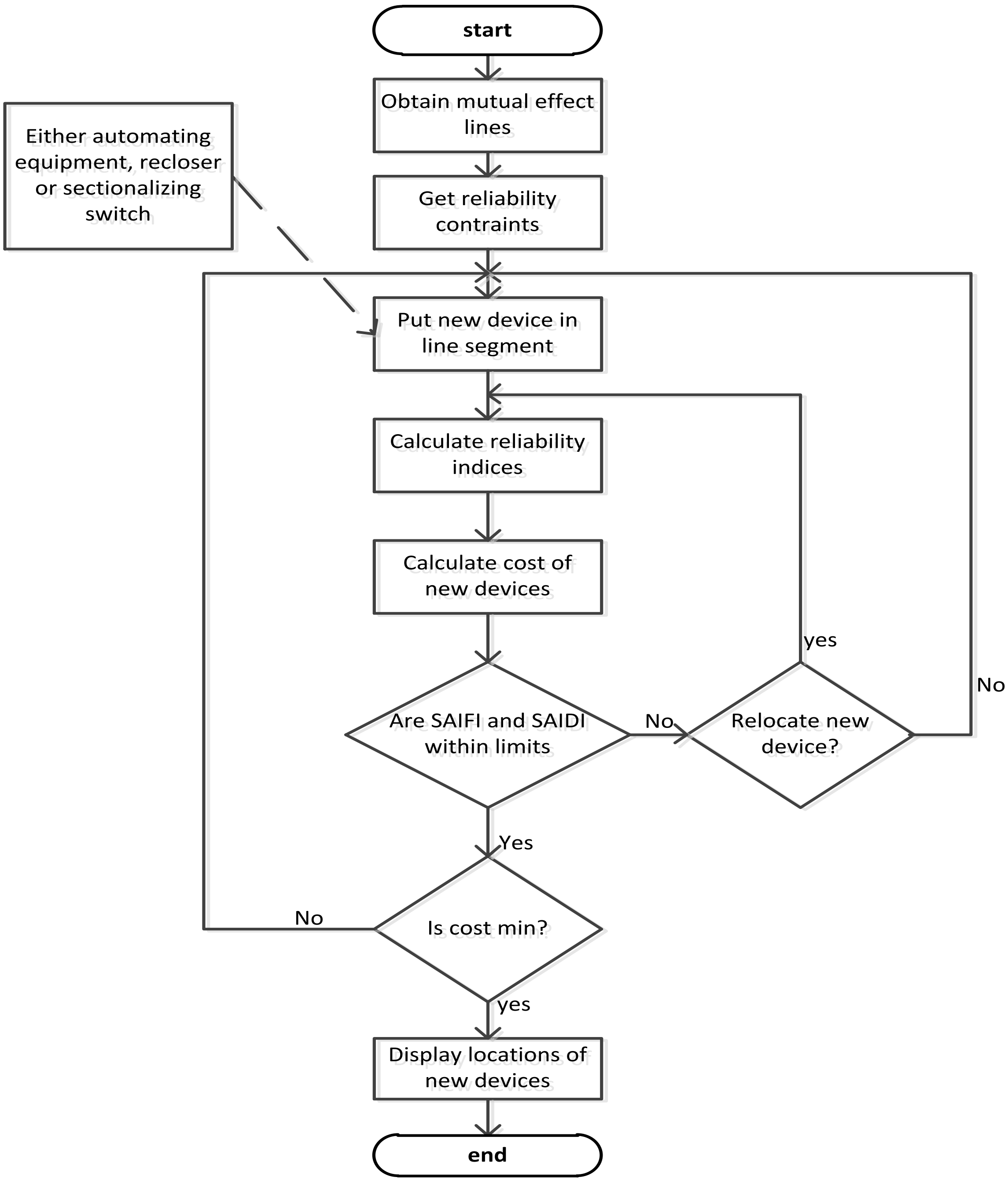


Figure 3.1 Automation, reclosing and switching flow chart for genetic algorithm optimization

3.3 Network Reconfiguration

In this study, a Network reconfiguration of lateral path is designed using genetic algorithm optimization. The design assumes two types of problems of optimization; Priority to customer or priority to supplied energy. This is because in each node of feeder-02, the number of customers and the power supplied in the nodes is not proportional. i.e., Some Large capacity (kVA) transformers supply few numbers of customers or some small capacity (kVA) transformers supply high number of customers. If design is made only to maximize the number of customers reconnected, the energy supplied may not be as maximized as before reconfiguration. Because reconnecting maximum of customers does not guarantee maximum power supplied through the configured network, laterals that can moderate both needs shall be designed. The optimization is done from theory of connectivity of distribution network matrix. The connectivity matrix of feeder is established from the number of nodes in the feeder. If a feeder has K number of nodes, then connectivity matrix of that feeder will be a K by K matrix. Within the elements of the matrix, the ones and zeros represent the nature of connection among the nodes of the feeder. If a node is connected to particular node, value one is set otherwise it's zero. The whole matrix is formulated by looking into the interconnection among the node points in the feeder. The existence of more zeros in the matrix shows more connectivity options for lateral path selection. Connecting these zero valued parts in the matrix, lateral networks that can reconnect large number of customers are chosen as optimal network lines for reconfiguration during outage. Appendix D part A is the connectivity matrix of feeder Bellla-02.

$$B_{ij}=\begin{cases} 1, & i = j \\ 1, & \text{i is connected to } j \\ 0, & \text{i is not connected to } j \end{cases}$$

i and j are nodes in the feeder

i,j=1,2,3……n. n is total number of nodes in the feeder.

The connectivity matrix, Bij, is used as initial population for Genetic Algorithm optimization. B is K x K matrix. This matrix represents points of interconnection for new lateral design. The points of interconnection are nodes from where alternative network paths are established. By use of these paths, duration of interruption of reconnected customers is improved. A permanent fault that would have caused long duration of interruption will not have long duration interruption effect. Because the network will be reconfigured if permanent fault occurs.

Existence of a number of zeros in the matrix indicates new candidates for new interconnections. As size of matrix increases, the number of alternative interconnection candidate increases. The probability of getting optimal result of objective function increases. The objective functions to the optimization are stated in results and discussion section of network reconfiguration.

The alternative path network shown in flow chart algorithm Fig. 3.2, designed is used. Searching for optimal alternative path is started by obtaining the initial population, i.e., the connectivity matrix. Then, calculation of objective functions follows. Objective functions for this case are maximizing number of customers and supplied energy. These functions are calculated for the selected initial individuals. Next step is checking whether the obtained objective function values are optimal. If objective function values are not maximum, genetic recombination of populations is carried out.

But if objective function values are maximum, the algorithm checks if the values attained are within the feeder capacity. In order for the reconfiguration to be within capacity, recombination (crossover and mutation) of chromosomes is done to reach in optimal solution. The program iterates till best connectivity is reached. If recombination has not improved the resulting solution, the program stops and best solution is displayed.

The flow chart represents the algorithm for both customers based and supplied energy based optimization. The Mat Lab code for the simulation is programmed such that the resulting optimal solution meets both priorities.

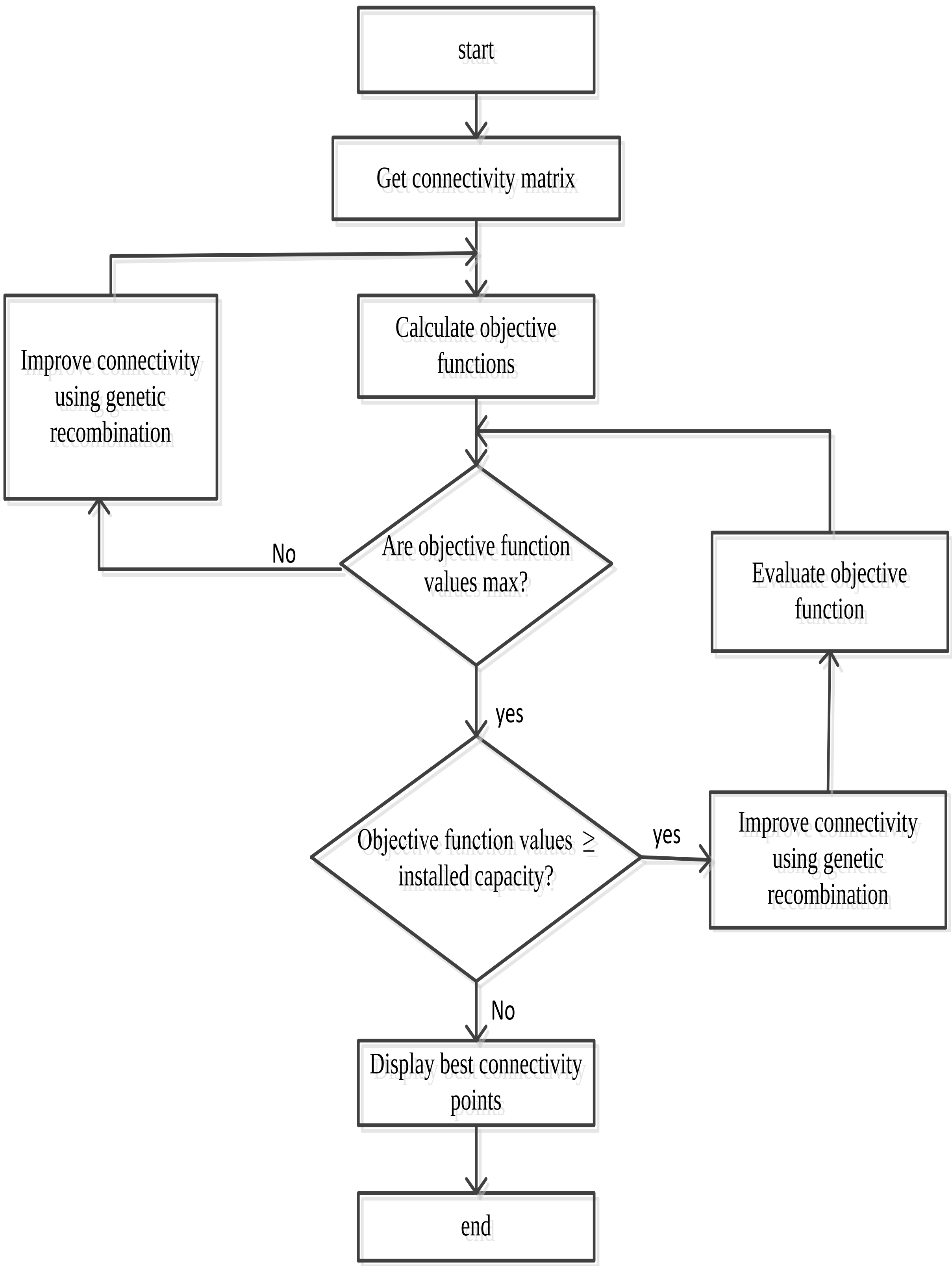


Figure 3.2 Flow chart algorithm for network reconfiguration lateral design

3.4 Method Of Rapid Restoration

Power restoration is technique of restoring power to the rest of distribution network after fault area is isolated or during fault clearing. When fault occurs in a feeder, fault location and isolation actions are taken place. Faulted segments or segmented affected by the fault are disconnected or sectionalized from the feeder. Isolation of faulted sections from the feeder is carried out by changing the on/off state of switches. Switching operation of sectionalizing switch and tie switch is made to reconfigure the network. The mechanism searches for optimal network configuration to supply the rest of the network after fault localization. Rapid restoration is carried out under power flow constraints.

The plan to obtain target network to supply power to the rest of the un-faulted area must take few time to minimize cost and loss. Therefore, Power restoration should meet distribution line plans and requirements. These are: [27]

- Restore power by maximizing reconnected customers
- Power flow constraints must be within limits
- Feasible reconfiguration network (cost and loss)
- Power balancing
- Rapid network configuration to restore power
- Keep network Radiality.
- Avoid equipment overloading

Power restoration functions as good method of improving reliability, system performance and system energy delivery. There could only be power restoration in a network with lateral supplies and remote control mechanisms. For effective power restoration with minimum power loss, short path of the power distribution network is obtained using minimum spanning tree. Minimum spanning tree is a power path network where a reconfigured distribution network covers shortest length to supply power. where there is different alternative lines to supply load, the minimum spanning tree is chosen to quickly restore power and minimize power loss.in this study, prim's algorithm is applied to find minimum spanning tree. This algorithm makes restoration quick and fulfilling objective functions. There are different methods of obtaining minimum spanning tree in graphic theory. These methods are either line based or node based. Line based algorithm adds a line with minimum weight connected to that node. One or more lines connected to a node may exist. Line with shortest length is added to the MST. During searching for minimum spanning tree (MST), Power flow constraints must be kept in consideration for the restoration to be beneficiary.

The two basic purposes of automatic power restoration are: 1). to restore as possible maximum load depending on the feeder and substation capacity and 2). To maintain power flow constraints that's to keep normal working state as of the pre-outage. Restoration time should be as minimum as possible. These algorithms give the shortest possible route for power supply. Restoration depends on the location of fault. By considering different locations of occurrence of permanent faults, MST to supply the rest network is obtained. The paper uses prim's algorithm due to ease of use and simplicity in simulation. Minimum spanning tree can be reached using different algorithms. [27]

- Line based algorithms
    a. Reverse Delete Algorithm
    b. Kruskal Algorithm
- Node based algorithm
    Prim's algorithm

The prime's algorithm

In this case, the weight of the lines is the length of the distribution line through which power routing can be done. Bella substation feeder-02 has 50 nodes with branches geometrically viewed as shown in Fig. 3.3. The label X in the figure represents a sectionalizing switch. A recloser is represented an X with label R. Nodes are points where step down transformers are connected. The vertices in Fig. 3.3 are points of distribution line spread to customers. For example, node between switch 1 and 2 is point for line that goes to switch 12. The whole geometry represents undirected connected graph of bell-02. Undirected connected graph is a geometry that shows power paths that doesn't show the flow of current. If a graph is directed, only one direction is allowed to transmit power from one node to another. Undirected graph allows bidirectional power flow unless loop exists. The branches are the lines segments between vertices. Line segment between switch 1 and switch 2 is a branch. A branch can have one or more distribution transformers. So, for various faulted points in different branches, minimum spanning tree is obtained. The problem of power restoration is to achieve power supply route by localizing fault within the faulted branch. The requirement and conditions for restoration are discussed in simulations and result discussion section.

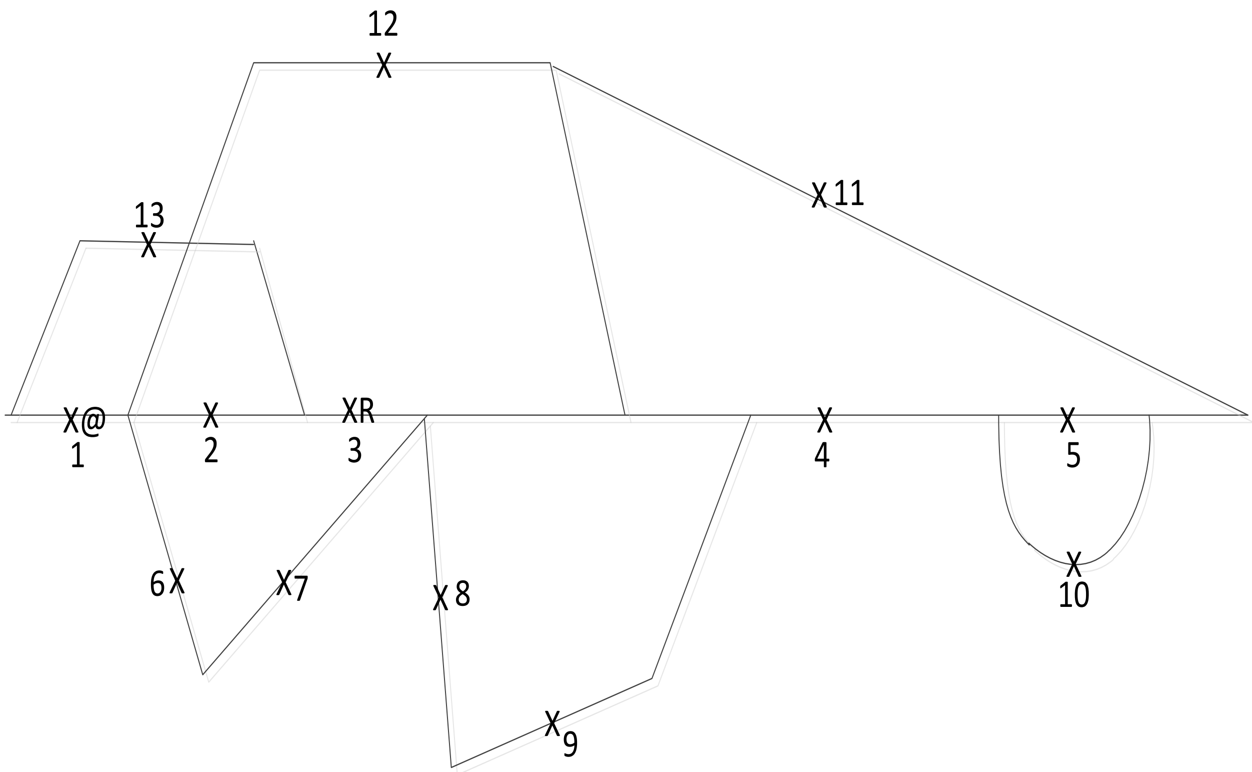


Figure 3.3 feeder-02 undirected connected graph with newly designed lateral and new installed devices

The pseudo code of prim's algorithm is described as follows. It considers a graph with V-vertices and K edges. The minimum spanning tree is, G_e, is obtained by adding weighted line, e* containing vertices (v*, u*). Only the light weighted lines are considered into the MST of a graph. The algorithm completes finding the minimum spanning tree when the vertex of the MST is less by unity than the original graph. V_e and K_e are vertices and edges of the minimum spanning tree.

Prim's algorithm to obtain minimum spanning tree

My Graph= (V, K)

V-vertices and K -edges

Find minimum spanning tree G_e

Ge=0 initially and V_e is vertices and K_e edges in G_e

For i=1:V-1

Find minimum weighted line e= (v*, u*)*

Among all lines (v, u)

V E Vt and u E V-Vt

Return Ge

The geometric representation is made for ease of analysis. Loads that can be supplied with single distribution line are taken as points of one geometric line. Any branch emerging from the geometric line creates another geometric line in the graph. The sectionalizing switches are represented as letter X. sectionalizing and tie switch enable to restore power to customers. The normally closed and normally open switches can be operated to supply customer before even faults are repaired. They allow faults to be isolated. This decreases the duration of a fault. SAIDI value of a system can be improved with use of sectionalizing switches.

Sectionalizing switches: $\mathbf{X}_1$, $\mathbf{X}_2$, $\mathbf{X}_3$, $\mathbf{X}_4$, $\mathbf{X}_5$, $\mathbf{X}_6$, $\mathbf{X}_8$

Tie switches: $\mathbf{X}_7$, $\mathbf{X}_9$, $\mathbf{X}_{10}$, $\mathbf{X}_{11}$, $\mathbf{X}_{12}$, and $\mathbf{X}_{13}$

The node representation of feeder-02 is shown in Fig. 2.1. Hence the minimum spanning tree is found using prim's algorithm given the edges and vertices of the connected graph. The open/closed state of the switches determines which path to select. The geometric representation shown in Fig. 3.4 is based on optimization results obtained as shown in Fig. 4.11 and Fig. 4.14.

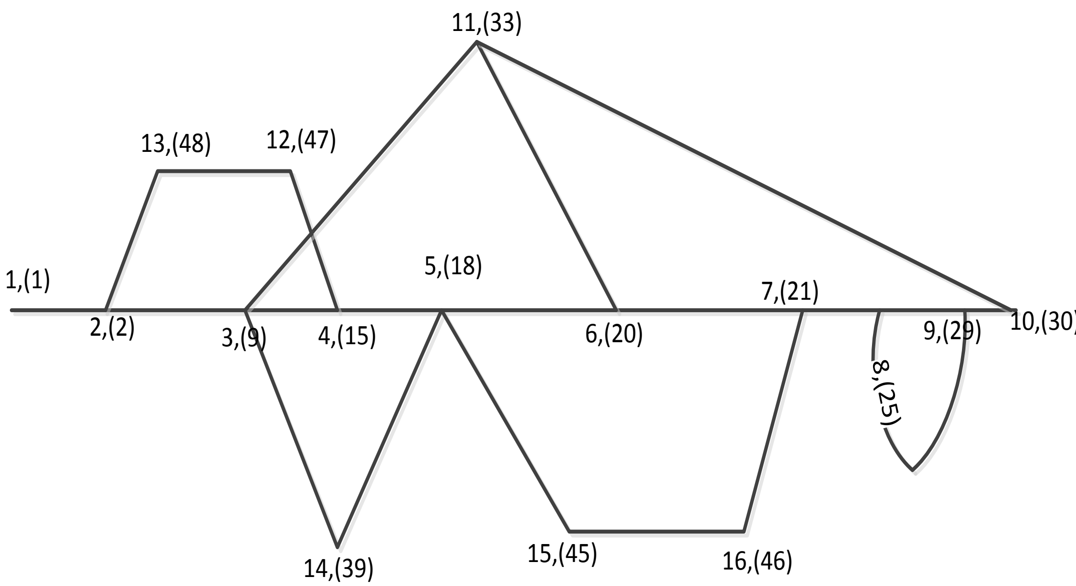


Figure 3.4 Network node and geometric node representation of feeder Bella 02

Restoration problem

To find the minimum spanning tree for power restoration in Bella Feeder-02, the objective function has to maximize the power supplied to that point.

