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INSTITUTE OF ENGINEERING  
PULCHOWK CAMPUS**

**THESIS NO:076/MSPSE/010**

**Optimal Re-Closer Placement in Power Distribution of Rural and Urban Feeder of  
Nepal Based on Reliability and Cost Benefit Analysis**

**by**

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**A THESIS  
SUBMITTED TO THE DEPARTMENT OF ELECTRICAL ENGINEERING IN  
THE PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE  
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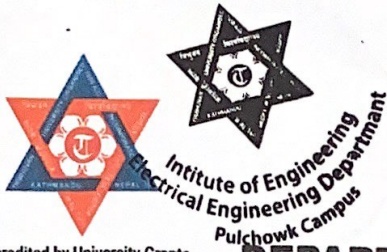
**DEPARTMENT OF ELECTRICAL ENGINEERING  
LALITPUR, NEPAL**

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### CERTIFICATE OF APPROVAL

The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a dissertation entitled “**Optimal Re-closer Placement in Power Distribution of Rural and Urban Feeder of Nepal based on Reliability and Cost benefit analysis**”, submitted by Chij Bahadur Gurung, in partial fulfillment of the requirement for the award of the degree of **Master of Science in Power System Engineering**.

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## ABSTRACT

Reliability improvement of power distribution systems is a major concern for electric utilities due to its direct impact on customer satisfaction and economic performance. In Nepal, frequent power interruptions in both rural and urban distribution feeders are primarily caused by long feeder lengths, exposure to environmental conditions, and limited automation. This thesis investigates the optimal placement of auto-reclosers in rural and urban 11 kV distribution feeders of Nepal by considering reliability enhancement and cost–benefit analysis.

Two practical feeders were selected for analysis: Feeder-4 under Birgunj Distribution Center representing an urban feeder, and Khoplang feeder under Gorkha Distribution Center representing a rural feeder. Historical outage data were analyzed to estimate failure rates and repair times. Base-case reliability indices, including SAIFI, SAIDI, CAIDI, and Expected Energy Not Supplied (EENS), were evaluated using analytical reliability modeling and ETAP simulation.

A Genetic Algorithm (GA)–based optimization framework was developed to determine the optimal number and locations of auto-reclosers with the objective of minimizing EENS and maximizing economic benefit. The results show that the optimal configuration consists of two reclosers for the 11 kV feeder-4 (urban) feeder and four reclosers for the 11 kV Khoplang (rural) feeder. The optimized placement significantly reduced reliability indices, with SAIDI and EENS reductions exceeding 55% in both feeders.

A comprehensive cost–benefit analysis was conducted using reduced energy not supplied as the economic benefit indicator. The analysis yielded benefit–cost ratios greater than 2.0 and payback periods of less than four years for both feeders, demonstrating the economic feasibility of the proposed solution. The findings confirm that optimal recloser placement is an effective and economically justified strategy for improving reliability in Nepalese rural and urban distribution systems.

**Keywords:** Auto Recloser Placement, Distribution System Reliability, Genetic Algorithm, Cost–Benefit Analysis, Expected Energy Not Supplied

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## LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
AR	Auto Recloser
AS	Automatic Switch
ASAI	Average System Availability Index
ASUI	Average System Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CB	Circuit Breaker
DA	Distribution Automation
DG	Distributed Generation
DS	Differential Search
EDS	Electrical Distribution System
EENS	Expected Energy Not Supplied
ETAP	Electrical Transient Analyzer Program
FDISR	Fault Detection, Isolation, and Service Restoration
FOI	Frequency of Interruption
GA	Genetic Algorithm
GSA	Gravitational Search Algorithm
IEEE	Institute of Electrical and Electronics Engineers
ILP	Integer Linear Programming
IT	Interruption Time
kV	kilo Volt
MCS	Monte Carlo Simulation
MINLP	Mixed Integer Non Linear Programming
MIPSO	Mixed Integer Particle Swarm Optimization
MOPSO	Multi-Objective Particle Swarm Optimization
MV	Medium Voltage
NEA	Nepal Electricity Authority
PD	Power Distribution
PEM	Point Estimation Method
PSO	Particle Swarm optimization

QEA	Quantum- inspired evolutionary algorithm
RBTS	Roy Billinton Test System
RCS	Remote Control Switch
RDS	Radial Distribution System
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SDS	Smart Distribution System

# 1 INTRODUCTION

## 1.1. Background

The electric power system is generally classified into four sections; generation system, transmission system, distribution system, and load or consumer. The distribution system is a considerable part of the electric power system because it directly takes responsibility to the consumers. The main objective of an electrical distribution system (EDS) is to provide a reliable and cost-effective supply to consumers. Therefore, it is necessary to properly plan for upgrade and reinforcement of the EDS along with increased in load and technology advancement. It was reported that 80% of all interruptions in electric power system came from failures in the distribution system [6]. Since large number of loads or consumers is in distribution side, outages in distribution system causes huge amount of financial loss might occur. The power losses in distribution systems are the major losses in electric power systems, in Nepal there is 9.76% energy loss [14]. This figure includes only technical losses.