1. Maximize the power supplied to the target point.

Maximize $y = \sum_{i}^{n} L_i \; X_i$ (3.5)

Where,

n –total number of nodes in the feeder

L_i- the load at node point i

X_i- decision variable for the switch in the line

X_i is the position of the switches in the distribution line. The open or closed state of the sectionalizing and tie switched determine the binary decision variable X.

$$X_i=\begin{cases} 1 & \text{if switch i is closed} \\ 0 & \text{if switch i is open} \end{cases}$$

The number of switches determines reconfiguration options. For instance if a network has two switches, vector X can have value of X= [0 0], X= [1 0] X= [0 1] or X= [1 1]. Either of the switches can be closed, both can be closed or both can be open. Two switches have four different kinds of combinations. The network can be configured for various combinations of the switches. For network with n=3 switches, it will have switching options 2^3. It has eight patterns of reconnection options. Open/closed state of the switches can be combined to have eight different patterns. The vector can have the form of x=[0 0 0],x=[0 0 1],x=[0 1 0] and etc. .For network with n number of switches, the switching options for the network are 2^n. Therefore, the values of the variable X will be a decision vector with status of switches. Values in the decision vector show states of switches in sequential order of their representation. Index order of decision vector stands for switches from one up to the number of existing switches. The decision vector has the form:

$X=[\ X_1\ X_2\ X_3 \dots\dots\dots\dots\dots\dots\dots X_n]$

2. New power restoration path shall not contain loops. The supply method has to be radial.
3. Feeder capacity and load point capacity must be within limits. Node points must not be subjected to supply beyond the transformer capacity at that node.
4. Restoration problem shall reconnect as maximum number of customer as possible.

3.5 Load Management System

3.5.1 Demand Side Management

The demand side management is an effective method of modifying customer demand in order to optimize the operating cost of costly generators while tolerating capacity addition such that the environmental balance is maintained. Demand side activities are aimed to influence customer electricity consumption. Various ways of managing demand of customer are practiced in modern grid. Storage conservation techniques, valley filling system are included to maintain balanced cost and supply [68], [73], [80].

Basically the demand side management involves:

a. Load shifting

   Load shifting involves shifting from on peak periods to off peak period. Use of storage mechanism improves loading on distribution network hence customer load shift paves way of power continuity during high tension period of distribution network.

b. Peak clipping

   It's method of direct load control mechanism. It provides way of minimizing operating cost and system disturbance by reducing peak demand from customers.

3.5.2 Demand Response

Reliability issues can be addressed by controlling the demand shape and load forecast application. This technique provides options to customers in flexible Load –Demand relationship in relation to market conditions and resource constraints [80]. Operating condition of networks push the interest of applying customer based electricity management in mutual benefit to utility. In basis of mutual interest, the customers' desire and utility requirements are fulfilled in content. Customer's desire can lie in maintaining life style, satisfied needs and increased value of service [80]. Utility may require sustainability, improved financial performance, enhance image of utility and increased system utilization.

CHAPTER FOUR

SIMULATION AND RESULTS DISCUSSION

The objective of this simulation is to evaluate the re-designed distribution networks of Bella substation of feeder-02 for reliability improvement. It's to validate the design and test its implementation with software based analysis. Lateral design for network reconfiguration, automation and recloser placement optimization is simulated. Rapid Power restoration simulation is carried out to obtain minimum spanning tree in the distribution network. The network design optimization and effectiveness is simulated subjected to reliability constraints. The simulation is made in Mat Lab 2012 version software using prim's algorithm for finding shortest routing path and genetic algorithm for the rest of optimization problems. The drawings for the lateral-design are redrawn to the existing distribution network in Microsoft Visio software for illustration.

Mat Lab

Mat Lab (Matrix Laboratory) is software designed to make design analysis, programming applications, numeric computations and graphic user interface simulations. It has different library functions, visualization tools for analysis, design application and special tool packages. It has Simulink tools for power engineering and other streams that help to test and simulate electrical designs. Different optimization tools are provided in Mat Lab for various techniques of optimization applied in engineering. In this case, Mat Lab software is used for simulating network design with help of genetic algorithm optimization. Mat Lab has optimization tool for genetic algorithm with parameters provided to fill in for the problem at hand. But in this paper's simulation, a custom data input of the case study is available which can't be provided into the Mat Lab optimization tool. Therefore, m-file programming integrated application of Mat Lab is used to simulate the result. The entire programming is made suitable to the data available for ease of implementation. Finding minimum spanning tree simulation is carried out using prim's algorithm which is default algorithm for Mat Lab for such application.

M-File Programming

M-file programming is programming technique of writing in Mat Lab integrated environment. The integrated environment has its own type of program writing syntax. User defined functions and library function can be called all together in the same script file after identifying the directory of the file location in Mat Lab path. Except in its syntax, m-file programming is similar to that of C++. But it's simpler than C++ because of less syntax complexity. The controls, decision and looping expression are same in both programming environments. M-file programming is used to solve simulation problems and computational tasks by developing own problem based programs. Simulation programs and functions used in this paper are developed according to the data input and reliability constraint to obtain optimal solution.

Genetic Algorithm

The genetic algorithm is effective optimization technique to obtain optimal solution for lateral design, distribution automation and switch placement. Due to the combinational solution search capability, the genetic algorithm has been suitable and effective method of optimization. It enables to search for optimal solution in given generation by evaluating fitness functions to select individuals from population. It considers an initial population that can be reproduced to get fittest individuals through generations. Large number of initial population is more preferable to have option of getting better offspring. Individuals (chromosomes) in generations are represented in terms of binary strings with each bit representing genes in a chromosome. It recombines individuals to create offspring and those that lie in the fitness criterion are selected to go to the next generation. Elite individuals can be taken from the previous generation to have best individuals in the next generation. To avoid reaching in local optima while solutions have to be global optima, simulation program is run to several iteration to ensure best solution is reached. The functions (recombination, selection and fitness function) used to simulate the mentioned algorithm are developed in m-file programming for this particular problem only.

4.1 Distribution Network Reconfiguration

Lateral design optimization is made for two different scenarios. The capacity of transformers and number of customers connected in each transformer are not proportional. In some nodes in the feeder, transformers with large kVA capacity supply a few number of customers and some transformers with small kVA capacity supply high number of customers. If a design is assumed only to maximize reconnected number of customer, the energy supplied by that design can be small. Therefore, the design shall come up with a result that moderates both energy-supplied and customers reconnected. Consequently, the design optimization tries to simulate network laterals to maximize the served energy or maximize number of customers during reconfiguration.

A. Lateral Design With Priority To Energy-Supplied

Lateral design with priory to energy-supplied is a target of reconfiguring distribution network to maximize the energy the system supplies. Hence, during designing laterals, the optimization considers energy maximizing constraints. The intention of this optimization is; it doesn't consider whether maximum numbers of customers are reconnected. It only looks into how much of supply capability is transferred to customers after reconfiguration.

The simulation for designing lateral supply network from utility point of view is done in optimal recombination of node to node connection between the existing 50 nodes in Feeder-02. The objective of such recombination between tapping points is to maximize the energy that can be supplied in alternative path during contingency. From the initial population, with technique of recombination, new type of interconnection is created till it reaches the optimal solution. The size of initial population determines how shortly the optimization problem converges into the target solution. Large initial population creates more chromosomes to select for recombination which enable sufficient space of combinational searching. M-file program user defined function of mutation, crossover, fitness evaluation, selection function and caller program for the simulation are developed in this study. Program codes for these functions are provided in appendix D.

- Representation

  The connectivity matrix (n x n, where n is the number of nodes in the feeder, n=50) of feeder-02 is represented in binary form. This 50x50 matrix is an initial population of 50 members. It's stored as script file in Mat Lab to recall for simulation. Each row is considered as an individual or chromosome in a population while a bit or a column is a gene in the chromosome. One chromosome is represented using 50 binary bits. These bits represent the routing of node to node connection in the network. That gene of a chromosome is a node in the distribution network from where transformer tapping is made.

- Recombination
  - ✓ Crossover recombination

    Two-point crossover recombination is used to reach to the optimal solution in fewer run time. It creates varieties of genes in the new offspring after few generations. The combination is made between two chromosomes found in consecutive rows which give rise to two offspring. 30 genes of parent one are put in child two and 30 genes of parent two are put in child one. The other remaining genes in the offspring are taken from corresponding parents. This crossover step is undertaken to all of the members in the population.

Parent-1:

0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Parent-2:

0 0 0 0 0 0 0 0 1 1 1 0 0 0 00 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Child-1:

0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Child-2:

0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Form of recombination:

Child-1= |geneparent1 geneparent2 geneparent1|

Child-2 =|geneparent2 geneparent1 geneparent2|

Where

Geneparent1- genes from the first parent

Geneparent2 -genes from the second parent

- ✓ Mutation

  The assumption that mutation probability has to be small so that not to kill an individual in recombination, the mutation probability used is 0.08 (8%), which is very small. For each offspring found using crossover combination, 4 genes are mutated or altered in each generation providing variety of genes in chromosome. Default Mat Lab function provides mutation probability of its own. Mutation below the selected probability of 0.08 is preferably used. Otherwise, the mutation shall be 8%.

- Fitness function

  The fitness function for the served energy priority is to maximize kVA capacity of the chromosome. It's to maximize equation (4.6). Each node routed with status of 1 are added, its kVA capacity, to the whole capacity of the chromosome until the entire string is reached. Zeros in chromosome show the node is not considered into line connection in the sequence. Therefore, kVA capacity of the chromosome will be the total sum of all ones in its string. The supplying capacity of each node is stored in matrix form and then simulated with the program to obtain fitness function of chromosomes. The objective function of this optimization problem is to maximize the value of kVA supplied to the customer. Substation is taken as zero kVA and any line tapping nodes with no particular supplying transformers is assumed to be point of zero kVA.

$$\text{Maximize } Y=\sum_{i=1}^{n} S_i \tag{4.6}$$

S_i-The kVA capacity of node i,

Y ≤ Installed Capacity of the feeder (16805kVA)

i- Node in the feeder, i=1, 2…..≤ n, n=50.

- Selection function

The selection criterion used is the probability of fitness function. Fitness value of a chromosome is compared to the sum of the fitness of the population in that generation. The higher the probability, the greater the individuals will be selected to go to the next generation. The individual scores of members can't exceed the installed capacity of the feeder.

Probability of selection= $\frac{F_i}{\sum_{i=1}^{n} F_i}$, (4.7)

F_i is fitness value of an individual in row i.

n- Size of population, n=50 initially

Fig. 4.1 is flow chart of genetic algorithm applied for this optimization. Cmatrix is the connectivity matrix of Bella substation of feeder-02. The algorithm takes Cmatrix as initial population for natural selection. After selecting chromosomes with best fitness values, mating is carried out in two-point crossover recombination technique. Then to add variety into the generation created by crossover, mutation of genes is done. Hence, individuals in the next generation will give rise to better fitness values than the chromosomes in the previous generation. Based on the scores the chromosomes achieve, selected individuals are then re-brought to be recombined to get better offspring until the target solution is reached. The program stops when target values are obtained. The target function is to maximize equation (4.6). The lateral network shall be able to support the energy that could have been supplied by the faulted distribution line. That's why it has to be maximized.

Sum of fitness values can also be replaced using the installed capacity of the feeder. Individual's selection probability is found by dividing its fitness value to the installed capacity, 16.085MVA. In each iteration of the genetic algorithm program, two individuals with least selection probabilities are left out from advancing to the next generation and one best individual is selected for optimum solution. Then, the set of matrix of the resulting combination is fed to the next process until best five chromosomes are obtained. The simulation program orders the chromosome in ranking of from the maximum score to minimum score and hence the least scorers are vanished from promotion to the next generation. The iteration of the program runs until best individual with maximum score is obtained.

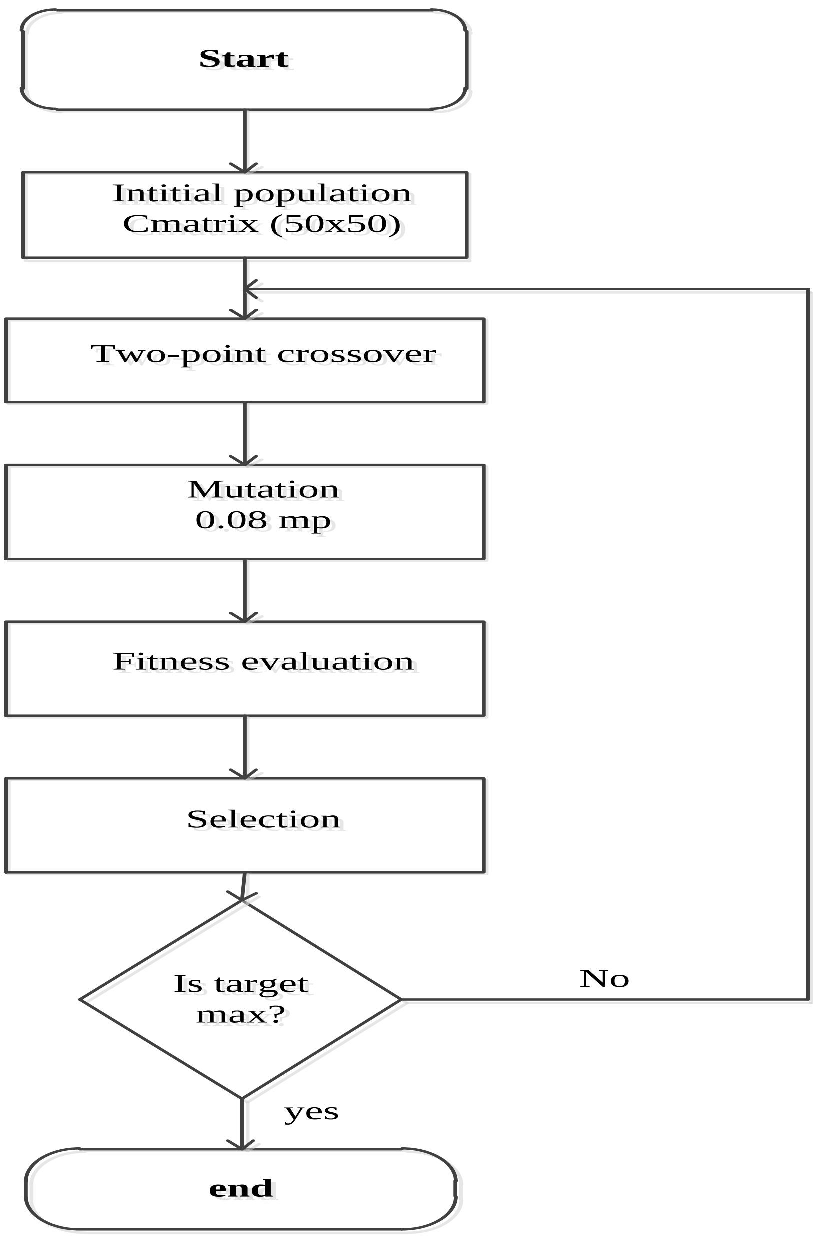


Figure 4.1 Flow chart of Genetic algorithm for lateral design with priority to energy-served

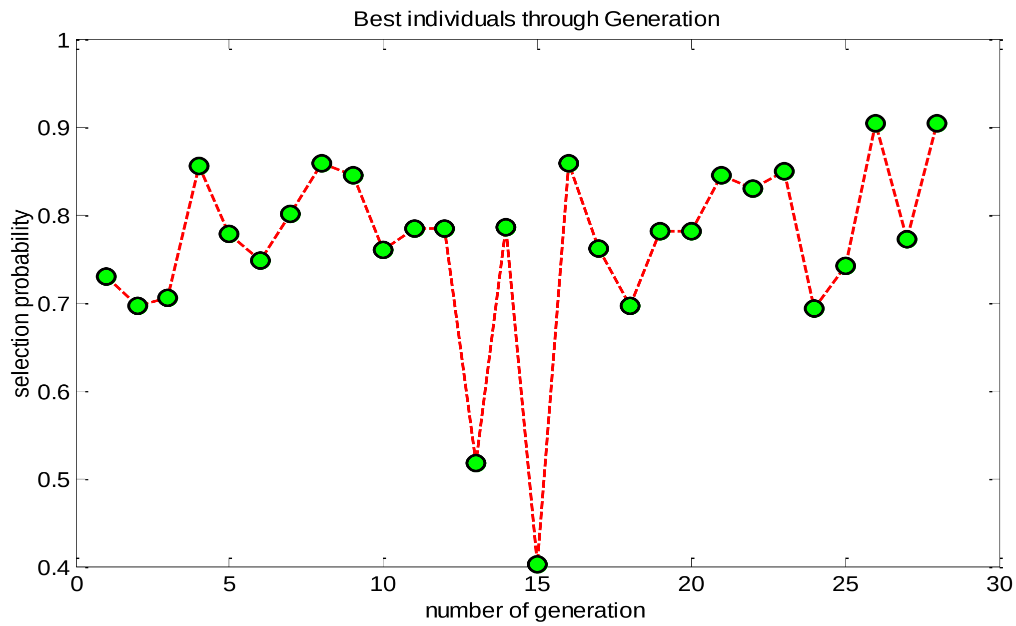


Figure 4.2 Simulation result of Selection probability of individuals through generations

A chromosome with selection probability of 0.9046 is obtained as a solution to the optimization problem. It has a fitness score of 14550 kVA as can be seen in Fig. 4.4. The node to node connection (string representation) of the best chromosome determines which node is connected to the rest of the load points.

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1

Fig. 4.2 and Fig.4.3 show the selection probability of chromosome and best individual of the optimization result respectively. The optimal solution is obtained in less than 30 simulation program run. To check whether the solution is a global maximum, for size of 50 initial populations, the program is run to obtain best fitness score taking one best individual at the end of evolutionary 50 generations. To avoid taking local maximum as a best chromosome, this simulation is run for 500 times to see if the program converges to the optimal solution. Referencing to simulation graph of Fig. 4.5, same maximum fitness value is scored throughout the iteration.

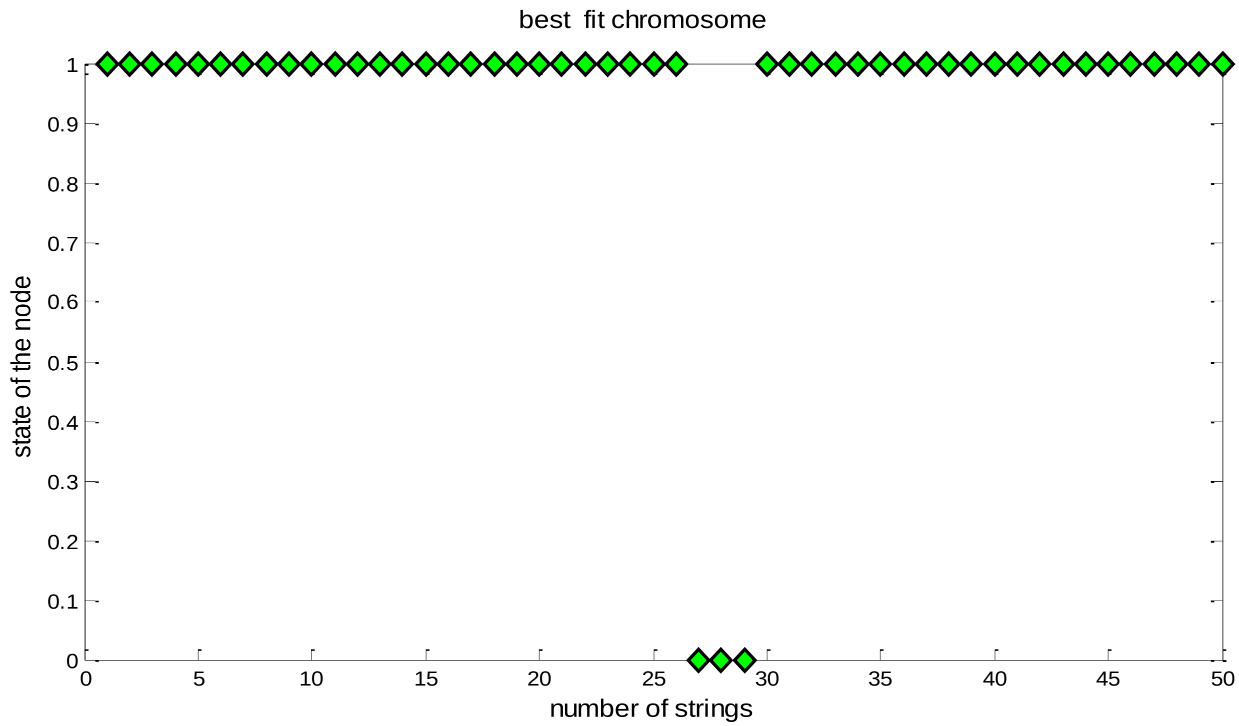


Figure 4.3 Best individual for node to node connection

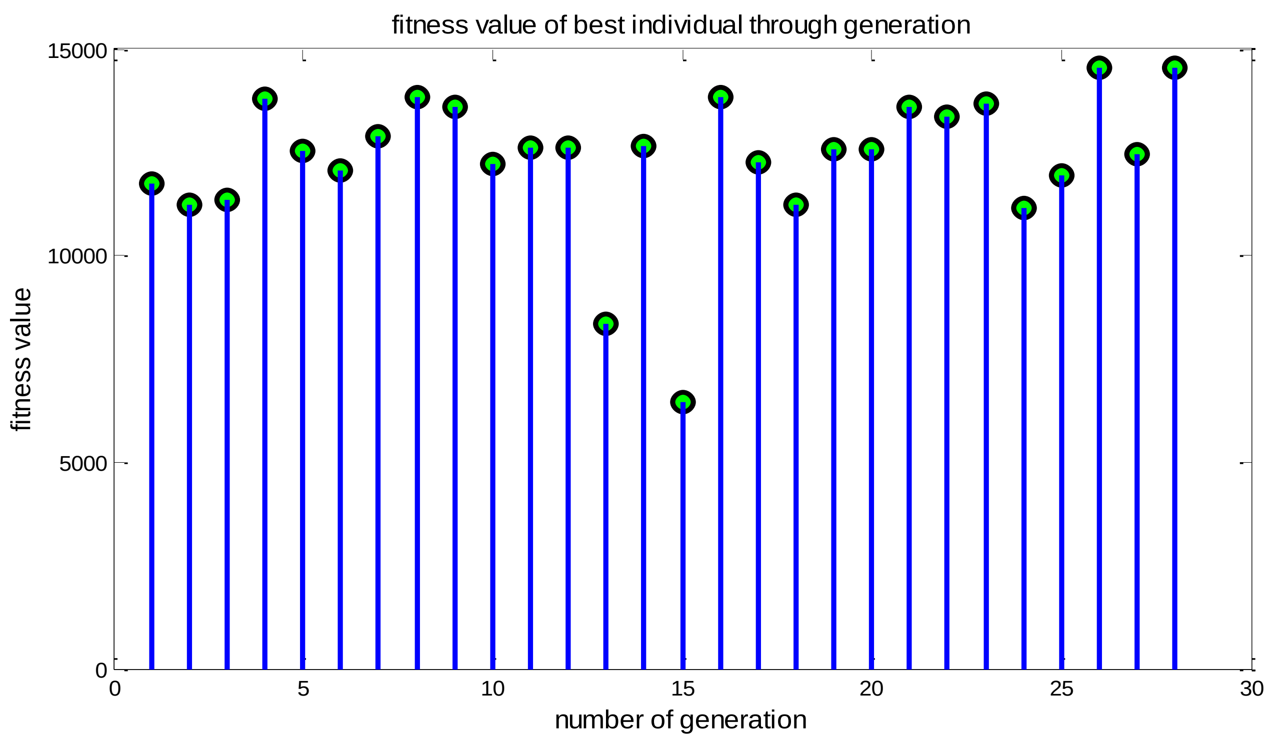


Figure 4.4 Fitness values of best chromosomes through generations

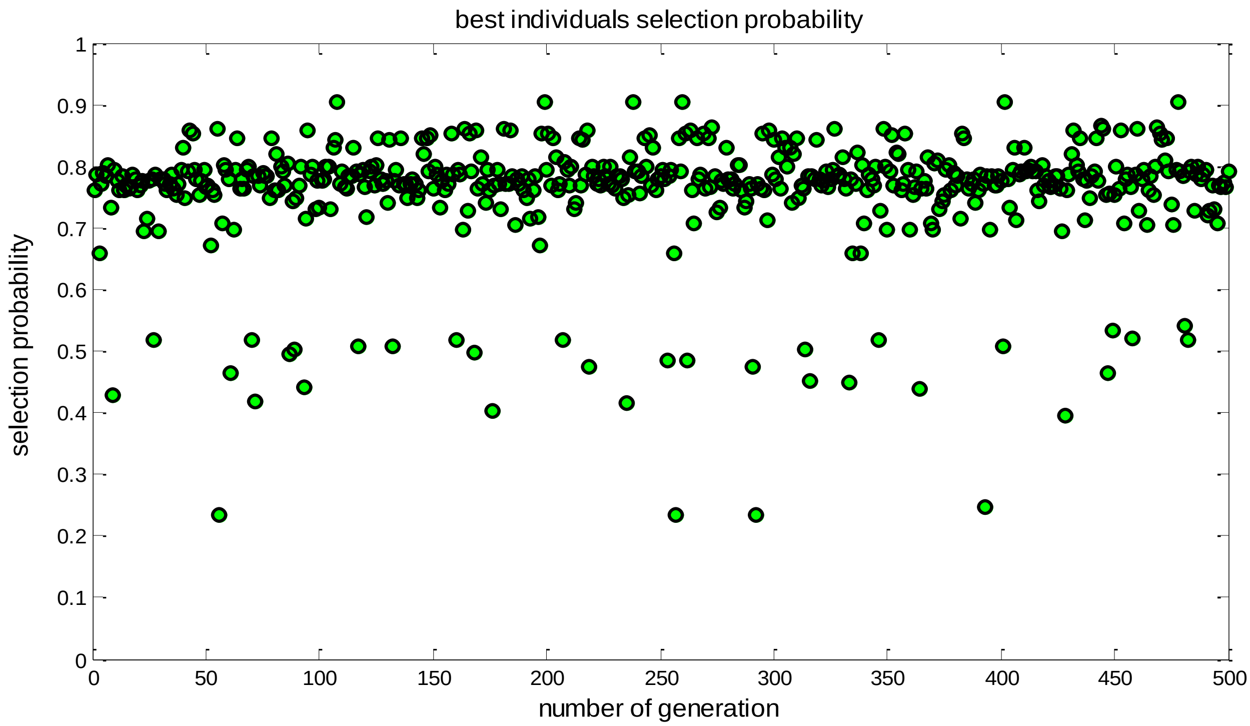


Figure 4.5 Graph of optimization problem simulation run for global maximum solution

Throughout the simulation for different mutation values, the results vary and convergence of objective function score is also altered. If mutation value is high, some chromosomes die and the computational space become smaller. As a result, the convergence of the generation to the require individuals takes long time. Chromosomes can end up before reaching in their high best fitness. In literatures, there are recommended mutation values when applying genetic algorithm optimization. 1%-8% mutation values are very recommended [61]. As shown from Fig. 4.5 graph, fittest individuals are condensed near to the optimal solution while chromosomes are scattered at low fitness value score. Due to mutation, some individuals can score low values or die from progressing to next generation. This shows the optimality of the solution as no growth in fitness value is seen for more simulation iteration. Because of recommended mutation values have to be small, the simulation is conducted for different values but 0.08 is found suitable for better convergence. Mutation values less than this value are in the range of the optimality space for this result.

Line interconnections are uniform for analysis purpose. Conductor types are not mentioned because of the system works in uniform medium voltage except after the transformer. There are also tie switches installed in each new lateral. These switches enable remote control capability and network reconfiguration. The pattern of binary string of a chromosome represents the sequence of node to node connection.

B. Lateral Design With Priority To Customers

The initial population used is the connectivity matrix of the feeder. Selected chromosomes (connection points) are reproduced to reach in best generation. Same as design part (A), Matrix of Feeder-02 data is stored in Mat Lab m-file with the first column the kVA of each node, second column to number of customer in each node and the third one to the line segments length between consecutive nodes. The program calls the customer value in each row that corresponds to the gene of a chromosome and all nodes with status one, the customer numbers are summed to get the fitness value of that individual. As only two individuals are left out from advancing to the next generation until best five are obtained, the whole matrix of the next population is rearranged into matrix form for next recombination. The size of the population decrease as evolutionary selection is carried out to get fittest individuals.

The fitness value the program returns is the number of customer the individual (chromosome) connects or gives lateral option to supply power. While running the program, the objective is to maximize the number of customers that can be reconnected after outage. It maximizes equation (4.8). Fig. 4.9 shows scores of best individuals through generations. Therefore, the network can be then reconfigured to minimize the duration an interruption lasts. The reconfiguration will reconnect possible number of customers.

The selection technique used for this part is similar to lateral design with priority to served energy. The score of each chromosome is compared to the total number of customers supplied by Feeder-02, 11235 customers. Additionally, same as part (A), two point crossover recombination is applied and chromosomes in each generation are selected according to the fitness value score.

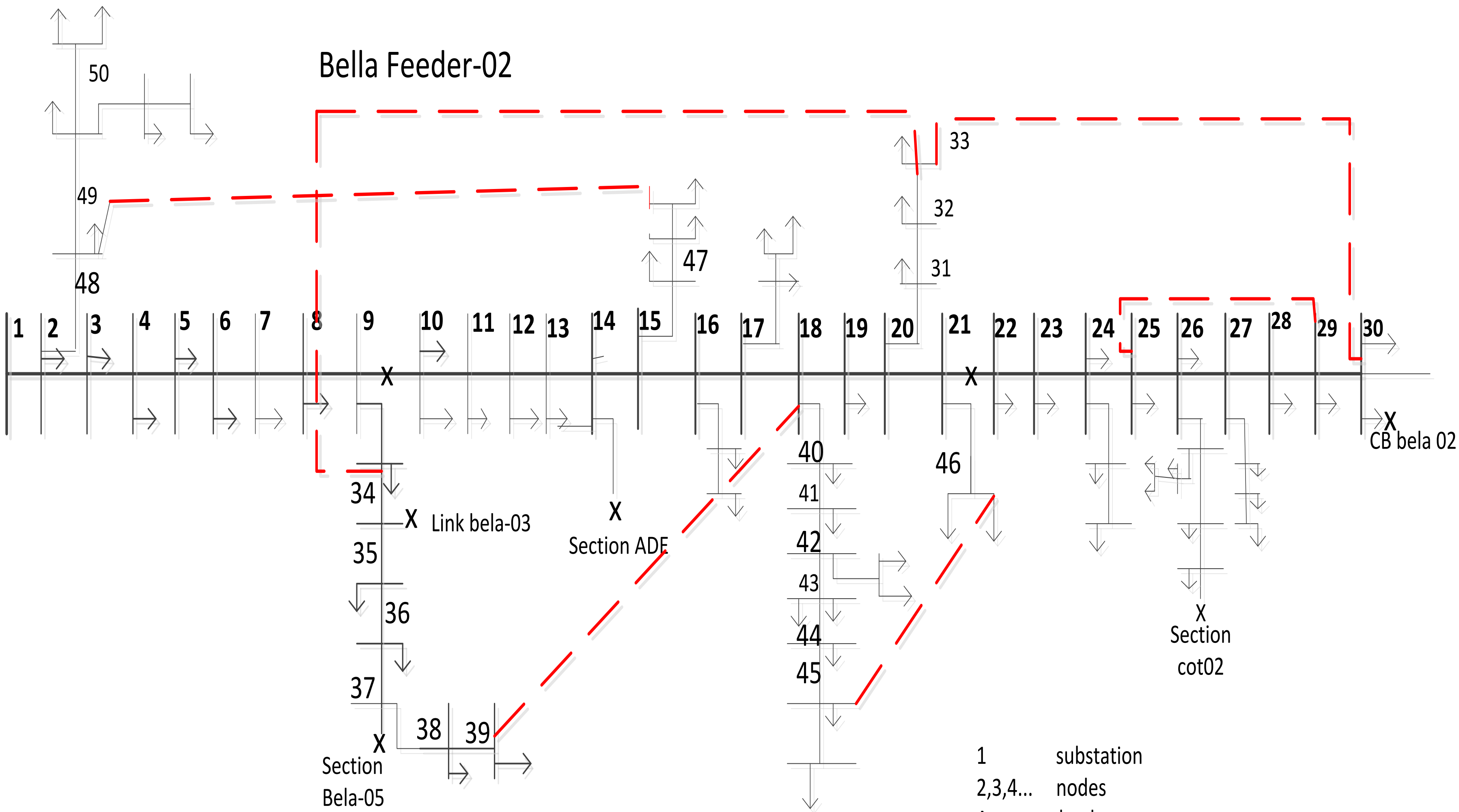


Figure 4.6 Lateral interconnection of Bella substation of feeder-02 for design with priority of supply energy

In each generation, mutation is applied to get best individuals so that moderate network path closer to the one obtained in part (A) can be achieved. Such searching for optimality meets both customer reliability and utility profit.

Maximize $C=\sum_{i=1}^{n} C_i$ (4.8)

C_i- number of customers connected in node i

i- Node in the feeder

The optimization problem reaches at an optimal solution of a chromosome with selection probability 0.9292 as shown in Fig. 4.7. This individual or lateral path reconnects 10440 customers during reconfiguration. In every simulation step that gives rise to population of new generation, one best chromosome is selected and from the set of chromosomes, individual having maximum score is chosen as optimal solution. Fig. 4.8 shows the string representation of the best individual or status of the nodes. It shows which node is connected to another. Two consecutive nodes with value 1 mean they are connected to each other.

Similarly, the lateral networks obtained in Fig. 4.10, are drawn in red to show which node is connected to the rest. Except for one more connectivity option in supplied energy based design, customer based lateral design gives almost similar network connectivity to the one obtained for served energy simulation. Hence, the priority to served energy is best one to minimize un-served energy and improve reliability. The tie switch installed in the network connectivity with alternative path is shown in Fig. 4.11. This is the best candidate.

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1
1 1 1 1 1 1 1 1 1 0 0 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1

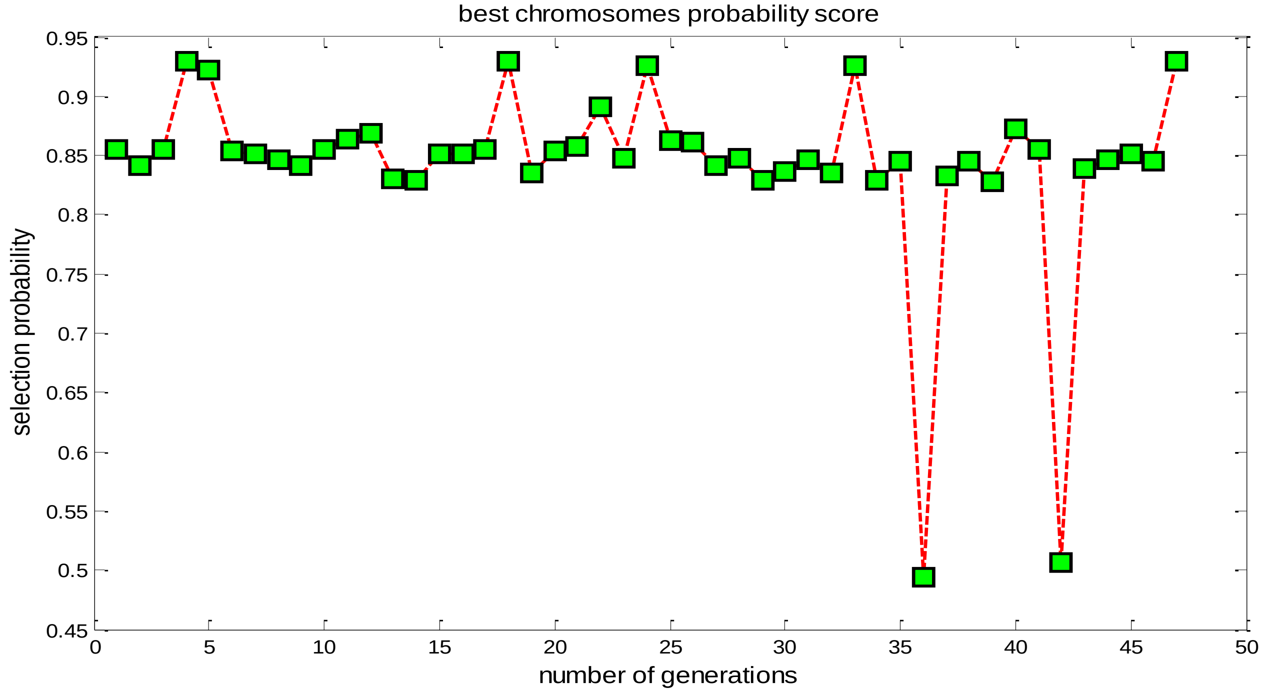


Figure 4.7 Probability of selection for individuals through generations

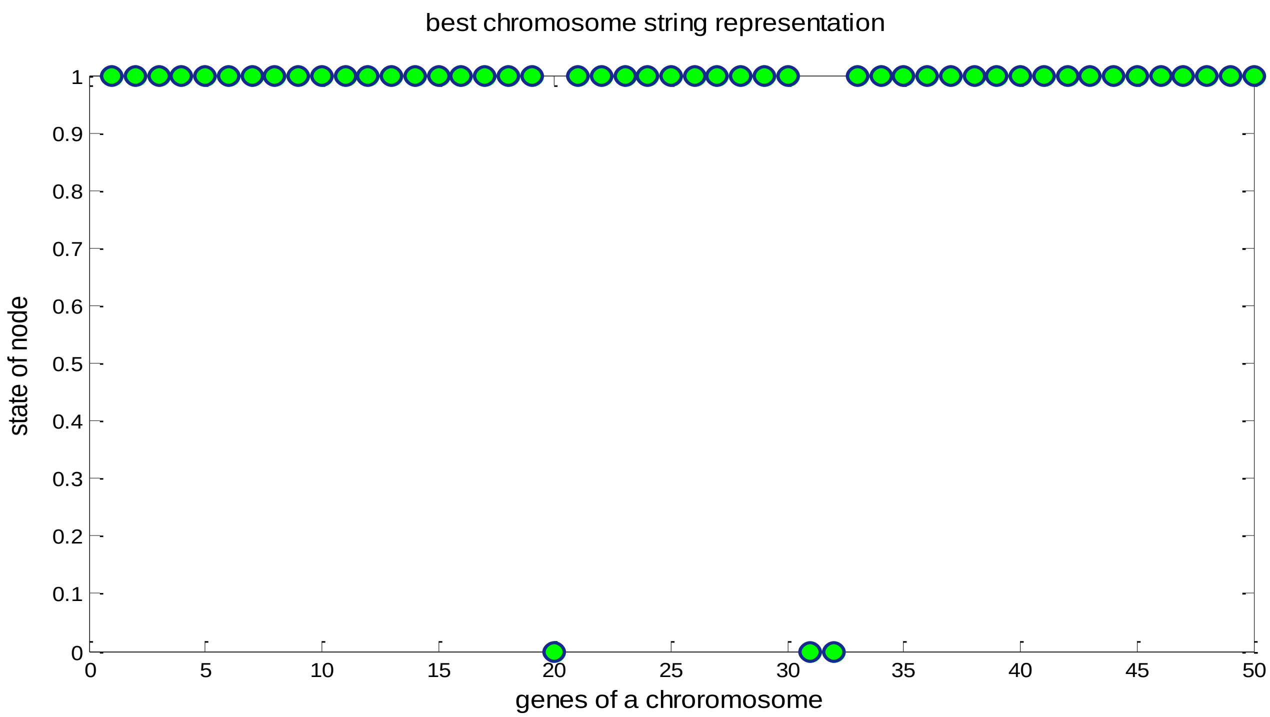


Figure 4.8 Best node to node connection chromosome for customer priority lateral design