In the whole power distribution system, the percentage and recurrence of faults in a distribution system are higher than the other parts of the system. Study shows that the weightage of average unavailability per customer per year due to interruption on 11kV distribution system is 58.8 minutes out of 96.8 minutes which is 60.7% of total faults occurred in the whole power system [16]. Most of the interruptions which occur in a power distribution system are momentary but not sustained due to poor weather conditions, thunderstorms, birds, human blunders, etc. Study showed that the component failures accounted for approximately 15% of the total number of sustained outages for the overhead distribution system. The remaining 85% of the sustained outages are caused by external reasons (75%), while 10% were caused by a lack of supply. This implies that, at the current component failure rate levels, overhead distribution system dependability is generally insensitive to component failures [20]. Hence, to minimize these momentary and sustained outages (external reasons 75%) would be eliminated by optimal placing of protective devices such as fuse save & fuse blow schemes, remote-controlled switches, sectionalizers, reclosers, etc. These interruptions occurred in the distribution system can

be reduced by the use of recloser and switch for isolating the faulted feeder section and improving the reliability. Weather conditions such as winds, lightning, icing, and so on can significantly increase the probability of outages. Due to the radial nature of many distribution systems around the world, an outage of a single component due to adverse weather conditions can cause multiple overlapping outages.

Achieving high-distribution reliability levels and concurrently minimizing capital costs can be considered as the main issues in distribution power system optimization. To improve system reliability for radial distribution systems under fault conditions, auto recloser and switch placement schemes are proposed by various algorithms such as Genetic Algorithm, Simulated Annealing, Immune Algorithm [16],

Following the end of the countrywide load shedding, the NEA has concentrated on the reliability and quality of the electricity supply. Considering the demand of consumers regarding reliability and quality of electricity supply, NEA is implementing number of projects in system expansion and reinforcement. Some of the projects are;

- Conductor up-gradation/reinforcement of distribution system
- Placement of Load break switches.
- Feeder reconfiguration
- Capacitor Bank installation.
- Underground cabling works for Distribution system.

Along with having a diverse physical location, Nepal has a different pattern of energy usage. There is no discernible change in energy demand in the hilly region, but in the tarai region (madhesh Pradesh), summertime energy demand is high and wintertime demand is low. In hilly regions, bad weather and falling trees can disrupt the distribution system, while in the tarai region, supply disruptions are primarily caused by overload.

## **1.2 Power Distribution System**

The electric power distribution system is the final stage of the electrical power network, responsible for delivering electricity from the sub-transmission system to the end

customers. It forms the link between high-voltage transmission networks and low-voltage consumers. Its primary objective is to deliver electric power safely, reliably, and efficiently to residential, commercial, agricultural, and industrial loads.

Distribution system typically operates at medium voltages such as 11 kV and 33 kV and consists of feeders, distributors, distribution transformers, and service mains. Distribution systems may be structured as radial, loop, or meshed networks depending on reliability requirements and load density. Due to their high R/X ratio, extensive exposure to environmental conditions, and numerous tapping points, distribution systems are more vulnerable to faults and interruptions than transmission systems. As a result, protection and automation devices like reclosers, sectionalizers, and SCADA play a vital role in maintaining continuity, minimizing power losses, and enhancing overall reliability.

Fig. 1.1 illustrates a typical radial DS that supplies power to rural customers, while Fig. 1.2 depicts a DS with a ring main network typically serving urban customers. These DSs are collectively referred to as utility DSs and they serve a wide variety and a large number of customers.

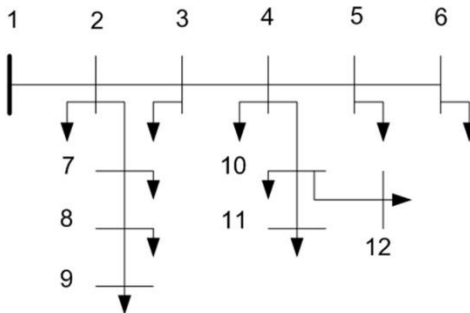


Figure 1.1 A typical radial distribution system

Typically, urban distribution feeders are relatively short, whereas rural distribution feeders are long and widely dispersed. Urban distribution feeders are often designed with the capability to transfer load from neighboring feeders in case of contingencies or maintenance on any given feeder. The selection of a DS in a particular area is influenced by technical, economic, environmental, and geographical factors, as well as the nature of customers and the types of loads to be supplied.

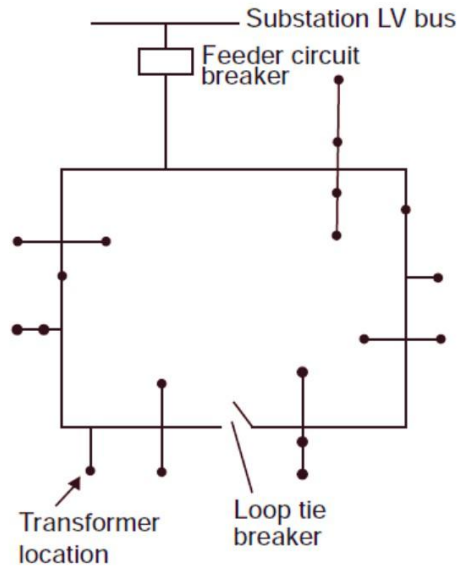


Figure 1.2 A typical urban distribution system

### 1.3 Reliability of Distribution System

The reliability of an electrical distribution system refers to its ability to supply continuous, high-quality electric power to consumers with minimal interruptions. Since distribution systems directly serve end-users, they have the highest impact on customer satisfaction and utility performance. Some terminologies used during reliability evaluation of distribution systems are:

**Availability(A):** Availability refers to the duration during which a component remains operational at any given time. It pertains to the period in which the system functions fully and effectively to fulfill its designated purpose.

$$\text{AVAILABILITY (A)} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \dots\dots\dots (1.1)$$

**Unavailability(U):** Unavailability refers to the duration during which a component is not in operational at any given time.

$$\text{UNAVAILABILITY(U)} = \frac{\lambda}{\lambda + \mu} \dots\dots\dots (1.2)$$

**Failure Rate( $\lambda$ ):** The failure rate is the expected number of failures of a component or a system per year.

$$\text{Failure rate } (\lambda) = \frac{\text{Number of outages on component in a given period}}{\text{Operating time in year (i.e.8760 hour)}} \dots\dots (1.3)$$

**Mean Time to Repair (MTTR):** MTTR is the average duration during which a component remains out of service due to faults before being restored to normal operation.

$$\text{MTTR} = \frac{\text{Total Duration of Outages}}{\text{Frequency of Outage}} \dots\dots\dots (1.4)$$

**Mean Time Between Failure (MTBF):** It represents the duration elapsed before a component, assembly, or network fails, assuming a constant failure rate. It characterizes the total operational time of the element.

$$\text{MTBF} = \frac{\text{Total System Operating Time}}{\text{Frequency of Outage}} \dots\dots\dots (1.5)$$

## 1.4 Reliability Indices

### 1.4.1 Customer Oriented Indices

#### System Average Interruption frequency index (SAIFI)

SAIFI represents the average number of interruptions experienced by each utility customer within a specified analysis period. It is computed by dividing the total number of customer interruptions by the total number of customers served by the network. Typically, SAIFI is measured over the span of a year.

$$\text{SAIFI} = \frac{\sum(\lambda_i * N_i)}{N_T} \dots\dots\dots (1.6)$$

$\lambda_i$  = Number of Interruption

$N_i$  = Total number of interrupted customers.

$N_T$  = Total number of customers supplied.

#### System Average Interruption Duration Index (SAIDI)

SAIDI represents the average duration of all interruptions experienced by each utility customer over the analysis period. It is computed by dividing the total sum of interruption durations for all customers by the total number of customers served by the network.

Typically, SAIDI is assessed annually to provide a comprehensive view of network reliability and outage impact on customers.

$$SAIDI = \frac{\sum(r_i * N_i)}{N_T} \dots\dots\dots (1.7)$$

$r_i$  = Restoration time

**Customer Average Interruption Duration Index (CAIDI)**

It is the average time needed to restore service to the average customer per sustained interruption. It gives the average duration of a customer interruption and calculated by dividing sum of all customer interruption durations with the total number of customer interruptions.

$$CAIDI = \frac{\sum(r_i * N_i)}{\sum(\lambda_i * N_i)} = \frac{SAIDI}{SAIFI} \dots\dots\dots (1.8)$$

**The Average Service Availability Index (ASAI)**

ASAI specifies the fraction of time that a customer has received the power during the predefine interval of time. ASAI is the ratio of the total number of customer hours that service was available during a given time period to the total customer hours demanded. It is normally expressed in percentage.

$$ASAI = \frac{\text{Customers Hours of Available Service}}{\text{Customers Hours Demanded}} * 100\%$$

$$ASAI = \frac{8760 - SAIDI}{8760} * 100\% \dots\dots\dots (1.9)$$

**The Average Service Unavailability Index (ASUI)**

This is the ratio of the total number of customer hours that service was unavailable during a year to the total customer hours demanded.

$$ASUI = (100 - ASAI) \% \dots\dots\dots (1.10)$$

**1.4.2 Load or Energy Oriented Indices**

**Expected Energy Not Supplied Index (EENS)**

EENS Specified the average energy that is not supplied to the customer in the predefined time.

$$EENS = P_i * U_i \dots\dots\dots (1.11)$$

$P_i$  = Average load of load point i.