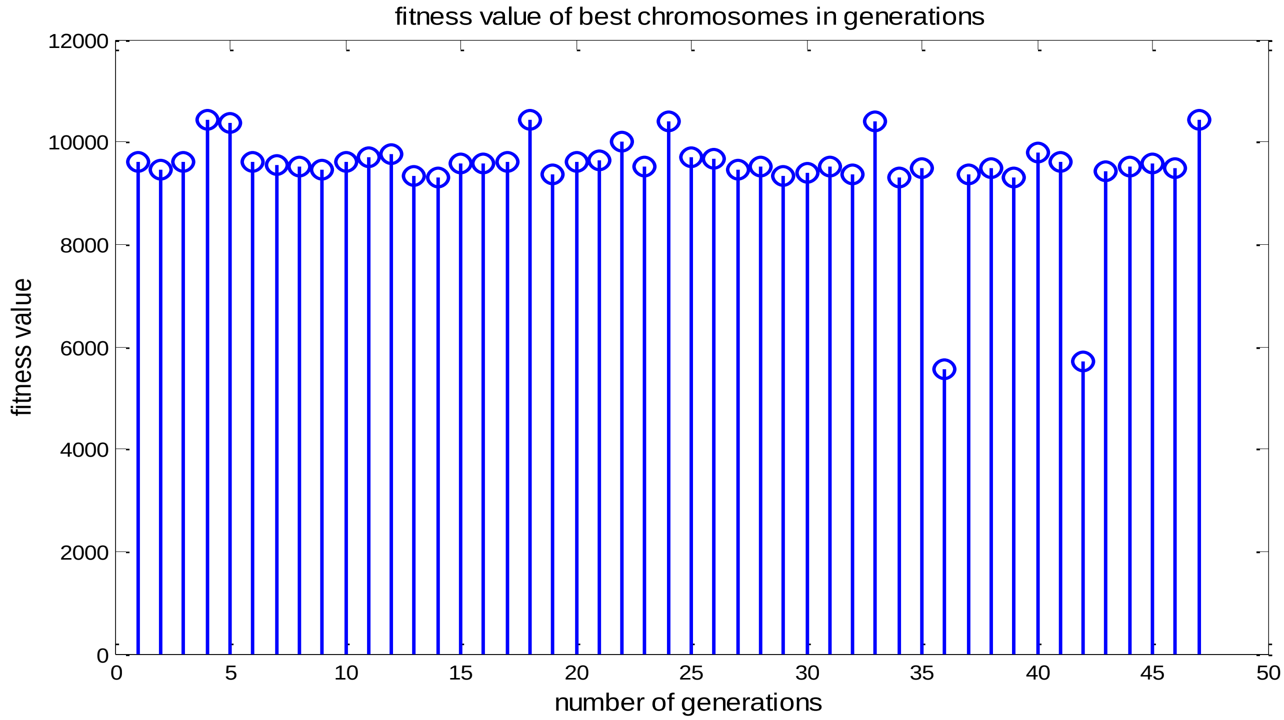


Figure 4.9 Graph of fitness values of best chromosomes through generations

4.2 Automation and Switching

In the existing network of Bella feeder-02, automation and switching capabilities are limited to substation circuit breaker and few sectionalizing switches. The need for better reliability demands installment of recent technologies which can enhance system flexibility for quick restoration capability. In this section, placement of new devices is simulated to locate which line segments give best options to optimize the reliability target. The target line segments are treated as candidate locations for reliability improvement test. Hence, any line segment that lies within the reliability target is chosen to placement of new device. Labeling of line segments starts from the substation and goes downstream. Line lengths of segments are measured from the small digit numbered node to the greater neighboring node. For instance, line segment L_2 is the length of line segment between node 2 and 3.

This simulation considers placement of recloser, sectionalizing switch and a switch with automating equipment. Placement of Automating devices is made to either the newly placed switches or existing ones. Automation of switches helps to advance use of remote control capability by dispatch centers.

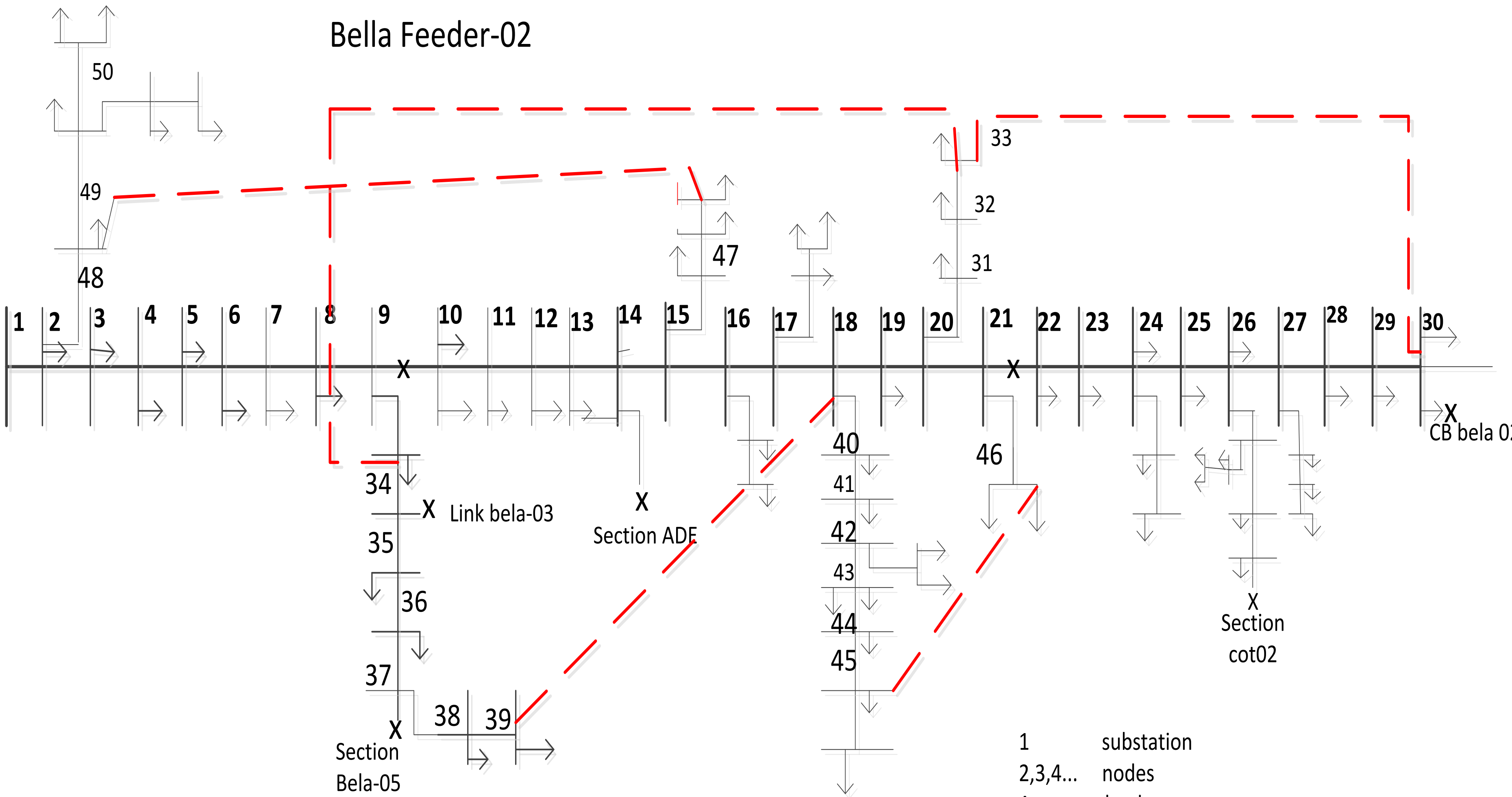


Figure 4.10 Bella substation of Feeder-02 lateral designed with priority to customers

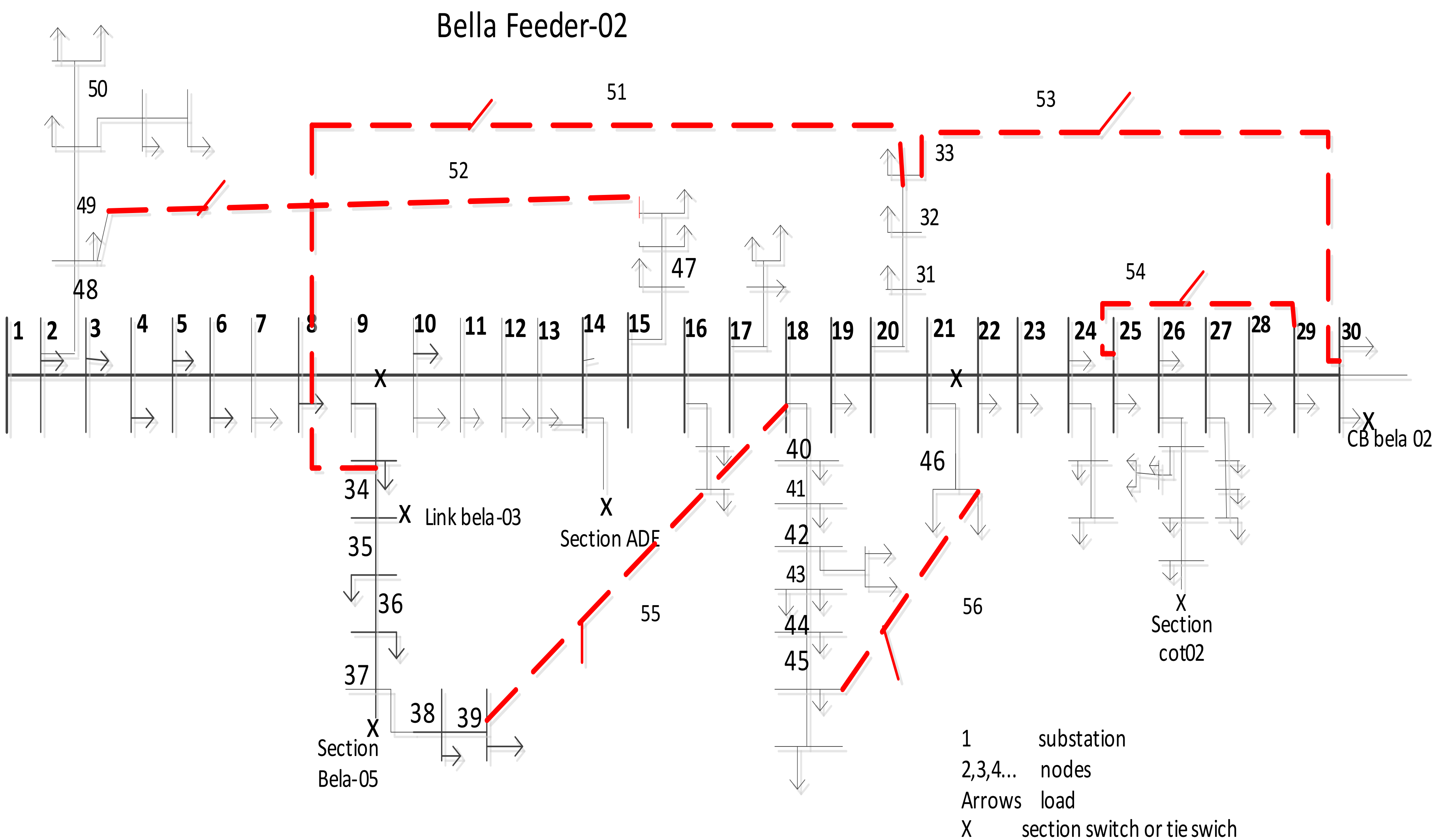


Figure 4.11 Lateral lines (red colored lines) and tie switches for simulation result of served energy priority design

The problem of improving reliability by the use of reclosing and switching capability is subjected to cost of installation of new devices. The cost optimization is done under reliability target constraints to achieve reliability targets. The more devices used to reclosing and switching are placed in a feeder, the higher the reliability of the feeder will be. As a result, cost of installing new devices increases.

Defined Genetic Algorithm Components

- Initial population

  Fifty line segments are assumed as initial population for this optimization. These chromosomes are test points where new devices are placed. 50x9 matrix of line segment make up the initial population and is stored as script file in Mat Lab. Line segment one is location of the circuit breaker. Therefore, other locations are in searching space of the optimization algorithm for placement of recloser, switch and automating equipment.

- Representation of line segments

  Line segments of Feeder-02 are represented in binary string. Nine digits are used to number the location and the type of device that will be installed. The maximum line number is 50 and it can be represented in six binary digits. The whole string represents a chromosome of the population in the generation. Therefore, Single chromosome is made up of nine genes.

  $$\overbrace{B_1B_2B_3B_4B_5B_6}B_7B_8B_9$$

  The six digits, B1 to B6, represent the line segment in the feeder. B_7 stands for the installment of new device. Value of B_7 is one implies new device is placed in the line segment (chromosome) and value of zero means no device is placed. B_8 represent if the installed device is switch or recloser. B_8=1 means recloser is placed and B_8=0 indicates the newly installed device is a switch. If the switch installed has an automating device or not is represented using the ninth digit of the chromosome. B_9 =1 applies to automating device installment.

1. B_7=1, B_8=0, B_9=1 represent the new device placed as sectionalizing switch that has automating equipment connected with it. If there is previously an existing switch, only automating equipment is required.
2. For B_7=1, if B_8=1, it represents new recloser is installed. B_9, automating equipment, is required to enable remote-control capability of sectionalizing switches. It's not required if the installed device is recloser. Therefore, in this case, the value of B_9 doesn't represent anything.
3. B_7 =0 shows the status of B_8 and B_9 has no effect in the process. It means no device is installed. However, if an existing switch is there no matter the value of B_7, the value of B_8=0, B_9=1 implies the existing switch is automated.

Therefore, this kind of representation is used for all of the fifty line segments. Line sections or chromosomes that have existing switch have initially B_7=1 value. If no switch exists, B_7=0. But after recombination, the value of B_7 can be changed, i.e., it can have value zero though a switch exists initially.

- Recombination
  - ✓ Crossover combination

    Except the type of crossover applied differs, the way of combination of individuals in the population is conducted similar to the previously defined lateral design techniques. One-point crossover is carried out in this section. One portion genes of a chromosome are exchanged with another mate that gives rise to new chromosome. The combination assumes that variation of location points in the last three genes can reach into the optimal solution. The cross over at this point enables alternative approach to installment of device at different location (chromosomes).

    Parent-1: 0 0 1 0 0 1 1 0 0
    Parent-2: 0 0 1 0 1 0 0 0 0

    Child-1: 0 0 1 0 0 1 0 0 0
    Child-2: 0 0 1 0 1 0 1 0 0

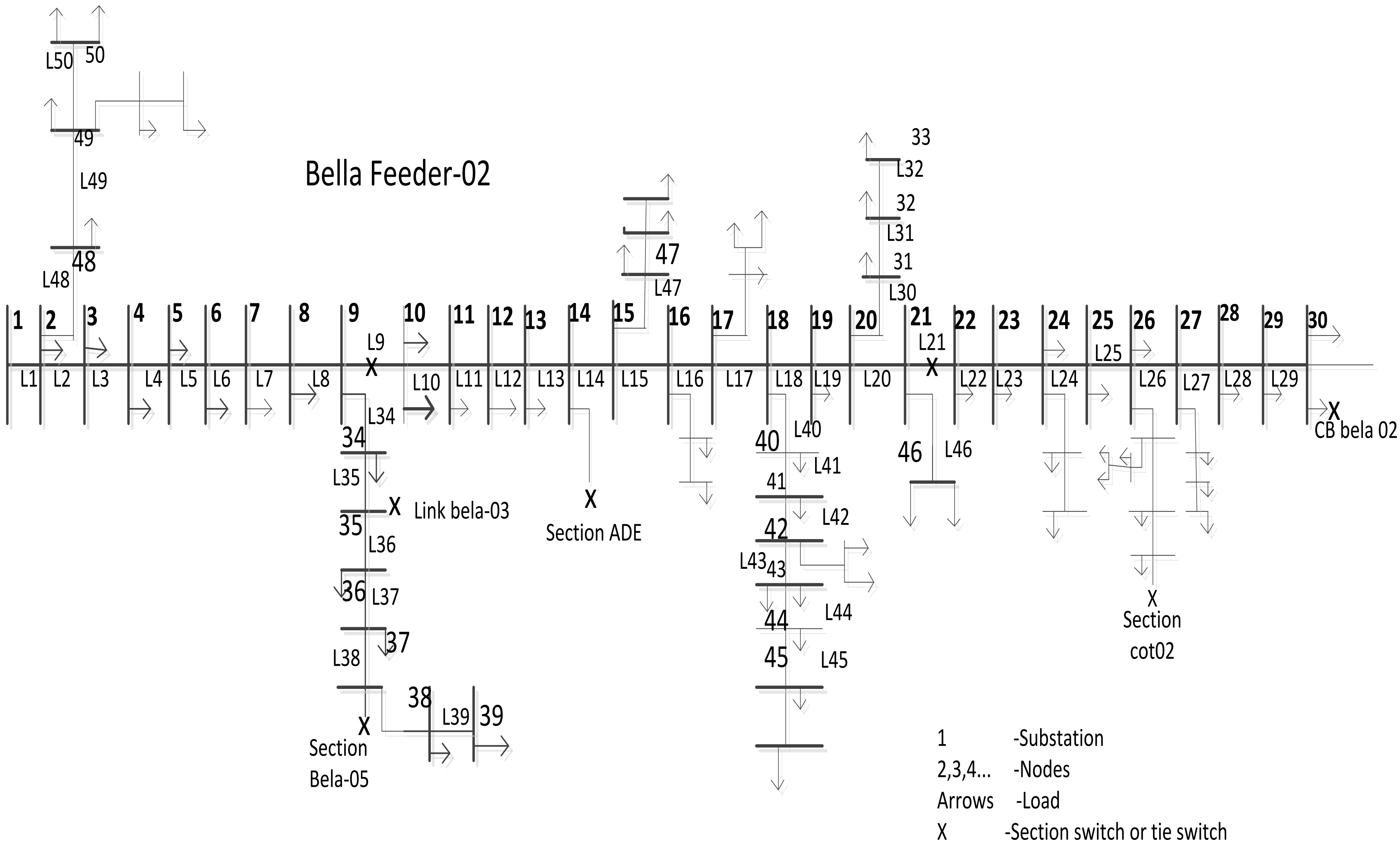


Figure 4.12 Feeder-02 line segments and labels of candidates for recruitment to new device installment

Form of recombination:

Child-1= |geneparent1 geneparent2 |

Child-2 =|geneparent2 geneparent1 |

Where, the abbreviations stand for

Geneparent1 -Genes from parent-1

Geneparent2-Genes from parent-2

Six genes from parent one is placed in the first offspring and same from parent two in the second offspring. Gene exchange occurs after the sixth digit. The last three of the first parent is put into the second offspring and vice versa. Such combination is applied to consecutive chromosomes in the population. At first the initial population gives 50 new individuals and using selection function fittest ones are promoted to the next era. Mat Lab user defined function in m-file programming is developed for this recombination.

- ✓ Mutation

  In this optimization, a mutation probability of 0.08 is applied in the offspring. Alteration of genes brings about different placement location opportunity. This enables alternative way of checking reliability improvements due to installments of new devices. In each generation, the application of such mechanism develops chromosome fitness value to reach into the optimal locations of new candidate sections.

- Fitness function

  The objective of this optimization is to minimize the cost of installing new devices in Bella substation feeder-02. Cost optimization is done under reliability constraints. The objective function for this optimization is taken for the cost values of installment of new devices stated as in [69]. The program analyzes the fitness value of individuals only those who have B_7=1 in their chromosomes. Sections having existing switch before this optimization are only provided to automating equipment installment. Hence cost of B_7=1 for existing switch is reduced from the total sum of the optimized cost.

$$Minimize\ \ y = 1000 * Ns + 15000 * Nr + 5000 * Na \quad (4.9)$$

Subjected to

SAIFI≤ 0.15 Int./cust./yr.

SAIDI≤ 0.25 hr./cust./yr.

Where

N_s-new switch installed

N_r-new recloser installed

N_a-new automating equipment installed

cust. -a customer

yr- year

This optimization considers failure rate of lines, recloser, sectionalizing switch and automating equipment. For every generation, the reliability of the feeder is evaluated to see any improvement of the cost minimization process. Because of different individuals represent different line segments in a generation, it is the cumulative reliability of the system that corresponds to the cost minimization process. Hence by improving fitness values of chromosomes in a particular generation, the average reliability value of that generation can be improved. Therefore, a generation is considered instead of individuals. Reliability indices are evaluated for each generation to minimize the cost within the constraint.