$U_i$  = Outage duration at load point i.

$$ECOST = \text{Cost of EENS} = EENS * \frac{\text{Cost}}{\text{KWhr}} \dots\dots\dots (1.12)$$

### 1.5 Auto Recloser

An Auto Recloser (ACR) is a smart protection device used in distribution systems (typically 11 kV, 22 kV, 33 kV) that automatically interrupts and recloses the circuit when a fault occurs. It improves reliability by clearing temporary faults and reducing outage duration and customer interruption frequency. It is reported in distribution systems, 70–90% of faults are temporary (tree contact, lightning, animals).

#### Working Principle

- Recloser detects the fault: Senses short circuits or abnormal conditions on the line.
- It trips (opens): Opens the circuit to stop the fault current.
- Automatic Reclosing: After a short delay, it automatically closes the circuit, testing if the fault is gone.
- Sequence Control: Performs a programmed sequence of trips and recloses (e.g., 2-4 times).

If fault is cleared → power restored

If fault is still present → it attempts 2–4 reclosing cycles

- Lockout: If the fault persists after the sequence, it stays open (locks out) to prevent damage, requiring manual reset.
- Components: Includes a circuit breaker, a control unit (relay), current/voltage sensors, and batteries, often pole-mounted.

## **1.6 Problem Statement**

Power distribution systems in Nepal, particularly in rural and urban feeders, experience frequent interruptions due to faults, aging infrastructure, long feeder lengths, and limited automation. These interruptions significantly affect system reliability and result in economic losses to both utilities and consumers. Although reclosers are effective devices for improving distribution system reliability by isolating faults and reducing outage durations, their installation involves considerable investment costs. Currently, recloser placement in many Nepalese distribution feeders is often based on heuristic practices or limited technical analysis rather than systematic optimization. As a result, reclosers may not be installed at locations that yield maximum reliability improvement and economic benefit. Therefore, there is a need for a structured and optimized approach to determine the optimal placement of reclosers in rural and urban distribution feeders of Nepal by simultaneously considering reliability indices and cost–benefit analysis.

## **1.7 Research Questions**

Here are some research questions related to the above problem statement:

- How does recloser placement affect the reliability indices (SAIFI, SAIDI, CAIDI, EENS etc.) in rural vs. urban distribution feeders?
- What are the differences in optimal recloser placement strategies between rural and urban feeders due to their distinct network characteristics?
- What is the optimal number and location of reclosers in rural and urban feeders to maximize reliability while minimizing cost?
- What is the cost–benefit trade-off of installing reclosers in rural and urban feeders, considering investment cost, maintenance cost, and economic savings from reduced outages?

## 1.8 Objectives

### General Objectives: -

- To enhance the performance of power distribution system in rural feeder and urban feeder by optimal placement of reclosers considering system reliability and economic efficiency.

### Specific Objectives: -

- To analyze reliability indices (SAIFI, SAIDI, CAIDI, EENS etc.) before and after recloser placement in rural feeder and urban feeder.
- Assessment of Recloser placement in Rural feeder and Urban feeder.
- To find the optimal number of recloser and location of recloser placement, which will maximize the profit of utility and improve the reliability of distribution system.
- To carry out the cost benefit analysis of recloser placement in rural feeder and urban feeder.

## 1.9 Scope and Limitations

### Research Scope:

Optimal placement of reclosers in a power distribution system will reduce outage duration, improve system reliability and maximize profit.

**Reducing outage duration:** Optimal placement of reclosers can reduce the duration of outages by quickly identifying faulted section and isolate it. This can help to minimize the impact of power outages on consumers and reduce economic losses due to outages.

**Improve system reliability:** Auto-reclosers isolate the faulted section quickly which helps to minimize the number of consumers affected by outages.

**Maximize profit:** Auto-reclosers assist to restore the system within few seconds, if there is temporary fault due to lightning stroke, storms etc. Thus, due to continuity in supply and minimum maintenance cost utilities profit get maximized.

**Research Limitations:**

- Only one distribution feeder is considered in both rural and urban region. The reliability of upstream equipment such as high voltage substations, transmission lines, other 11 kV feeders and generators will be excluded from this study.
- This research analyzes optimal recloser placement using one rural and one urban 11 kV feeder. Due to the limited number of feeders, the findings may not fully represent all feeder types or operating conditions across different systems. The study relies on system-specific failure rates, repair times, load data, and cost parameters, which may vary in other geographical locations. The optimization model assumes radial operation, static load characteristics, and fixed recloser technology, without considering DG penetration or seasonal variations. Economic analysis is based on assumed or utility-specific cost inputs. Therefore, the results should be interpreted as case-specific insights rather than universally applicable solutions.

## 2 LITERATURE REVIEW

### 2.1 Reliability Evaluation of Distribution Systems

Distribution systems contribute the largest share of customer interruptions in power networks. Unlike generation and transmission systems, distribution networks are exposed to environmental conditions and consist of numerous components such as overhead lines, switches, transformers, and protective devices. Hence, improving distribution system reliability has become a critical objective for utilities.

Distribution system reliability has received significant attention in power system planning due to its direct impact on end consumers. Billinton and Allan provided the foundational framework for reliability assessment of power systems, introducing analytical methods and standardized reliability indices such as SAIFI, SAIDI, CAIDI, and Expected Energy Not Supplied (EENS)[1].

Their work established that radial distribution systems are particularly vulnerable to outages because a single component failure can interrupt all downstream loads. These indices provide quantitative measures of interruption frequency, duration, and energy not supplied and are widely used in both planning and operational studies.

Analytical reliability evaluation methods use component failure rates and repair times to calculate reliability indices in a deterministic manner. These methods are computationally efficient and are widely used in planning and optimization studies, especially for radial feeders. Simulation-based methods, such as Monte Carlo simulation, offer greater modeling flexibility but require higher computational effort and detailed probabilistic data[2].

Roy Billinton Test System (RBTS), particularly Bus-4, has been extensively adopted as a benchmark for evaluating distribution system reliability due to its realistic feeder structure and detailed load modeling. Several studies validate analytical and simulation-based reliability methods using RBTS Bus-4, making it suitable for comparative and optimization studies.

## **2.2 Analytical and Simulation-Based Reliability Evaluation**

Reliability assessment techniques are broadly classified into analytical methods and simulation-based methods. Analytical approaches evaluate reliability indices using failure rates and repair times combined with network topology. These methods are computationally efficient and particularly suitable for radial distribution systems, where fault impact zones are clearly identifiable.

Sailaja and Prasad applied Failure Mode and Effect Analysis (FMEA) for RBTS Bus-4 and demonstrated that analytical methods provide accurate results when validated against Monte Carlo simulation[3]. Their study confirms that analytical reliability modeling is appropriate for planning-level studies where repeated evaluations are required.

Monte Carlo simulation, while more flexible in capturing stochastic behavior, is computationally intensive and less suitable for optimization problems involving multiple decision variables, such as recloser placement.

## **2.3 Failure Rate Data of Distribution System Components**

Accurate failure rate data is essential for realistic reliability assessment. Horton et al. conducted an extensive study on overhead distribution systems using data from 85 rural and 95 urban feeders[4]. The study developed service-time failure rates for major distribution components including transformers, switches, fuses, reclosers, and conductors.

Their findings indicated that component failures contribute approximately 15% of sustained outages, while the majority of interruptions are caused by external factors such as weather and vegetation. Importantly, the study revealed that transformer failure rates differ between rural and urban feeders, whereas recloser failure rates are relatively similar. This work provides a reliable data foundation for analytical reliability modeling of both rural and urban distribution feeders.

## **2.4 Role of Auto-Reclosers in Reliability Improvement**

Auto-reclosers are widely used protective devices in distribution systems to clear temporary faults and restore supply automatically. Their installation significantly reduces interruption duration and frequency, particularly in overhead radial feeders where temporary faults are common.

Studies on optimal recloser placement highlight that improper placement may result in marginal reliability improvement while increasing investment cost. Therefore, optimal placement strategies are necessary to balance reliability enhancement and economic feasibility.

Several researchers have demonstrated that reclosers significantly reduce SAIFI, SAIDI, and EENS, especially in long radial feeders with high exposure to faults[5].

Thepmahavong et al. investigated optimal auto-recloser placement in a practical distribution system in Laos using Monte Carlo simulation[6]. Their study demonstrated notable reductions in SAIFI, SAIDI, and ENS following recloser installation and highlighted that optimal recloser locations are generally near the feeder midpoint. The study also emphasized the importance of combining reliability improvement with economic evaluation.

Early work by Ennis et al. demonstrated that overhead distribution systems experience a high proportion of transient faults and that pole-mounted auto-reclosers significantly improve continuity of supply by reclosing after temporary disturbances [7]. Their study highlighted the evolution of auto-recloser technology and emphasized its importance in rural and overhead distribution systems.