To evaluate reliability of the system, the line failure and the portion of the feeder it affects is considered. The failure rates of newly installed devices are also assumed in each line segment. Failure rate data of new devices installed is assumed according to data values stated in [62]. Line sections and load points affected by upstream and downstream failure are exclusively and mutually grouped.

$$X_1 = \begin{vmatrix} 1\ 2\ 3\ 4\ 5\ 6\ 7\ 8\ 9\ 34\ 35\ 36\ 37\ 38\ 39\ 48\ 49\ 50 \\ 1\ 2\ 3\ 4\ 5\ 6\ 7\ 8\ 34\ 35\ 36\ 37\ 38\ 39\ 48\ 49\ 50\ 0 \end{vmatrix}$$

First row of X_1 is the load points in Feeder-02 and the second row is line segments where any failure occurring in line sections affects the load points. Because these load points are isolated using sectionalizing switch at line L_9. It's to estimate the reliability of this portion according to how many customers are affected for each lines failure.

X_2=10 11 12 13 14 15 16 17 18 19 20 21 31 32 33 40 41 42 43 44 45 44 47 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

X_3=|22 23 24 25 26 27 28 29 30|

The same is true to node points between L_9 and L_{21}. Any failure in the upstream of these loads and within the section of L_9 and L_{21} interrupts power to the section. Second row of X_2 is the lines sections whose failure affected loads in the first row. It shows failure in the upstream affects loads in the downstream but the reverse is not true. However nodes downstream of L_{21}, X_3, are affected by any failure in the feeder.

Table 4.1 Line segments candidates for new device installment simulation result

Line segment binary string									Line segment number
B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	
0	0	0	0	0	1	**1**	**0**	**0**	**1**
0	0	0	1	1	0	**1**	**0**	**1**	**6**
0	0	1	0	0	0	**1**	**0**	**0**	**8**
0	0	1	1	0	1	**1**	**0**	**0**	**11**
0	0	1	1	1	1	**1**	**1**	**0**	**15**
0	1	0	1	1	1	**1**	**1**	**0**	**23**
0	1	1	0	0	1	**1**	**0**	**0**	**27**
1	0	0	1	0	0	**1**	**0**	**0**	**36**
1	0	1	0	0	1	**1**	**0**	**0**	**41**

This optimization problem result shows line candidates for automation, reclosing and switching as shown in Table 4.1. The rest line segments are same as in the existing feeder. The simulation result indicates the installment of automating equipment for new switch installed in line segment 6. A new switch placed in line 1 is not economical since the circuit break is in line segment one. Because the circuit breaker trips for fault that occurs near to the substation. Placing a sectionalizing switch in line one will have same purpose as that of circuit breaker. Therefore, a switch placed in line segment one is not considered in the total cost of the optimization. Similarly because of sectionalizing switch exists in L_9, placement of new sectionalizing switch in lines 8 and 11 is of less importance. Additionally, the simulation program gives placement of recloser in middle point of the feeder and in line L_{23}. To test the reliability improvement by placing single recloser, only the middle point recloser is considered.

The remaining obtained optimal candidates line segments shown in Table 4.1 are considered as location points for new integrated devices. New switches are installed at line segments L_{27}, L_{36} and L_{41}. Therefore, the cost of placement of these new devices is calculated. The fitness score and the selected devices installed diagram are shown in Fig. 4.13 and Fig. 4.14.

Reliability improvement by new installed devices

Recloser

From the reliability analysis in chapter two, the time it takes to restore power in feeder-02 is 0.8833 hours per interruption. For feeder-02, a new recloser is installed in segment 15. The recloser improves reliability of customers upstream of the faults. The simulation is done for all faults downstream of the recloser location.

Fault downstream of recloser:

- 5679 customers are out of service
- 5556 customers remain unaffected
- 5679*0.8833 hours=5016.261 customer hours outage

Without the installment of the recloser, sustained fault event will result in

- 11235 *0.8833 hours=9923.8755 customer hours outage

The reliability improvement by the recloser is

% improvement by recloser = $\frac{9923.8755-5016.261}{9923.8755}$*100% =49.45%

The placement of a recloser in middle point of feeder-02 will improve the reliability of upstream customer by nearly 50%. Reliability indices of upstream customers will be reduced by factor of 0.5. The SAIDI value which was 163.3 hr./cust./yr will be reduced to 81.65 hr./cust./yr. similarly the SAIFI value is reduced from 184.89 int./cust./yr to 92.445 int./cust./yr.

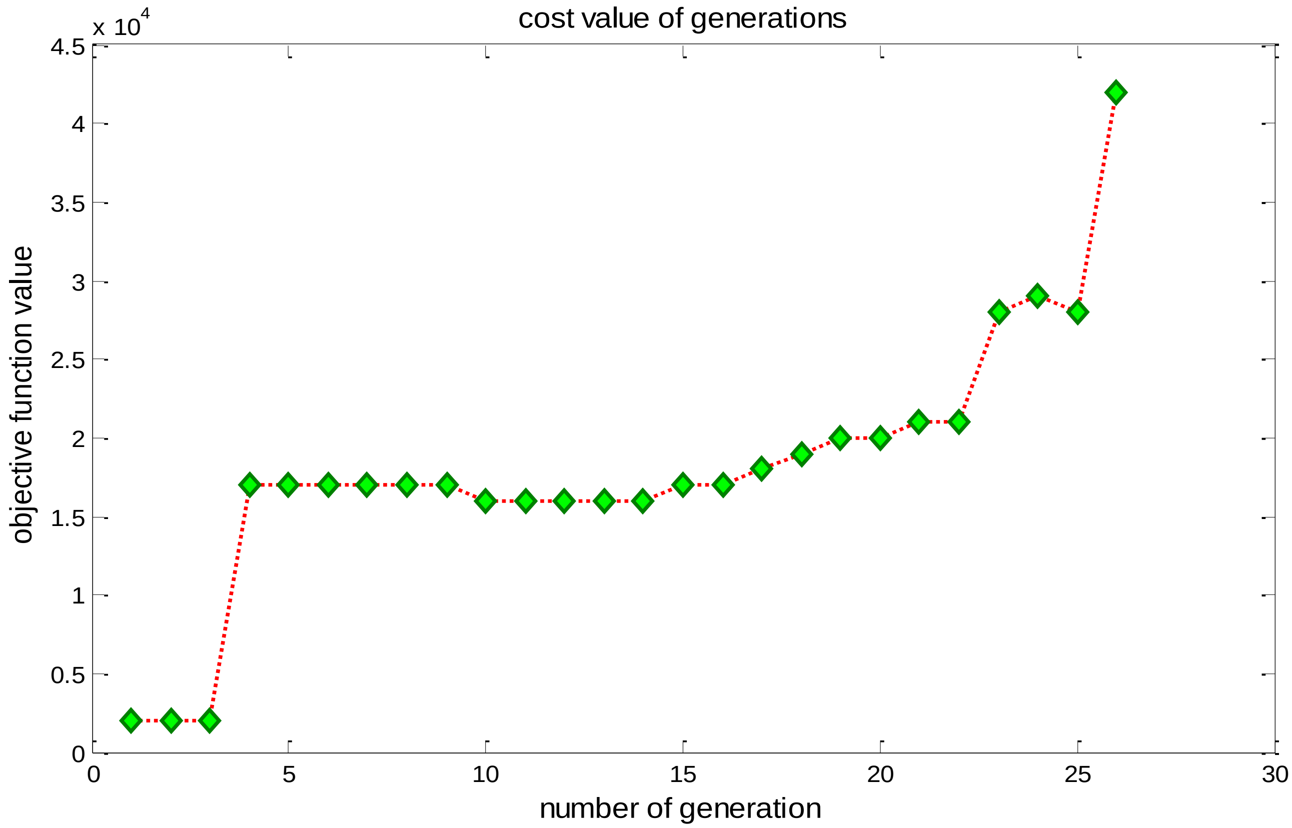


Figure 4.13 Fitness values of chromosomes of generation for automation, reclosing and switching optimization

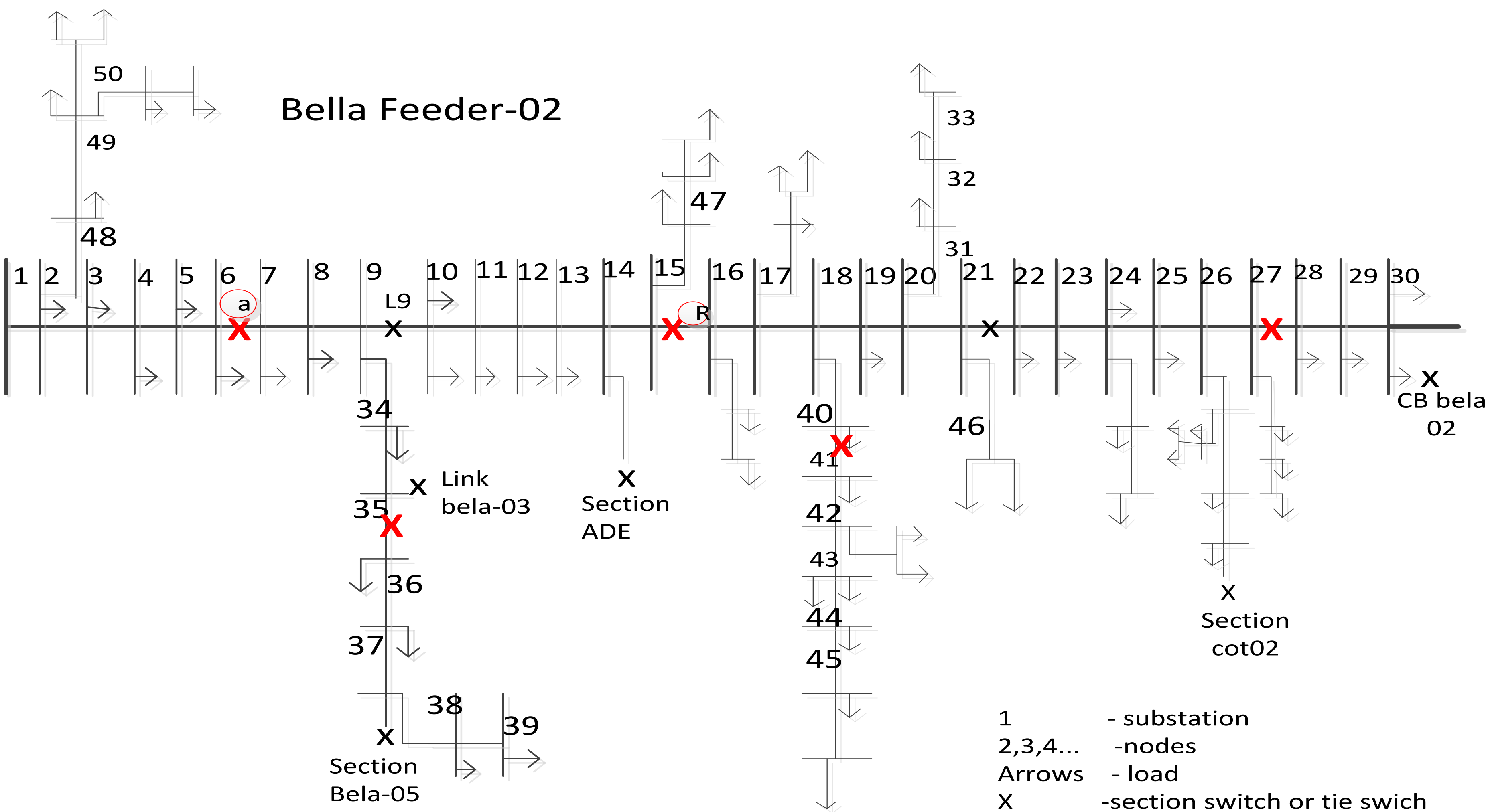


Figure 4.14 New installed devices in feeder-02: *Circled a* -Automated switch, *circled R*- Recloser and *red x* -newly installed sectionalizing switch.

Switch with automating equipment

The main purpose of this sectionalizing switch with automating equipment is to avoid sustained interruption due to momentary faults. The switch isolates permanent faults in the downstream. As a result, it improves reliability of upstream customers.

Permanent fault downstream of automated switch:

- 2445 customers remain unaffected
- 8790 customers are out of service
- 8790customers*0.8833hours=7764.207 customer hours outage number

Without the automated switch, sustained fault will result in 11235*0.8833 = 9923.8755 customer hours of interruptions.

Reliability improvement due to automated switch only:

% improvement=$\frac{9923.8755-7764.207}{9923.8755}$*100% = 21.762%

The installed automated switch improves the reliability of upstream customers by nearly 22%. Reliability indices values are improved by factor of 0.22. The indices value improvement of recloser and automated switch is shown in Table 4.2.

Sectionalizing switch at line L_{36}

The location of this switch is shown in figure 4.14. Permanent fault downstream of switch in line L36:

- 447 customers become out of service
- 10788 customers remain unaffected.
- 447*0.8833 =394.8351 customer hours outage number

The improvement in reliability due to this switch is:

% improvement=$\frac{9923.8755-394.8351}{9923.8755}$*100% = 96%

Table 4.2 Reliability improvements by installing recloser and automated switch

Device	Reliability index	Before	After
Recloser	SAIDI	163.301	81.65
	SAIFI	184.884	92.44
	CAIDI	0.883	0.883
	ASAI	0.981	0.990
Automated switch	SAIDI	163.301	127.763
	SAIFI	184.884	144.649
	CAIDI	0.883	0.883
	ASAI	0.981	0.985

For fault downstream of switch L_{36}, upstream customers remain unaffected. Hence the reliability of the system is highly improved. But this improvement is because the fault is assumed to occur downstream of this switch. Another sectionalizing switch is installed in segment L_{41}. For fault downstream of L_{41} switch, 1136 customers become out of service. This results in interruption of 1003.428 customer hours. It improves the reliability of upstream customers by 89.88%. Similarly downstream faults of switch L_{27} will have customer hour interruption of 928.348. That improves reliability of upstream customers by 90.64%. Table 4.3 is the reliability improvements due to switches at L_{27}, L_{36} and L_{41}.

Table 4.2 and Table 4.3 show the individual reliability improvement by new installed devices. The overall optimization of Automation, Reclosing and Switching is simulated under reliability constraint defined in equation (4.9). The simulation result shows Feeder-02 reliability is improved by 69.69% in SAIFI and 39.788% in SAIDI. Therefore, SAIFI value is reduced to 56.025 int./cust./yr. from 184.884 int./cust./yr. The SAIDI value is also reduced from 163.301 hr./cust./yr. to 98.33 hr./cust./yr. The proper use of the existing switches and the new installed devices will improve the reliability further. Sectionalizing switches improve reconfiguration capability of the network. This network reconfiguration is tested in power restoration section for various fault locations.

Table 4.3 Reliability improvements by installing sectionalizing switches

Device	Reliability Index	Before	After
Switch in L36	SAIDI	163.301	6.532
	SAIFI	184.883	7.395
	CAIDI	0.883	0.883
	ASAI	0.981	0.999
Switch in L41	SAIDI	163.301	16.526
	SAIFI	184.883	18.710
	CAIDI	0.883	0.883
	ASAI	0.981	0.998
Switch in L27	SAIDI	163.301	15.285
	SAIFI	184.883	17.305
	CAIDI	0.883	0.883
	ASAI	0.981	0.998

4.3 Power Restoration

The problem of searching power restoration path after fault occurrence is simulated using prim's algorithm. The prim's algorithm works as default minimum spanning tree finding algorithm to Mat Lab. It finds the shortest path to supply to the rest of non-faulted nodes. The program for this simulation is developed in Mat Lab programming script file based on the underlined ideas in chapter three power restoration portions. Sparse matrix is used to set nodes and line segments into undirected connected graph. Sparse matric of nodes and respective loads is constructed according to Fig. 4.15 node representation of Feeder-02. The simulation is made to find minimum spanning tree and the kVA capacity it can support during fault occurrence in any line in the network. Specifying which line is faulted, the program finds shortest path for the remaining graph by removing the faulted line.

A value zero in sparse matrix is vanished and hence faulted line weight is set zero. Therefore, the faulted line is removed from the connected graph. The decision vector can be found from the resulting minimum spanning tree which helps to actuate on switching in status of switches. Any further decision on power supplying mechanism lies in the current decision vector. The source m-file code developed for this simulation is found in Appendix F.

The program sums the kVA capacities of loads in the minimum spanning tree. During no fault situation, the feeder remains in normal state of operation hence no change in decision vector values. But when any permanent fault exists, the program sectionalizes the faulted line and supplies the rest power network.

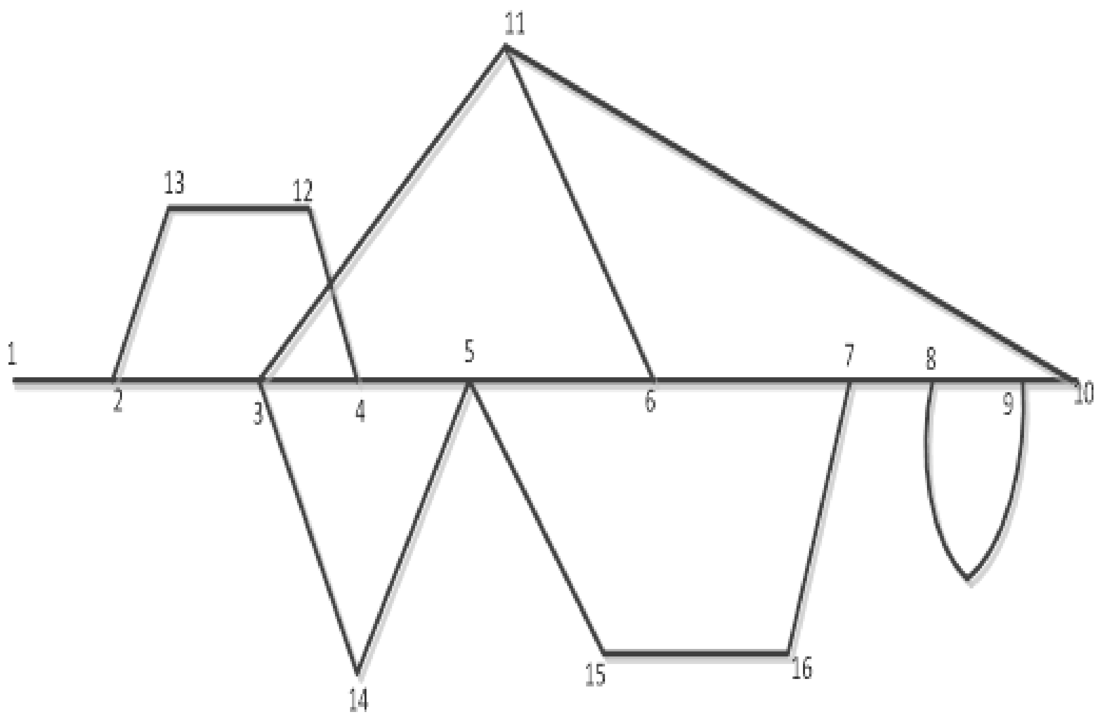


Figure 4.15 Feeder-02 node representation undirected connected graph

Table 4.4 Labeling of nodes and line segments with loads in the branches of Fig.4.15

Node pair	Node length (km)	Line segment	Load points in a branch
(1,2)	0.087	1	none
(2,3)	0.9707	2	2, 3 ,4 ,5 ,6 ,7 ,8 ,9
(3,4)	1.975	3	10, 11, 12 ,13, 14, 15
(4,5)	0.6473	4	16, 17
(5,6)	0.2324	5	18 ,19, 20
(6,7)	0.149	6	none
(7,8)	1.0724	7	21, 22, 23 ,24
(8,9)	0.8060	8	25, 26 ,27 ,28, 29
(9,10)	0.1036	9	30
(10,11)	2.456	10	lateral
(11,3)	2.0826	11	lateral
(2,13)	0.193	12	48, 49, 50
(13,12)	2.2684	13	lateral
(12,4)	0.4861	14	47
(3,14)	1.675	15	34 ,35 ,36 ,37 ,38, 39
(14,5)	3.1092	16	lateral
(5,15)	1.1064	17	40 ,41 ,42, 43, 44, 45
(15,16)	0.92516	18	lateral
(16,7)	0.195	19	46
(9,8)	0.8060	20	lateral
(11,6)	0.8984	21	31 ,32 ,33

There are thirteen switches, including the newly installed ones, in Feeder-02. It has 8192 switching options according to the formula, 2^n. For each of the minimum spanning tree found, decision vector is formulated to be actuated by the operator in to switches' open/closed state.

A flow chart algorithm as shown in Fig. 4.16 is used to develop the m-file program of this restoration. The objective function of the restoration is to maximize power restoration to the network after removal of faulted line, equation (4.10). Capacity of MST shall not exceed the total capacity of the feeder. Searching of shortest path enables to avoid the existence of loops in the graph.