Wang et al. analyzed operational data from pole-mounted auto-reclosers to study nuisance tripping and pre-fault characteristics [8]. Their findings showed that recloser event records can be used to identify deteriorating feeder conditions and prevent permanent faults, thereby enhancing system reliability.

The effectiveness of auto-reclosers strongly depends on their location within the feeder. Improper placement may lead to limited reliability improvement or coordination problems. Kim et al. investigated recloser–fuse coordination in distribution systems and showed that improper coordination could result in unnecessary recloser lockouts and increased customer interruptions[9]. Their work emphasized the need for systematic planning of recloser locations.

Zeinalzadeh et al. proposed an optimization-based approach for determining optimal recloser placement using reliability indices as objective functions [10]. Their results demonstrated that strategic placement of a limited number of reclosers can significantly reduce SAIFI and SAIDI compared to conventional placement practices.

A practical application was presented in the Sabah Electricity Distribution Network, where optimized recloser placement based on feeder fault data showed substantial reliability improvement compared to heuristic approaches [11].

## **2.5 Optimization Techniques for Recloser and Switch Placement**

Optimization techniques have been widely applied to determine the optimal placement of reclosers, sectionalizing switches, and circuit breakers. Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and other metaheuristic methods are commonly used due to their ability to handle non-linear, multi-objective problems.

Optimal placement of protective devices is a complex combinatorial optimization problem. Moradi and Fotuhi-Firuzabad applied Particle Swarm Optimization (PSO) to determine the optimal number and locations of sectionalizing switches and circuit breakers in radial distribution systems[12]. Their work demonstrated that heuristic optimization techniques outperform traditional trial-and-error methods, particularly for large-scale systems.

Genetic Algorithm (GA)–based approaches have also been widely adopted due to their robustness in handling discrete decision variables. Alam et al. proposed a GA-based framework for optimal recloser placement in radial distribution systems, showing

significant improvements in customer-oriented reliability indices[13]. Their work further extended the formulation to handle bidirectional power flow caused by distributed generation.

Amanulla et al. proposed a probabilistic reliability-based optimization framework using Binary Particle Swarm Optimization (BPSO) to enhance reliability while minimizing power loss.[14]. Their work demonstrated that analytical reliability models can be effectively integrated into optimization algorithms without excessive computational burden.

Ziari et al. employed a modified discrete Particle Swarm Optimization technique to solve a comprehensive distribution reinforcement problem considering reliability, line loss, and investment cost [15]. Their work demonstrated that heuristic optimization methods are effective for large-scale distribution planning problems.

Reliability performance of distribution networks is commonly assessed using standard indices defined in IEEE Std. 1366. The most frequently used indices include System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI) [16].

In addition to conventional indices, Sonal et al. introduced advanced performance indicators such as Relative Network Reconstruction Efficiency (RNRE) and Average Recloser Application Efficiency (ARAE). RNRE quantifies the percentage improvement in reliability after recloser installation, while ARAE evaluates the investment efficiency required to achieve a unit improvement in reliability [16]. Furthermore, Energy Not Served (ENS) was used to link reliability performance with economic evaluation.

Similarly, several IEEE studies on optimal switch and recloser placement emphasize minimizing EENS as a primary objective, since it directly reflects both reliability and economic impact.

## **2.6 Reliability and Cost–Benefit Analysis of Recloser Placement**

While reliability improvement is technically desirable, utilities must justify investments through economic evaluation. Cost–benefit analysis (CBA) compares the capital and operational costs of protective devices against the monetary value of reliability improvement, typically quantified using reduced EENS.

Reliability improvement measures must be economically justified to ensure practical applicability. Goel and Billinton introduced the concept of reliability worth, linking Expected Energy Not Supplied (EENS) with customer interruption costs[17]. This approach allows utilities to quantify the monetary benefits of reliability enhancement.

Recent studies emphasize integrating reliability indices with cost–benefit analysis. Dhole et al. performed a comprehensive cost–benefit analysis of auto-recloser placement considering investment cost, outage cost, and system reliability[18].

Their results demonstrated that optimal recloser placement yields favorable benefit–cost ratios and acceptable payback periods for both radial and meshed networks.

Research has shown that optimal recloser placement often results in Benefit–Cost Ratios (BCR) greater than 1, indicating economic feasibility even in rural feeders with low load density[19].

However, rural and urban feeders exhibit different characteristics: rural feeders are longer with lower load density and higher fault exposure, whereas urban feeders are compact with higher customer density.

Therefore, comparative reliability and cost–benefit analysis between rural and urban feeders is essential for informed planning decisions.

## **2.7 Research Gap and Motivation**

From the reviewed literature, the following gaps are identified:

- Most studies are based on test systems, with limited application to real distribution feeders.
- No comparative analysis of rural and urban feeders.
- Economic evaluation is often treated separately from reliability analysis.
- Limited studies address Nepalese distribution system characteristics, such as long rural feeders and high outage frequency.

Motivated by these gaps, this research focuses on the optimal placement of auto-reclosers in real urban and rural distribution feeders of Nepal, using analytical reliability modeling and Genetic Algorithm optimization. The study integrates reliability indices and cost–benefit analysis.

## **3 PROPOSED METHDOLOGY**

### **3.1 Introduction**

This chapter presents the methodology adopted to determine the optimal placement of auto-reclosers in rural and urban distribution systems based on reliability improvement and cost–benefit analysis. The proposed methodology integrates distribution system modeling, reliability assessment, genetic algorithm–based optimization and economic evaluation to identify technically and economically optimal recloser locations.

Two 11kV feeders; Namely Feeder-4, under Birgunj DC as an urban feeder and Khoplang feeder, under Gorkha Distribution Center, as a rural feeder are selected for study purpose.

The figure below shows the generalized methodology.

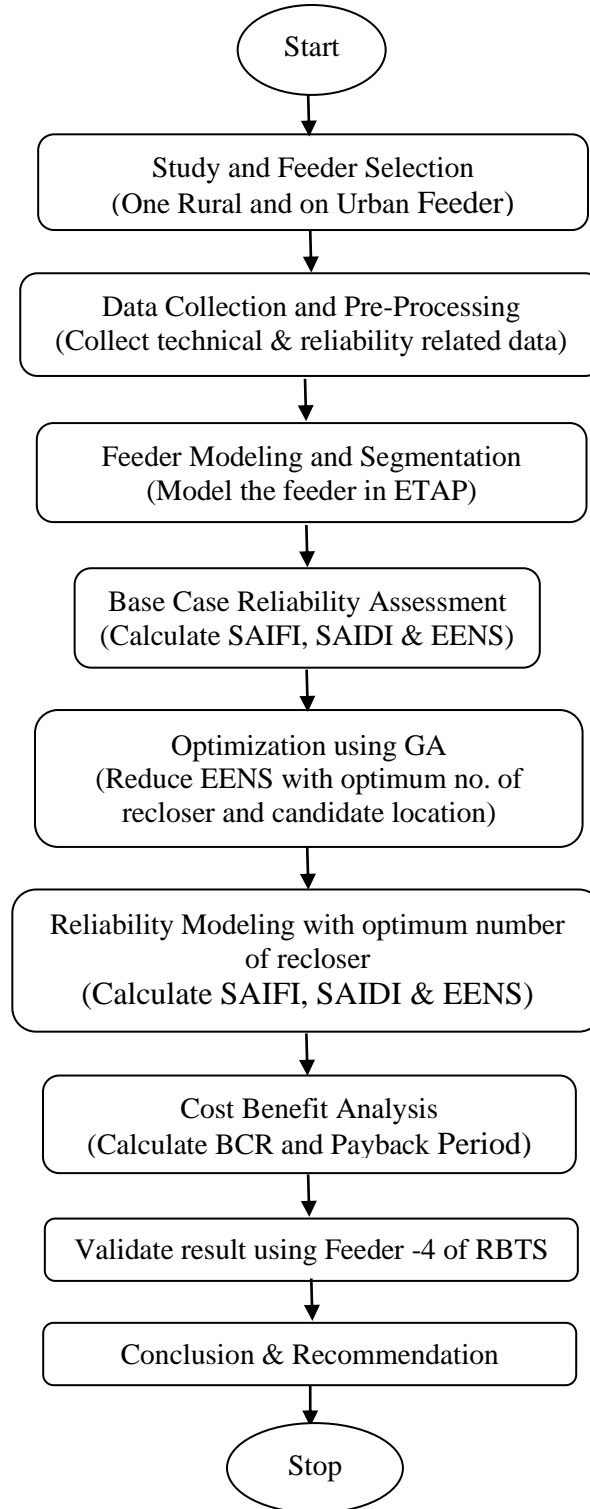


Figure 2.1 Flowchart for research Methodology

## **3.2 Research Framework**

The methodology consists of four major stages:

- system modeling
- reliability evaluation
- optimization using genetic algorithm
- cost–benefit analysis.

### **3.2.1 Distribution System Modeling**

Distribution system modeling is the process of representing the physical, electrical, and operational characteristics of a power distribution network in a computational environment. In this study, distribution system modeling is carried out to enable reliability assessment, auto-recloser placement, and economic evaluation of rural and urban distribution feeders. An accurate system model is essential to correctly identify load points affected by faults and to evaluate the impact of protection devices on system reliability.