Maximize $y = \sum_{i}^{n} L_I \; X_i$ (4.10)

Where

n –total number of node in the feeder

L_i - The load at node point i

X_i - decision variable for the switch in the line

The decision vector helps to alternatively check optional switch for power supplying routes. Switches of the decision vector elements are according to the naming in Fig. 3.2.

X=[$X_1 \; X_2 \; X_3 \ldots \ldots \ldots \ldots \ldots \ldots \ldots X_n$]

Any alternation in the decision vector shows change of supply path in the feeder. For each line segments fault, the power capacity of the MST is recorded as in Table 4.3 and Fig. 4.17.The assumption for power restoration is, during fault, the faulted branch is sectionalized and isolated from the connected graph until it is reconnected after fault clearing. At normal operation, the shortest routing path of feeder is as Fig. 4.18 b.

Feeder-02 has 16 nodes and 21 edges. The prim's algorithm takes one node as reference and searches across the 15 remaining nodes connecting a segment with shorter length.

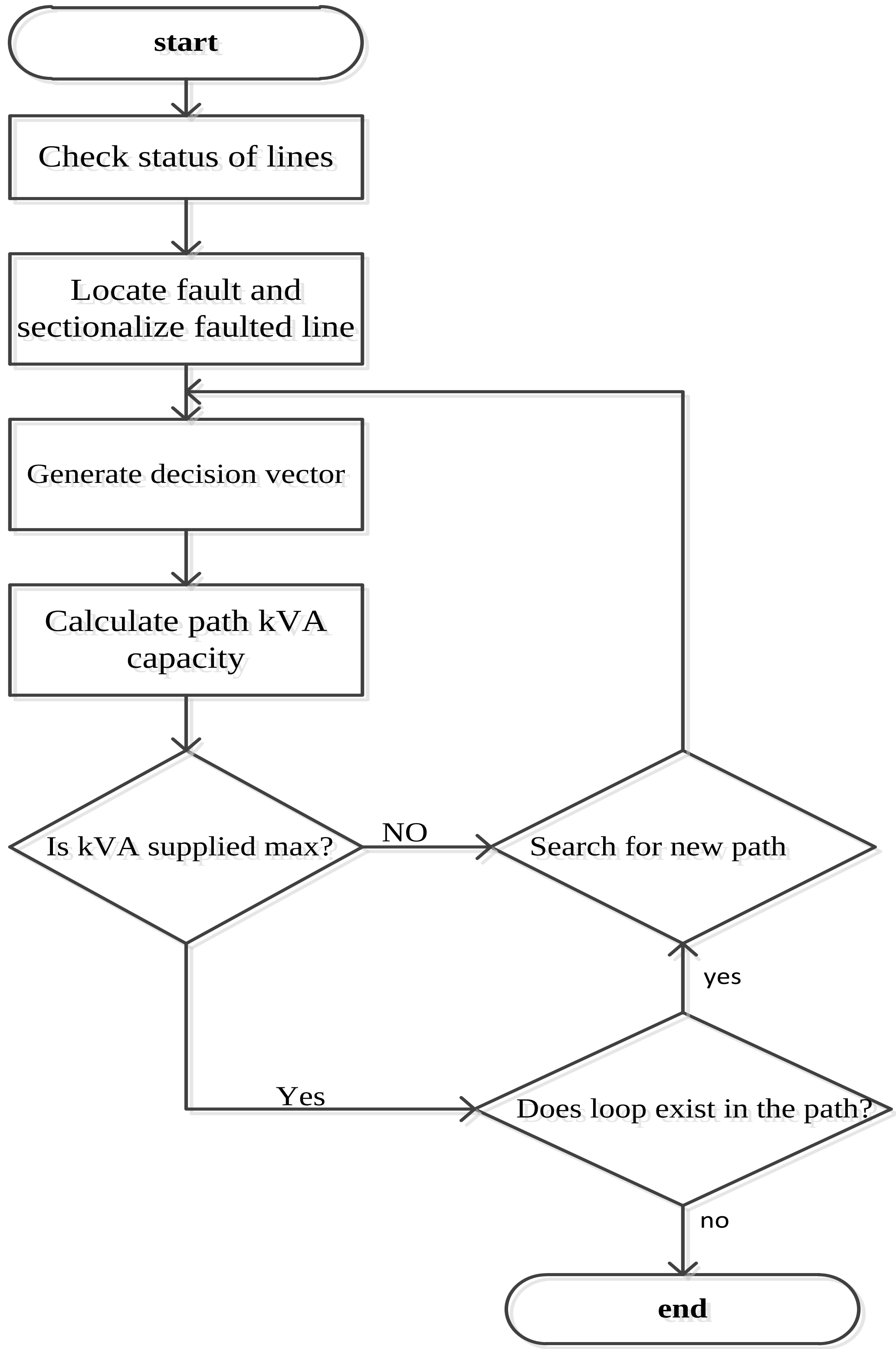


Figure 4.16 Flow chart algorithm for finding minimum spanning tree

Table 4.5 Simulation result of power restoration for faults at different line segments

Faulted Line segment	No customers reconnected	Power Restored(MVA)	Decision vector X=[1 2 3 4 5 6 7 8 9 10 11 12 13]
L1	None	Power can't be restored	[1 1 1 1 1 1 0 1 0 0 0 0 0]
L2	8995	12.905	[0 1 1 1 1 1 0 0 1 0 0 0 1]
L3	10273	13.405	[1 0 1 1 1 1 0 0 1 0 0 1 0]
L4	10331	12.660	[1 1 0 1 1 1 0 0 1 0 0 1 0]
L5	10934	14.400	[1 1 1 1 1 1 0 1 1 0 0 0 0]
L6	11235	14.550	[1 1 1 1 1 1 0 1 1 0 0 0 0]
L7	10736	14.160	[1 1 1 0 1 1 0 0 1 0 1 0 0]
L8	9998	13.370	[1 1 1 1 0 1 0 0 1 1 0 0 0]
L9	10822	14.035	[1 1 1 1 1 1 0 0 1 0 1 0 0]
L12	10190	12.475	[1 1 1 1 1 1 0 0 1 0 0 0 1]
L14	10617	13.605	[1 1 1 1 1 1 0 0 1 0 0 0 1]
L15	10512	13.520	[1 1 1 1 1 0 1 0 1 0 0 0 0]
L17	9976	12.210	[1 1 1 1 1 1 0 0 1 0 0 0 0]
L19	10998	13.920	[1 1 1 1 1 1 0 1 1 0 0 0 0]
L21	10642	14.035	[1 1 1 1 1 1 0 0 1 0 0 1 0]

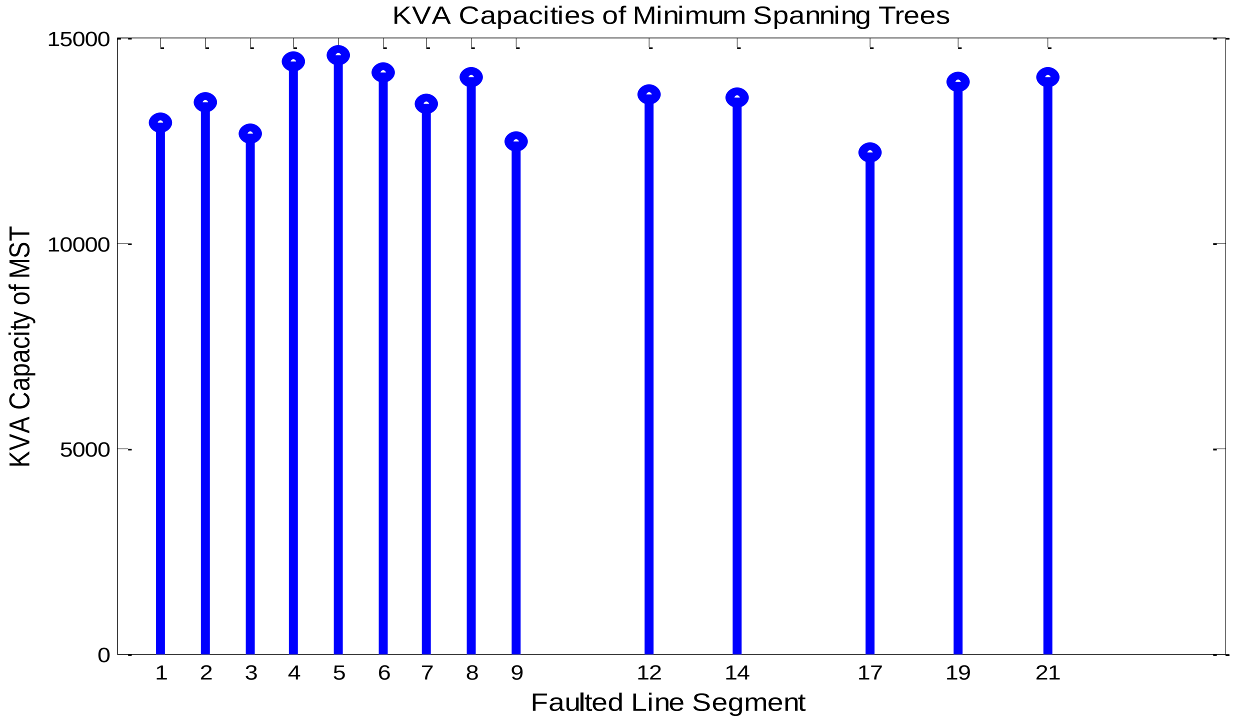
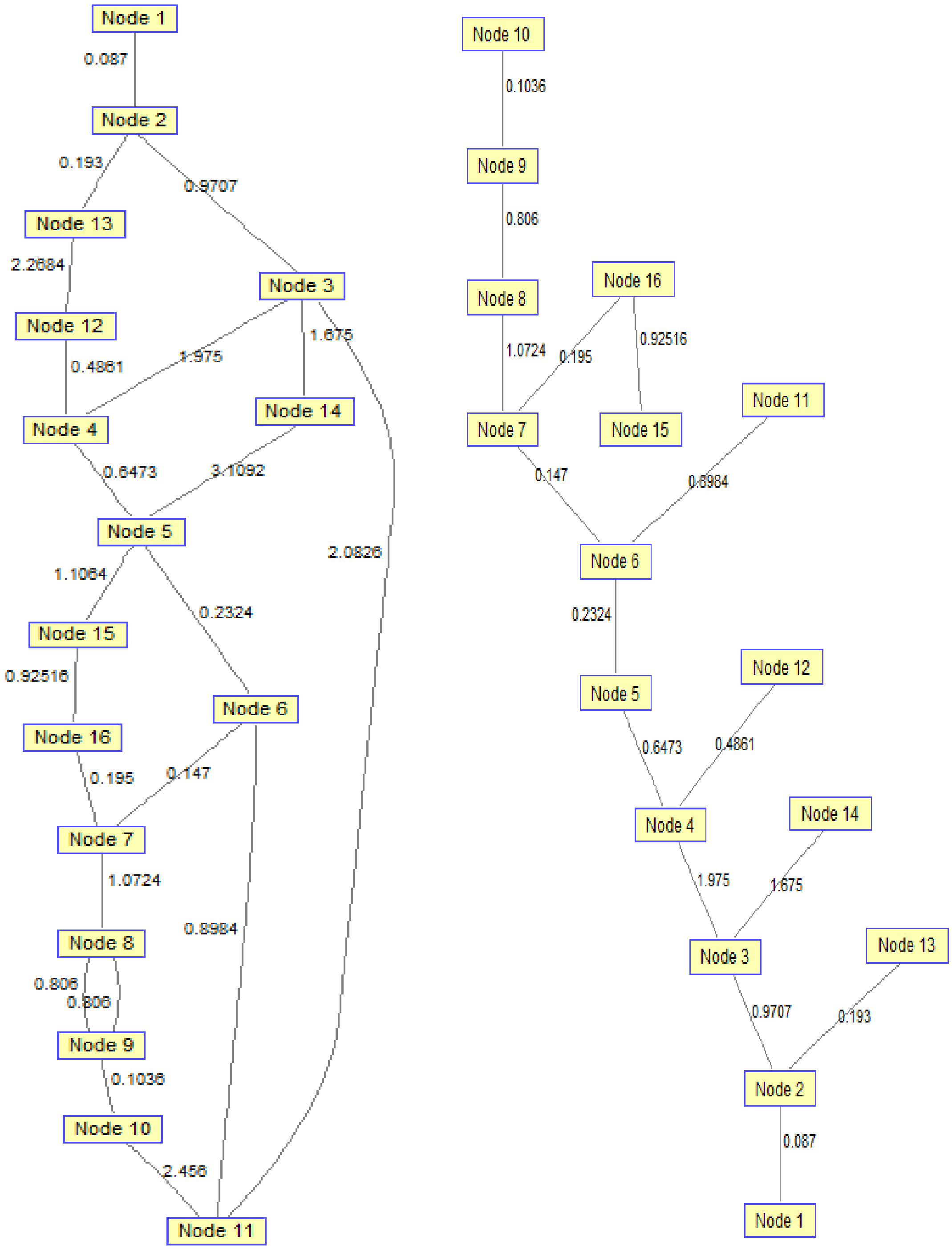


Figure 4.17 MSTs supplying capacities during occurrence of permanent fault

Depending on the location of the fault, the capacity of power restored to the network till the fault is cleared varies. The assumption is only load point lines other than laterals are considered as potential fault points. As shown in Fig. 4.17, high complex power is supplied to the delivery points for faults near to the substation. The simulation program returns the capacity of the network that can supply the rest network during fault clearing with minimized loss. The MST searches the path with least routing length.

For more accurate and flexible restoration, the location of sectionalizing and tie switches and their number determines. This simulation assumes only single fault occurs in the original network. Any further fault in the resulting network is not analyzed. This is because the sectionalizing degree of the network depends on the number of switches in that network. The restoration also relies on how the network is operated. Any failure of single switch to perform switch affects the construction of minimum spanning tree.



(a) (b)

Figure 4.18 Bella substation feeder-02 undirected connected graph and MST simulation result

Table 4.6 Reliability improvement by Network Reconfiguration

Fault location	Reliability improvement			
	SAIDI	SAIFI	CAIDI	ASAI
L1	No restoration	No restoration	No restoration	restoration
L2	32.558	36.861	0.883	0.9963
L3	13.982	15.830	0.883	0.9984
L4	13.139	14.876	0.883	0.9985
L5	4.375	4.953	0.883	0.9995
L6	0	0	0	1
L7	7.253	8.211	0.883	0.9991
L8	17.979	20.356	0.883	0.9979
L9	6.003	6.796	0.883	0.9993
L12	15.189	17.197	0.883	0.9982
L14	8.982	10.170	0.883	0.9989
L15	10.509	11.897	0.883	0.9988
L17	18.299	20.718	0.883	0.9979
L19	3.444	3.900	0.883	0.9996
L21	8.619	9.758	0.883	0.9990

Reconfiguration of feeder-02 after fault achieved reconnection of customers and restored energy as shown in Table 4.5. The restoration is done assuming that the hour it takes to restore power in feeder-02 of Bella substation is 0.8833 hr./int. The reconfiguration improves reliability of reconnected customers. Restoration is tested for different fault locations. The improvement of reliability indices is tabulated in Table 4.6.

Reliability improvement is calculated as:

% improvement =

$$\frac{\text{Total outagecustomerhours} - \text{outage hours after reconfiguration}}{\text{Total outage customer hours}} \quad (4.11)$$

Improvements in SAIDI and SAIFI values are found by multiplying the percentage improvement of reliability of reconnected customers.

Improved SAIDI= Current SAIDI-(Current SAIDI* % Improvement) (4.12)

Improved SAIFI= Current SAIFI-(Current SAIFI* % Improvement) (4.13)

For different fault points, the use of lateral distribution lines helped to increase reconfiguration capability of the distribution system. Reliability improvement of customers after reconfiguration is calculated. Reliability indices are within Ethiopia's reliability standard except for fault at segment L_1 and L_2. The reliability indices can be calculated for the energy restored. The simulation is conducted to restore maximum power and maximum number of customers. Reliability can also be verified based on restored energy.

The reliability of the system can be improved further by reducing the number of hours the distribution system takes to restore power. This can be done either increasing momentary interruptions or reducing the duration of interruption of the system.

CHAPTER FIVE

SUMMARY AND CONCLUSION

Distribution reliability improvement for Addis Ababa city Bella substation in smart grid environment is achieved by applying network reconfiguration, rapid restoration and automation. Basically, reliability of distribution system in smart grid context is assumed to improve the distribution adequacy by application of switching, automation and reclosing in the existing distribution system.

Reliability data obtained for the substation is analyzed in graphs to illustrate potential unreliability in terms of frequency and duration of interruption. Potential causes of interruption are identified which helped to select what feature of smart grid in distribution system can tackle these problems. Reliability indices are used to quantify and state the reliability of Bella substation. Because of limitation in available data, Only SAIDI and SAIFI are used to evaluate the reliability of the distribution system. Besides, System Fault assessment and data recording is made in terms of how many delivery points are affected during outage event and the number of customers affected by the fault.

The fault types and causes are identified for the feeder-02 at Bella substation. Reliability improvement ideas are identified to reduce frequency of interruption and the time an interruption lasts. Ethiopia's standard in reliability limits SAIDI to 25 Hr./cust./yr and SAIFI to 20 Int. /cust./yr. Taking Ethiopia's reliability requirement as bench mark to improvement, laterals and automation upgrade are designed using genetic algorithm optimization. Reliability Improvement of feeder-02 is analyzed.

Lateral lines for alternative power supply path are designed under constraints of feeder capacity. Feeder-02 is chosen for this implementation because of its high installed supply capacity and high record of interruption. Genetic algorithm optimization is applied to search for optimal point of interconnection of laterals and network reconfiguration. The genetic algorithm is selected for this design because of its effective combinational searching and representation of potential candidates is easy. Connection points (candidates) are represented only by ones and zeros.

Besides, searching space of design candidates are improved through generations enabling rapid arrival to optimal targets. The Lateral design has considered two targets of potential increase in reliability. One is maximizing number of customers after network reconfiguration. The other is maximizing the energy that can be supplied by the restoration network. A moderate design simulation result in Mat Lab programming is achieved to both target considerations.

Other feature assumed to alleviate interruption-automation, reclosing and switching- is suggested to increase network flexibility and rapid reconnections. New devices are installed in Feeder-02 network under constraint of reliability in SAIDI and SAIFI. The design considered cost minimization while improving reliability. Automating equipment, a recloser and sectionalizing switches are installed. These devices increased the switching and reclosing capability of the feeder. The automating equipment has improved remote control capability. Reliability improvement as result of new installed devices is calculated for each device as shown in Table 4.2 and Table 4.3. The automation, reclosing and switching optimization simulation resulted in reduction of 69.69% in SAIFI and 39.788% in SAIDI. The current SAIDI value is reduced to 98.33 hr./cust./yr. and SAIFI value is reduced to 56.025 int./cust./yr. as a result of installment of new devices.

Additionally, power restoration using minimum spanning tree, prim's algorithm, is simulated based on decision vector of status of switches in the network. Any change in decision vector of switches manifested changes of network path. Searching for new power path network is operated by changing values of binary digits of the decision vector. During fault occurrence, faulty line is sectionalized and network path is analyzed for shortest path selection and maximum power supply. Power supplying capacities at different fault location is simulated in Mat Lab. The search for shortest path is aimed at minimizing power loss in conductors. Reconfiguration to restore power is simulated. Reliability of reconnected customers is calculated as shown in Table 4.6. In average, SAIDI of 11.452 hr./cust./yr., SAIFI of 12.966 int./cust./yr. and ASAI of 0.9986 has been achieved for network reconfiguration at various fault points.

To conclude, reliability of a distribution network can be improved by ultimate use of smart grid features. The reliability of a distribution network has direct relationship to the number of existing reconfiguration possibilities and automating a distribution system reduces duration of interruptions. Besides, Reclosing and switching capabilities are possible in the existence of alternative interconnections. On the other hand, Interconnection between neighboring feeders can be tested using genetic algorithm based on sequential sectionalizing events of switches. This can also be simulated using Mat Lab programming or C++. While using GA, optimization constraints can be easily designated during simulation as long as the constraint is computable. Genetic Algorithm can be implemented in reliability improvement of vast and complex distribution networks.

Power flow variables of reconfigured network can be tested to achieve stable operating conditions. The representation of chromosomes in such case can be double vector form or binary string. During design procedure, reliability constraints can be extended to reliability indices for momentary interruptions. A design subjected to more reliability constraint variables will have more reliability improvement. Additionally, for various fault events, the prim's algorithm for finding minimum spanning tree is applicable to different network interconnection complexities.

Future works

This section presents the possibilities of extension of this thesis paper in the future.

1. In this thesis, it's assumed that the feeder supply points are within capacity ranges. Genetic algorithm application in lateral design can be extended to interconnection between neighboring feeders and different conductor sizes.
2. Reliability data available is only in sustained interruption level. The optimization can also be conducted in wider sense of momentary events inclusion and cost-reliability subjected design.
3. Automation, reclosing and switching target is restricted to generation based reliability improvement. The target can also be extended to cut-set based reliability including faults beyond the transformer secondary side.
4. Power restoration range is possible to enhance it to case of distributed generation injection at target points. Reliability improvement using DG enhanced system can be simulated using genetic algorithm.

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APPEDIX A

Table 2.16 Addis Ababa city Distribution network problems and records in 2010/11

	Distribution Interruption Reasons	Outage In Number	
		Freq.	Dur(Hr.)
Network Technique Problem	1. medium voltage lines contact due to wind	179	252.52
	2. medium voltage cut	258	456.99
	3. aged tower broken due to heavy rain	13	8.64
	4. medium voltage underground cable explosion	22	27.6
	5. aged tower broken and contact of Ganch and distribution line	19	26.88
	6. line disconnected from legatura and contact to cross arm	26	45.59
	7. fire ignited due to transformer secondary side loose connection	25	24.55
	8. line outage due to oil leakage grounding of transformer	20	40.46
	9. feeder opens in switching station and fault tracing	32	18.44
	10. short circuit and earth fault line outages	3084	93.93
	11. high voltage contact with street lighting line	66	41.6
External Outage causes	1. car accident on medium voltage	23	40.07
	2. tree falling on medium voltage	72	101.77
	3. explosion of arrestor due to lightening	39	65.06
	4. dying bird contacts distribution line	79	108.65
	5. interrupted lines for windy rain time	12	11.8
Outage due to Unknown causes	1. interrupted line during windy rain	128	40.84
	2. substation breaker opens for unknown source	440	234.17
	3. switching station breaker opens	934	169.32
	4. tapped point cutting and fault tracing	155	146
	5. interrupted lines and then reconnected for unknown fault source	217	204.88

Table 2.17 Data of problems occurring in distribution system 20011/12(July -January)

	Distribution Outage Reason	Outage Source In Number	
		Freq.	Dur(Hr.)
Network Technical Problem	1. Medium Voltage Lines Contact Due To Wind	82	153.7
	2. Medium Voltage Cut	271	527.95
	3. Aged Tower Broken Due To Heavy Rain	21	24.81
	4. Medium Voltage Underground Cable Explosion	24	36.91
	5.Aged Tower Broken And Contact Of 'Ganch' And Distribution Line	21	70.93
	6.Fire ignited due to transformer secondary side loose connection	22	15.11
	7. line outage due to oil leakage grounding of transformer	19	26.48
	8. feeder opens in switching station and fault tracing	871	93.41
	9. short circuit and earth fault line outages	3149	148.96
	10. high voltage contact with street lighting line	17	40.96
	11. medium voltage loose line fire ignition	5	9.57
	12. sudden opening of circuit breaker and fault clearing	173	233.29
	13. clamp loose and cut in tapping line	181	207.13
	14. disconnected lines due to sudden increase in load	75	71.28
External Outage cause	1. car accident on medium voltage	41	53.21
	2. tree falling on medium voltage	57	124.82
	3. explosion of arrestor due to lightening	14	56.71
	4. dying bird contacts distribution line	48	98.86
	5. interrupted lines for windy rain time	92	48.56

Freq. = frequency, Dur (Hr.) =duration (hour)

APPENDIX B

Table 2.18 Interruption frequency and duration of Bella substation in 2009/10

Month	Outage in number	Feeder Name					
		Bella-1	Bella-2	Bella-3	Bella-4	Bella-5	Bella-6
July	Freq.	8	12	8	8	5	0
	Dur(Hr.)	4.3	8.5	11.62	7.72	5.65	0
August	Freq.	16	15	5	11	6	1
	Dur(Hr.)	11.566	5.966	2.916	6.183	5.033	0.616
September	Freq.	1	37	20	16	15	5
	Dur(Hr.)	3.08	24.77	16.43	13.25	19.53	10.3
October	Freq.	5	23	20	15	13	1
	Dur(Hr.)	13.57	12.87	25.47	16.9	41.55	3.38
November	Freq.	14	18	22	22	15	2
	Dur(Hr.)	25.67	29.43	23.92	47.6	32.78	2.33
December	Freq.	12	27	16	9	13	0
	Dur(Hr.)	11.65	25.766	28.983	10.55	30.566	0
January	Freq.	6	15	7	10	11	2
	Dur(Hr.)	6.283	2.266	6.533	11.816	11.25	2.283
February	Freq.	8	25	9	7	6	1
	Dur(Hr.)	14.216	15.466	27.1	6.9	11.183	0.033
March	Freq.	2	22	4	1	4	1
	Dur(Hr.)	0.066	4.866	0.95	0.033	0.183	0.033
April	Freq.	14	23	22	12	17	4
	Dur(Hr.)	13.7	17.5	23.7	14.333	17.866	6.016
May	Freq.	9	12	14	15	18	2
	Dur(Hr.)	10.983	9.6	21.683	19.033	43.783	3.25
June	Freq.	10	32	13	8	17	1
	Dur(Hr.)	10.3	32.783	13.95	7.85	20.066	3.666
Total interruption frequency						820	
Total interruption Duration (Hr.)						951.953	

Freq. = frequency, Dur (Hr.) =duration (hour)

Table 2.19 Bella substation interruption frequency and duration in 2010/11

Month	Outage in number	Feeder Name					
		Bella-1	Bella-2	Bella-3	Bella-4	Bella-5	Bella-6
July	Freq.	10	31	14	13	27	2
	Dur(Hr.)	18.65	46.13	28.57	21.8	35.37	2.13
August	Freq.	10	13	11	2	9	0
	Dur(Hr.)	11.35	8.266	12.583	1.116	5.733	0
September	Freq.	9	19	9	4	12	0
	Dur(Hr.)	3.983	15.916	3.683	4.2	16.533	0
October	Freq.	9	11	5	7	8	1
	Dur(Hr.)	5.783	11.7	3.833	6.1	9.233	1.833
November	Freq.	10	15	13	14	13	0
	Dur(Hr.)	11.12	13.12	8.37	18.36	6.04	0
December	Freq.	4	8	8	5	12	0
	Dur(Hr.)	2.833	9.133	3.783	3.416	5.083	0
January	Freq.	5	5	5	2	12	3
	Dur(Hr.)	4.9	6.616	4.616	2.666	11.233	2
February	Freq.	4	10	12	3	11	0
	Dur(Hr.)	7.066	7.4	16.65	3.25	13.75	0
March	Freq.	1	2	5	0	1	0
	Dur(Hr.)	1.5	5.666	9.833	0	0.5	0
April	Freq.	3	5	2	13	7	0
	Dur(Hr.)	0.916	3.85	1.1	6.383	5.583	0
may	Freq.	6	8	10	8	7	0
	Dur(Hr.)	3.9	5.166	7.95	1.666	6.966	0
June	Freq.	5	8	9	14	6	8
	Dur(Hr.)	7.8	9.433	11.233	15.4	15.366	17.566
Total interruption frequency						538	
Total interruption duration						573.6933	

Table 2.20 Bella substation interruption frequency and duration 2011/12(July-January)

Month	**Outage in number**	**Feeder name**					
		Bella-1	Bella-2	Bella-3	Bella-4	Bella-5	Bella-6
July	Freq.	2	4	3	10	11	0
	Dur(Hr.)	4.33	1.1	3.583	15.783	6.466	0
August	Freq.	6	14	12	11	12	3
	Dur(Hr.)	4.6	13.783	11.483	25.166	15.45	1.833
September	Freq.	13	15	8	18	15	0
	Dur(Hr.)	9.25	19.0833	9.5	19.7333	15.1167	0
October	Freq.	9	6	7	10	12	1
	Dur(Hr.)	7.083	4.366	3.833	17.433	11.616	0.92
November	Freq.	8	16	8	10	11	0
	Dur(Hr.)	5.5	11.766	7.883	20.95	22.583	0
December	Freq.	6	12	10	5	9	2
	Dur(Hr.)	1.916	14.65	30.933	14.416	3.466	2.066
January	Freq.	6	14	7	4	10	1
	Dur(Hr.)	5.683	24.383	6.083	16.083	14.366	11.166

Freq. = frequency, Dur (Hr.) =Duration (hour)

Table 2.21 Bella substation interruption frequency and duration summary

Feeder Name	2002-2003		2003-2004		2004-2005(July - January)	
	F	D(Hr.)	F	D(Hr.)	F	D(Hr.)
Bella-01	105	125.387	76	79.803	50	38.37
Bella-02	261	189.787	135	142.4	81	89.13
Bella-03	160	203.257	103	112.207	55	73.3
Bella-04	134	162.17	85	84.36	68	129.57
Bella-05	140	239.443	125	131.393	80	89.07

F=Frequency, D (Hr.) =Duration (Hour)

APPENDIX C

Table 4.7 Bella substation Feeder-02 nodes: connected load, number of customer and segment length data

Feeder-02 nodes	load connected(KVA)	no. of customer	segment	Line number	Length(m)
1	substation	----	1-2	L1	87.298
2	200	175	2-3	L2	114.24
3	200	175	3-4	L3	34.535
4	315	480	4-5	L4	78.45
5	200	394	5-6	L5	200.97
6	100	176	6-7	L6	333.05
7	315	420	7-8	L7	28.942
8	315	420	8-9	L8	180.489
9	tapped point	-----	9-10	L9	401.689
10	315	420	10-11	L10	702.5
11	200	175	11-12	L11	203.03
12	315	101	12-13	L12	203.03
13	315	266	13-14	L13	302.954
14	section	-----	14-15	L14	161.691
15	tapped point	------	15-16	L15	281.45
16	945	457	16-17	L16	235.665
17	945	447	17-18	L17	130.157
18	tapped point	-----	18-19	L18	117.9506
19	50	128	19-20	L19	114.495
20	100	173	20-21	L20	148.978
21	tapped point	-----	21-22	L21	172.822
22	50	128	22-23	L22	302.482
23	25	105	23-24	L23	384.013
24	315	266	24-25	L24	213.082
25	100	176	25-26	L25	371.523
26	315	423	26-27	L26	108.671
27	465	290	27-28	L27	193.166
28	200	175	28-29	L28	132.683
29	100	173	29-30	L29	103.640
30	515	413	20-30	L30	-------
31	100	204	20-31	L31	195.429
32	315	418	31-32	L32	323.885

33	200	175	32-33	L33	377.528
34	100	173	9-34	L34	382.935
35	315	101	34-35	L35	184.58
36	200	173	35-36	L36	184.58
37	tapped point		36-37	L37	229.98
38	315	101	37-38	L38	507.569
39	100	173	38-39	L39	185.115
40	315	123	18-40	L40	132.255
41	315	257	40-41	L41	425.438
42	365	266	41-42	L42	84.1062
43	515	109	42-43	L43	40.197
44	315	266	43-44	L44	83.795
45	515	238	44-45	L45	340.649
46	630	237	21-46	L46	195.023
47	945	618	15-47	L47	40.2977
48	200	175	2-48	L48	193.04
49	1045	420	48-49	L49	113.76
50	830	450	49-50	L50	305.6

Table 4.8 Failure rate of equipment for overhead distribution system [62]

Device	Failure rate per year	Repair time(hr.)	Auto reclosing time
Sectionalizing switch	0.05	3	-
sectionalizer	0.001	6	10/3600
Auto-recloser	0.001	6	5/3600
line	0.0124/km	2	

APPENDIX D

Genetic algorithm components developed program code for served energy priority and customer priority lateral design

A. Connectivity matrix

% the below matrix is a 50x50(nodes x nodes) connectivity matrix of Feeder-02

% each of the rows are treated as chromosomes (individual)

%with the length of the column as the binary length of the representation

% each chromosome has length of 50 genes

% 1-means that the two nodes are connected

% 0-means that the two nodes are not connected

cmatrix=

[1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0

0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

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0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

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0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0

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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0

0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1];

B. Fitness function

Fitness function program for customer based lateral design and served energy based lateral design is the same.

```
%this function adds up the KVA values or number of customers of the connected
%nodes in a chromosome
% the KVA is the values of the first column in cmatrix in file bella.m
% t-is the matrix taken from the connectivity matrix or the connectivity
% matrix itself
% u-is the column vector of KVA of each load in the nodes
function [valuefit,minimum_value_individual]=myfit(t,u)
[x,y]=size(t);
[p]=0;
h=u';
for i=1:x
    s=0;
    for j=1:50
        if t(i,j)==1
```

```
        s=s+h(1,j); % sums the kva of each node in the chromosome
      end
    end
   p(1,i)=s;
end
valuefit=p;
[d,w]=min(p);
minimum_value_individual=w;
end
```

C. Crossover recombination function

```
%the below function takes the crossover of two parents
% parent1 is the ith row of the matrix of encodings
%parents two is (i+1)th row of the matrix of encodings
% child1 is the form of [geneparent1 geneparent2 geneparent1]
%child2 is the form of [geneparent2 geneparent1 geneparent2]
%two point cross over is taken for the 50 bit string individuals
% matrix d is the parent matrix for the next generation
% d is the matrix of previously selected individuals
   function [newpop]=mycrossover(d)
   [x,y]=size(d);
   i=1;
   a=1;
   mynewpop=zeros(x,y);% matrix of zeros with size of matrix d
   while i<x
      for j=11:40
         geneparent1(a,j-2)=d(i,j); %taking middle genes of the first  chromosome
      end
      t=i;
      i=i+1;
      for k=11:40
         geneparent2(a,k-2)=d(i,k);
```

```
      end
 % code for child1##################
      for e=1:10
      mynewpop(t,e)=d(t,e);% first ten genes from parent one
      end
      for n=11:40
       mynewpop(t,n)=geneparent2(a,n-2);% middle thirty genes from parent two
      end
      for w=41:50
       mynewpop(t,w)=d(t,w);% last ten genes from parent one
      end
%################################
      t=i;
      % code for child2#########################
      for e=1:10
      mynewpop(t,e)=d(t,e);
      end
      for n=11:40
     mynewpop(t,n)=geneparent1(a,n-2);
      end
      for w=41:50
         mynewpop(t,w)=d(t,w);
      end
      %################################################
     i=i+1;
   end
   newpop=mynewpop;
```

D. Mutation Function

```
 %mutation function for the crossed over population (new population)
% new crossover matrix is the connectivity matrix after crossover recombination
%stringlength is the number of bit strings of the representation
```

```
%mp is the mutation probability; it is usually small because it can kill
%the child if many of its genes are altered
% dimention is the number of variables in the binary string representing
% the individual
function newcrossover=mutation(newcrossover,stringlength,dimension,pm)
new_popsize=size(newcrossover,1);
for i=1:new_popsize
   if rand<pm
      mpoint=round(rand(1,dimension)*(stringlength-1))+1;
      for j=1:dimension
         newcrossover(i,(j-1)*stringlength+mpoint(j))=1-newcrossover(i,(j-
1)*stringlength+mpoint(j));
      end
   end
end
```

E. Chromosome Selection Function

```
%after fitness function and selection process has taken place the
%chromosomes selected according to the fitness value are placed in the same
%matrix for next crossover and mutation recombination
%d-matrix of the fitness value of the newly selected individuals
%t is the matrix of before newly selected individuals
%x is the fitness value of the original population (of the connectivity matrix)
%m number of generations
function [my_chromosome,first_generation_fitness_value]=mychromosome(t,x,m)
[r,y]=size(x);
for b=1:r
   for i=1:y
      for j=1:y
         if j~=y
            if x(b,j)>x(b,j+1)
               temp=x(b,j+1);
```

```
                x(b,j+1)=x(b,j);
                x(b,j)=temp;
                for f=1:length(t)
                    [icare(j,f)]=t(j,f);
                end
                for k=1:length(t)
                    t(j,k)=t(j+1,k);
                end
                for a=1:length(t)
                    t(j+1,a)=icare(j,a);
                end
            end
        end
    end
end
end
%x ...fitness value of individuals from the min to the max after crossover and mutation
x;
%t...matrix of individuals for fitness values in matrix x
t;
% the newly selected individuals and their fitness are:
%unselecting one unfit individual ( from first generation)
[p,y]=size(t);
newselected=zeros(p-1,y);
for i=2:p
    k=i-1;
        for j=1:y
            newselected(k,j)=t(i,j);
        end
end
x(1,m)=0;% the first individual is omitted from the population
```

```
my_chromosome=newselected;
first_generation_fitness_value=x;
```

F. Program code for simulation for lateral design with priority to served energy

```
%this program runs to maximize objective function using
% genetic algorithm optimization for lateral design with priority to
% served energy
unfit=zeros(1,50);
for runprogram=1:500
    tnode;
    bella;
    feederdata;% Feeder-02 custom data
    cmatrix;
    u=feederdata(:,1); % data values of each node in a chromosome
    k=cmatrix; % the connectivity matrix
    disp('initial fitness values of individuals')
    m=1;
    p=myfit(k,u);
    y=mycrossover(k);
    mymutated=mutation(y,1,50,0.15);
    [fittnessvalue,unfit_individuals]=myfit(mymutated,u);
    first_generation=mymutated;
    n=50;
    while n>5
        y=mycrossover(first_generation);
        mymutated=mutation(y,1,50,0.15);
        [fittnessvalue,unfit_individuals]=myfit(mymutated,u);
        unfit(1,m)=unfit_individuals;
[first_generation,first_generation_fitness_value]=mychromosome(mymutated,fittnessvalue,
m);
        n=n-1;
        m=m+1;
```

```
        end
    [last_fitness_value,unfit_individuals]=myfit(first_generation,u);

[first_generation,first_generation_fitness_value]=mychromosome(mymutated,last_fitness_
value,m);
    last_generation=first_generation;
    last_generation;
    last_generation_fitness_value=first_generation_fitness_value;
    last_generation_fitness_value;
    myvalue(1,runprogram)=max(last_generation_fitness_value);
    if myvalue(1,runprogram)==14550
        runprogram
        break
    end
end
myvalue
last_generation
runprogram
last_generation_fitness_value
unfit
probaility_of_each_generation=myvalue/16085;
plot(probaility_of_each_generation,'--rs','LineWidth',2,...
                'MarkerEdgeColor','k',...
                'MarkerFaceColor','g',...
                'MarkerSize',10)
title('the probability of best chromosomes')
```

G. Program code for simulation of lateral design with priority to customers

```
%this program runs to maximize number of customers to be reconnected
% genetic algorithm based optimization for lateral design with priority to customers
unfit=zeros(1,50);
for runprogram=1:500
```

```
tnode;
bella;
feederdata; % Feeder-02 customer data
cmatrix;
u=feederdata(:,2);%data values of each node in a chromosome
k=cmatrix;% the connectivity matrix
%disp('initial fittness values of individuals')
m=1;
p=myfit(k,u);
y=mycrossover(k);
mymutated=mutation(y,1,50,0.08);
[fittnessvalue,unfit_individuals]=myfit(mymutated,u);
first_generation=mymutated;
n=50;
while n>5
    y=mycrossover(first_generation);
    mymutated=mutation(y,1,50,0.08);
    [fittnessvalue,unfit_individuals]=myfit(mymutated,u);
    unfit(1,m)=unfit_individuals;
[first_generation,first_generation_fitness_value]=mychromosome(mymutated,fittnessvalue,
m);
    n=n-1;
    m=m+1;
end
[last_fitness_value,unfit_individuals]=myfit(first_generation,u);
[first_generation,first_generation_fitness_value]=mychromosome(mymutated,last_fitness_
value,m);
last_generation=first_generation;
last_generation;
last_generation_fitness_value=first_generation_fitness_value;
last_generation_fitness_value;
```

```
    myvalue(1,runprogram)=max(last_generation_fitness_value);
    if myvalue(1,runprogram)==10440
        runprogram
        break
    end
end
myvalue
last_generation
runprogram
last_generation_fitness_value
unfit
probability_of_each_generation=myvalue/11235;
plot(probability_of_each_generation,'--rs','LineWidth',2,...
                'MarkerEdgeColor','k',...
                'MarkerFaceColor','g',...
                'MarkerSize',10)
title('the probability of best individuals')
```

APPENDIX E

Genetic algorithm components developed codes for automation, reclosing and switching simulation program

A. Line code

```
% this is the line segment code representation of Feeder-02
%six binary digits represent the line number and the other three represents
%device installments
  feederlinecode=
        [0 0 0 0 0 1 0 0 0
          0 0 0 0 1 0 0 0 0
          0 0 0 0 1 1 0 0 0
          0 0 0 1 0 0 0 0 0
          0 0 0 1 0 1 0 0 0
          0 0 0 1 1 0 0 0 0
          0 0 0 1 1 1 0 0 0
          0 0 1 0 0 0 0 0 0
          0 0 1 0 0 1 1 0 0
          0 0 1 0 1 0 0 0 0
          0 0 1 0 1 1 0 0 0
          0 0 1 1 0 0 0 0 0
```

0 0 1 1 0 1 0 0 0
0 0 1 1 1 0 0 0 0
0 0 1 1 1 1 0 0 0
0 1 0 0 0 0 0 0 0
0 1 0 0 0 1 0 0 0
0 1 0 0 1 0 0 0 0
0 1 0 0 1 1 0 0 0
0 1 0 1 0 0 0 0 0
0 1 0 1 0 1 1 0 0
0 1 0 1 1 0 0 0 0
0 1 0 1 1 1 0 0 0
0 1 1 0 0 0 0 0 0
0 1 1 0 0 1 0 0 0
0 1 1 0 1 0 0 0 0
0 1 1 0 1 1 0 0 0
0 1 1 1 0 0 0 0 0
0 1 1 1 0 1 0 0 0
0 1 1 1 1 0 0 0 0
0 1 1 1 1 1 0 0 0
1 0 0 0 0 0 0 0 0
1 0 0 0 0 1 0 0 0
1 0 0 0 1 0 0 0 0
1 0 0 0 1 1 0 0 0
1 0 0 1 0 0 0 0 0
1 0 0 1 0 1 0 0 0
1 0 0 1 1 0 0 0 0
1 0 0 1 1 1 0 0 0
1 0 1 0 0 0 0 0 0
1 0 1 0 0 1 0 0 0
1 0 1 0 1 0 0 0 0
1 0 1 0 1 1 0 0 0
1 0 1 1 0 0 0 0 0
1 0 1 1 0 1 0 0 0
1 0 1 1 1 0 0 0 0
1 0 1 1 1 1 0 0 0
1 1 0 0 0 0 0 0 0
1 1 0 0 0 1 0 0 0
1 1 0 0 1 0 0 0 0];

B. Bella substation Feeder-02 data

% the first column is for the KVA capacity served; the second column is for the number of customers connected to each node

% the third one is for the length

%of the conductor between

%consecutive nodes (in meters)

feederdata=[0 0 87.2983
200 175 114.24
200 175 34.535
315 480 78.45
200 394 200.97
100 176 333.05
315 420 28.9419
315 420 180.4895
0 0 401.6892
315 420 702.5
200 175 203.03
315 101 203.03
315 266 302.954
0 0 161.6912
0 0 281.45
945 457 235.6657

945 447 130.1572
0 0 117.9506
50 128 114.4951
100 173 148.9785
0 0 172.8226
50 128 302.4821
25 105 384.0133
315 266 213.0821
100 176 371.5235
315 423 108.6714
465 290 193.1665
200 175 132.683
100 173 103.6400
515 413 0
100 204 195.4297
315 418 323.8853
200 175 377.5279
100 173 382.935
315 101 184.58
200 175 157.3371
0 0 229.98
315 101 507.5695
100 173 185.1157
315 123 132.2552
315 257 425.4385
365 266 84.1062
515 109 40.1977
315 266 83.7954
515 238 340.6497
630 237 195.0229
945 618 40.2977
200 175 193.04
1045 420 113.76
830 450 305.6];

C. Line code crossover recombination

```
%this program returns individuals' offspring after crossover
% recombination technique is applied
% this program uses one point crossover
function [newpop]=mylinecrossover(d)
  [x,y]=size(d);
  i=1;
  a=1;
  mynewpop=zeros(x,y);% matrix of zeros with size of matrix d
  while i<x
    for j=7:9
      geneparent1(a,j-2)=d(i,j); %taking last genes of the first  chromosome
    end
```

```
        t=i;
        i=i+1;
        for k=7:9
            geneparent2(a,k-2)=d(i,k);
        end
  % code for child1##################
        for e=1:6
        mynewpop(t,e)=d(t,e);% first six genes from parent one
        end
        for n=7:9
         mynewpop(t,n)=geneparent2(a,n-2);% last three genes from parent two
        end
            %################################
        t=i;
        % code for child2#########################
        for e=1:6
        mynewpop(t,e)=d(t,e);
        end
        for n=7:9
       mynewpop(t,n)=geneparent1(a,n-2);
        end
        %#################################################
       i=i+1;
     end
     newpop=mynewpop;
```

D. Line Code Mutation

```
%mutation function for the crossed over population(new population)
% new crosssover matrix is line code matrix after crossover recombination
%stringlength is the representation of the line segments in binary string
%pm is the mutation probability; it is usually small because it can kill
%the child if many of its genes are altered
```

```
% dimention is the number of variables in the binary string representing
% the individual
function newcrossover=mutation(newcrossover,stringlength,dimension,pm)
new_popsize=size(newcrossover,1);
for i=1:new_popsize
   if rand<pm
      mpoint=round(rand(1,dimension)*(stringlength-1))+1;
      for j=1:dimension
            newcrossover(i,(j-1)*stringlength+mpoint(j))=1-newcrossover(i,(j-
1)*stringlength+mpoint(j));
       end
   end
end
```

E. Line code fitness function

```
% this program returns the fitness values of individuals in a population
% device installments are for sectionalizing switch, recloser, and
% automating device
function linefit=mylinefit(linepop)
[x,h]=size(linepop);
mysum1=0;
for i=1:x
   s=0;
   for j=0:5
      s=s+linepop(i,6-j)*2^j;
   end
  mylinecode(1,i)=s;

end
for i=1:x
   if linepop(i,7)==1
      if linepop(i,8)==0
```

```
            mysum1=mysum1+1000;
        end
        if linepop(i,8)==1
            mysum1=mysum1+15000;
        end
        if linepop(i,9)==1
            mysum1=mysum1+5000;
        end
    end
end
linefit=mysum1;
```

F. Line number code function

```
% this function displays the line number of the chromosome
% it takes 6 binary digits and converts to integer value of the line
% segment representing the chromosome
function [linenumber]=linenumbercode(linepop)
[x,t]=size(linepop);
for i=1:x
    s=0;
    for j=0:5
        s=s+linepop(i,6-j)*2^j;
    end
  mylinecode(1,i)=s;
end
linenumber=mylinecode;
```

G. Program code for simulation of automation, reclosing and switching optimization

```
% this program displays the selected candidates of optimization function
% minimize y=1000*Ns+15000*Nr+5000*Na, where
% NS-new switches to be installed
% Nr-new recloser to install
```

```
% Na-new automation equipment
linecode
feederlinecode;
bella
feederdata;
mycustomer=feederdata(:,2);
lineinmeter=feederdata(:,3);
x1=[1 2 3 4 5 6 7 8 9 34 35 36 37 38 39 48 49 50 % load points
 1 2 3 4 5 6 7 8 34 35 36 37 38 39 48 49 50 0]; % lines that affects the load points
x2=[10 11 12 13 14 15 16 17 18 19 20 21 31 32 33 40 41 42 43 44 45 44 47 0 0 0 0 0
        0 0 0 0 0 0 0 0 0 0 0 0 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 31 32 33 34 35 36 37 38 39 40
        41 42 43 44 45 46 47 48 49 50]; %Members of mutual effect
x3=[22 23 24 25 26 27 28 29 30];%Members of mutual effect in interruption
lamda=0.0124;% failure rate of lines per kilometer
failureratematrix=(lamda/1000)*lineinmeter;
gcode=feederlinecode;
lineno=zeros(50,1);
for myrun=1:50
   mycrossedover=mylinecrossover(gcode);
   mymutated=mutation(mycrossedover,9,1,0.08); % mutation function
   fitness(1,myrun)=mylinefit(mymutated); % evauluates  fitness function
   gcode=mymutated;
   [n,m]=size(mymutated);
   a=1;  k=1; f=1;
   linenumber=linenumbercode(gcode);
   for h=1:n
      lineno(h,1)=h;
      ppl=gcode(h,:); % takes the row at hand to evaluate the line number
      if a<=18 && h==x1(1,a)
            a=a+1;
```

```
s=0;% sum of interruption frequency per year
ss=0; % sum of interruption durations per year
%############################ case-1
if mymutated(h,7)==1% if there is a device
   if mymutated(h,8)==0 % 0-switch 1- recloser
      if linenumbercode(ppl)<=50
         s=s+0.05; % 0.05 is failure rate of sectionalizing switch
         ss=ss+0.05*3;
         for t=1:length(x1)-1
            s=s+failureratematrix(x1(2,t),1);
            ss=ss+failureratematrix(x1(2,t),1)*2;
         end
      else
         for t=1:length(x1)-1
            s=s+failureratematrix(x1(2,t),1);
            ss=ss+failureratematrix(x1(2,t),1)*2;
% 2 hr is mean time to repaire of distribution line
         end
      end
   end
end
%############# case-2
if mymutated(h,7)==1
   if mymutated(h,8)==1
      if linenumbercode(ppl)<=50
         s=s+0.001; % 0.001 is failure rate of autorecloser
         ss=ss+0.001*6;
         for t=1:length(x1)-1
            s=s+failureratematrix(x1(2,t),1);
            ss=ss+failureratematrix(x1(2,t),1)*2;
         end
```

```
                else
                  for t=1:length(x1)-1
                      s=s+failureratematrix(x1(2,t),1);
                      ss=ss+failureratematrix(x1(2,t),1)*2;
                  end
                end
            end
        end
        %####### case-3
        if mymutated(h,7)==0
            for t=1:length(x1)-1
                s=s+failureratematrix(x1(2,t),1);
                ss=ss+failureratematrix(x1(2,t),1)*2;
            end
        end
    else if h==x2(1,k)
        k=k+1;
        s=0;
        ss=0;
        % ################# case-1
        if mymutated(h,7)==1
            if mymutated(h,8)==0
                if linenumbercode(ppl)<=50
                    s=s+0.05; % 0.05 is failure rate of sectionalizing switch
                    ss=ss+0.05*3;
                    for t=1:length(x1)
                        s=s+failureratematrix(x2(2,t),1);
                        ss=ss+failureratematrix(x2(2,t),1)*2;
                    end
                else
                    for t=1:length(x1)
```

```
                s=s+failureratematrix(x2(2,t),1);
                ss=ss+failureratematrix(x2(2,t),1)*2;
            end
        end
    end
end
% ############### case-2
if mymutated(h,7)==1
    if mymutated(h,8)==1
        if linenumbercode(ppl)<=50
            s=s+0.05; % 0.05 is failure rate of sectionalizing switch
            ss=ss+0.05*6;
            for t=1:length(x1)
                s=s+failureratematrix(x2(2,t),1);
                 ss=ss+failureratematrix(x2(2,t),1)*2;
            end
        else
            for t=1:length(x1)
                s=s+failureratematrix(x2(2,t),1);
                ss=ss+failureratematrix(x2(2,t),1)*2;
            end
        end
    end
end
% ############# case-3
if mymutated(h,7)==0
    for t=1:length(x1)-1
        s=s+failureratematrix(x2(2,t),1);
        ss=ss+failureratematrix(x2(2,t),1)*2;
    end
end
```

```
else
   s=0;
   ss=0;
   %############### case-1
   if mymutated(h,7)==1
      if mymutated(h,8)==0
         if linenumbercode(ppl)<=50
            s=s+0.05; % 0.05 is failure rate of sectionalizing switch
            ss=ss+0.05*3;
            for t=1:size(failureratematrix,1)
               s=s+failureratematrix(t,1);
                ss=ss+failureratematrix(t,1)*2;
            end
         else
            for t=1:size(failureratematrix,1)
               s=s+failureratematrix(t,1);
               ss=ss+failureratematrix(t,1)*2;
            end
         end
      end
   end
   %############### case-2
   if mymutated(h,7)==1
      if mymutated(h,8)==1
         if linenumbercode(ppl)<=50
            s=s+0.001; % 0.05 is failure rate of sectionalizing switch
             ss=ss+0.001*6;
            for t=1:size(failureratematrix,1)
               s=s+failureratematrix(t,1);
               ss=ss+failureratematrix(t,1)*2;
            end
```

```
                    else
                        for t=1:size(failureratematrix,1)
                            s=s+failureratematrix(t,1);
                            ss=ss+failureratematrix(t,1)*2;
                        end
                    end
                end
            end
            %############## case-3
            if mymutated(h,7)==0
                for t=1:size(failureratematrix,1)
                    s=s+failureratematrix(t,1);
                     ss=ss+failureratematrix(t,1)*2;
                end
            end
        end
    end
    a=a+1;
    mylinefailurematrix(1,h)=s;
    myfailureduration(1,h)=ss;
end
mylinefailurematrix;
mysum=0;
mysum2=0;
for b=1:size(mycustomer)
    mysum=mysum+(mycustomer(b,1)*mylinefailurematrix(1,b));
    mysum2=mysum2+(mycustomer(b,1)* myfailureduration(1,b));
end
SAIFI(1,myrun)=mysum/11235;
SAIDI(1,myrun)=mysum2/11235;
if SAIFI(1,myrun)<=0.15 && SAIDI(1,myrun)<=0.25
```

```
      selfit(1,myrun)=mylinefit(mymutated);
      if mylinefit(mymutated)>40000
         break
      end
   end
end
SAIFI
SAIDI
fitness
last_gcode=[gcode lineno];
last_gcode
selfit % fitness of selected individuals that meet the criteria
selectedlines=[mymutated lineno]
plot(selfit,'--rs','LineWidth',2,...
            'MarkerEdgeColor','k',...
            'MarkerFaceColor','g',...
            'MarkerSize',10)
```

APPENDIX F

Program for MST using prim's algorithm

```
% this program displays the minimum spanning tree of a undirected connected
% Graph of Feeder-02 network. it returns the graph of the minimum spanning
% tree and the kVA capacity it can supply to the rest of network.
%########################################
%lineweight=[0.0873 0.9707 1.975 0.48681 0.6473 3.1092 0.2324 0.8984 0.1490...
% 0.1950 1.0724 0.8060 0.8060 0.1036 2.4560 2.0826 2.2684 0.1930 1.6750 1.1064 0.9252];
% vector weight of lines is the length of line segments in Feeder-02
lineweight=[0.087 0.9707 1.975 0.6473 0.2324 0.149 1.0724 0.8060 0.1036 2.456...
2.0826 0.193 2.2684 0.4861 1.675 3.1092 1.1064 0.92516 0.195 0.8060 0.8984];
% node1 and node2 are vector representation of pairs of nodes as below
%[1 2 3 12 4 14 5 11 6 16 7 9 8 9 11 3 13 2 3 5 15;2 3 4 4 5 5 6 6 7 7 8 8 9 10 10 11 12 13 14
15 16];
node1=[1 2 3 4 5 6 7 8 9 10 11 2 13 12 3 14 5 15 16 9 11];
node2=[2 3 4 5 6 7 8 9 10 11 3 13 12 4 14 5 15 16 7 8 6];
% creates sparse matrix of nodes and their weight
linenodes=sparse(node1,node2,lineweight);
% extracts triangular part of the sparsed matrix
newlinenode=tril(linenodes+linenodes');
%displays the graphic connection of nodes
mygraph=view(biograph(linenodes,[],'ShowArrows','off','ShowWeights','on'));
tes=allshortestpaths(mygraph);
[ST,pred]=minspantree(mygraph)
% displays graphs of minimum spanning tree
view(biograph(ST,[],'showarrows','off','showweights','on'));
lineweightconstant=lineweight;
%lines and node points that are affected during fault occurrence (line segments and load
points)
L2_3=[2 3 4 5 6 7 8 9];
L3_4=[10 11 12 13 14 15];
```

```
L4_5=[16 17];
L5_6=[18 19 20];
L7_8=[21 22 23 24];
L8_9=[25 26 27 28 29];
L9_10=30;
L4_12=47;
L6_11=[31 32 33];
L3_14=[34 35 36 37 38 39];
L5_15=[40 41 42 43 44 45];
L7_16=46;
L2_13=[48 49 50];
bella;
capacityKVA=feederdata(:,1);
customers=feederdata(:,2);
%accepts the line segment where fault occurs
x=input('enter faulted line number=');
for i=x:x
   lineweight(1,i)=0;% zero value in sparse matrix is removed from the matrix
   mylinenode=sparse(node1,node2,lineweight);% sparse matrix is constructed for the new lineweight
   newline=tril(mylinenode+mylinenode');
   mygraph=view(biograph(mylinenode,[],'ShowArrows','off','ShowWeights','on'));
   % to display the minimum spanning tree
   [ST,pred]=minspantree(mygraph)
   view(biograph(ST,[],'showarrows','off','showweights','on'));
   lineweight(1,i)=lineweightconstant(1,i);% regain original value
   Sum=0; %  sum of KVA capacity of minimum spanning tree is zero initially
   custrec=0;% number of customers reconnected after restoration
   if x==1 % fault occurs in line segment one
      % one line is removed due to fault. Fault occurred near to circuit
      % breaker
```

```
    disp(' power cannot be restored');
     disp(' no customers can be reconnected');
    % no power is restored to the system when fault occurs close to the circuit
    %  breaker. The circuit breaker trips for sustaining fault in line section
    % closer to the circuit breaker.
end
if x==2 % fault occurs in line segment two
    for k=1:50
        if k<=9 %for fault occurs in line segment L23
            sum=sum+0;
            custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
     disp('the number of customers reconnected is')
    custrec
end
if x==3% fault between node 3 and 4
    for k=1:50
        if 10<=k&&k<=15 % fault occurs in line segment L34
            sum=sum+0;
            custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
```

```
    disp('KVA capacity MST supplies is')
    sum
    disp('the number of customers reconnected is')
    custrec
end
sum=0;
if x==4% fault occurs in line segment four
    for k=1:50
        if k==16||k==17 % for fault occurring in line segment L45
            sum=sum+0;
            custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
    disp('the number of customers reconnected is')
    custrec
end
if x==5% fault occurs in line L56
    for k=1:50
        if 18<=k&&k<=20 % for fault occurs in line segment L56
            sum=sum+0;
             custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
             custrec=custrec+customers(k,1);
        end
    end
```

```
    disp('KVA capacity MST supplies is')
    sum
    disp('the number of customers reconnected is')
    custrec
end
if x==6% fault occurs in line L67(no load is supplied in this section)
    for k=1:50
        sum=sum+capacityKVA(k,1);
        custrec=custrec+customers(k,1);
    end
    disp('KVA capacity MST supplies is')
    sum
     disp('the number of customers reconnected is')
    custrec
end
if x==7% fault occurs in line L78
    for k=1:50
        if 21<=k&&k<=24 % for fault occurs in line segment L56
            sum=sum+0;
             custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
    disp('the number of customers reconnected is')
    custrec
end
if x==8
```

```
    for k=1:50
        if 25<=k&&k<=29 %  fault occurs in line segment L56
            sum=sum+0;
            custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
    disp('the number of customers reconnected is')
    custrec
end
if x==9% fault occurs in line L910
    for k=1:50
        if k==30 %  fault occurs in line segment L56
            sum=sum+0;
            custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
    disp('the number of customers reconnected is')
    custrec
end
if x==12% fault  occurs between node 2 and 13
    for k=1:50
```

```
        if 48<=k&&k<=50 % for fault occurring in line segment L2.13
            sum=sum+0;
           custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
    disp('the number of customers reconnected is')
    custrec
end
if x==14% fault between node 4 and 12
    for k=1:50
        if k==47 %  fault occurs in line segment L4.12
            sum=sum+0;
            custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
     disp('the number of customers reconnected is')
    custrec
end
if x==15% fault occurs between node 3 and 14
    for k=1:50
        if 34<=k&&k<=39 % for fault occurring in line segment L4.12
```

```
            sum=sum+0;
             custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
     disp('the number of customers reconnected is')
    custrec
end
if x==17
   for k=1:50
        if 40<=k&&k<=45% for fault occurring in line segment L4.12
            sum=sum+0;
             custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
     disp('the number of customers reconnected is')
    custrec
end
if x==19
    for k=1:50
         if k==46% fault occurs in line segment L4.12
            sum=sum+0;
```

```
            custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
     disp('the number of customers reconnected is')
    custrec
  end
  if x==21
    for k=1:50
        if 32<=k&&k<=33% fault occurs in line segment L4.12
            sum=sum+0;
             custrec=custrec+0;
        else
            sum=sum+capacityKVA(k,1);
            custrec=custrec+customers(k,1);
        end
    end
    disp('KVA capacity MST supplies is')
    sum
     disp('the number of customers reconnected is')
    custrec
  end
end
```