#### **3.2.1.1 Modeling Assumptions**

To simplify analysis and ensure consistency, the following assumptions are made:

- The feeder structure remains radial throughout the study.
- Failure rates are assumed constant.
- Repair time follows an exponential distribution.
- Loads are taken as lumped load and considered constant during outages.
- Reclosers operate with 100% success probability.
- Only corresponding feeder’s tripping data are considered, tripping of other feeders, higher system and scheduled outages has been neglected.
- The useful life of the Reclosers is assumed as 15 years.
- Population size and generation for GA are taken as 100 and 200 respectively.

These assumptions are commonly adopted in distribution system reliability studies and do not significantly affect comparative results.

### **3.2.1.2 System Description**

The distribution systems considered in this study consist of radial 11 kV feeders, representing typical rural and urban distribution networks. In addition, Feeder-4 of the standard RBTS Bus-4 system is used as a benchmark test system for validation purposes.

Each feeder is modeled with the following components:

- Source substation (sending end)
- Main feeder sections
- Lateral branches
- Distribution transformers
- Load points
- Protective devices (auto-reclosers, fuses)

The radial structure is maintained throughout the analysis to reflect actual operating conditions of distribution systems.

### **3.2.1.3 Network Topology and Bus–Branch Representation**

The feeder topology is modeled using a bus–branch representation, where:

- Buses represent connection points, load points, or junctions
- Branches represent feeder sections or laterals connecting two buses

Each branch is uniquely numbered and arranged sequentially from the source to the end of the feeder. This ordering is essential for identifying upstream and downstream relationships, which directly influence reliability calculations and auto-recloser placement.

### **3.2.1.4 Electrical and Reliability Parameters**

Each feeder section is assigned electrical and reliability parameters based on standard data or utility records. These include:

- Line length (km)

- Failure rate ( $\lambda$ , failures/year/km)
- Repair time (r, hours)
- Load demand (kW or kVA)
- Number of customers at each load point

These parameters form the basis for calculating reliability indices such as SAIFI, SAIDI, and Expected Energy Not Supplied (EENS).

### **3.2.1.5 Load Modeling**

Loads are modeled as constant power loads located at designated buses. Each load point represents an aggregation of customers supplied through a distribution transformer. Load data include:

- Connected load
- Average demand
- Customer count

Load modeling is critical for evaluating the impact of outages and calculating ENS and outage cost during reliability analysis.

### **3.2.1.6 Protection Device Modeling**

Auto-reclosers are modeled as protective devices installed on selected feeder sections. The recloser model includes:

- Fast and slow tripping characteristics
- Number of reclosing attempts
- Dead time between reclosing operations
- Lockout behavior for permanent faults

Although temporary and permanent faults are not explicitly labeled, their effects are incorporated through reclosing logic and analytical fault classification.

### **3.2.1.7 Modeling Tools and Data Sources**

The distribution system is modeled using ETAP for feeder representation and protection coordination, while MATLAB is used for reliability calculations and GA-based optimization.

### **3.2.2 Reliability Evaluation of Distribution System**

Reliability evaluation is performed to quantify the ability of a distribution system to supply electric power to customers without interruption. In this study, reliability evaluation is carried out to assess the impact of auto-recloser installation on system performance and to provide quantitative inputs for optimization and cost–benefit analysis. Reliability indices are evaluated for the base case and after optimal recloser placement to measure improvement.

#### **Reliability Modeling Approach**

The distribution system is modeled as a radial network, where outages propagate downstream from the faulted component. Reliability evaluation is conducted using an analytical approach, based on component failure rates and repair times. This method is suitable for radial distribution systems and provides accurate estimation of system-level and customer-oriented reliability indices.

#### **Impact of Auto-Reclosers on Reliability**

The presence of auto-reclosers alters reliability by:

- Reducing sustained interruptions due to temporary faults
- Isolating faulty feeder sections
- Limiting the number of affected downstream load points

For load points downstream of a recloser, the effective failure rate and outage duration are reduced, leading to improved reliability indices.

### 3.2.3 Optimization using Genetic Algorithm

The objective of optimization in this study is to determine the optimal locations of auto-reclosers in a radial distribution system such that system reliability is improved and overall economic benefit is maximized. Due to the discrete nature of recloser locations and the non-linear relationship between reliability indices and outage costs, conventional optimization techniques are not suitable. Therefore, a Genetic Algorithm (GA) is employed to solve the optimization problem efficiently.

#### 3.2.3.1 Overview of Genetic Algorithm

Genetic Algorithm is a population-based metaheuristic optimization technique inspired by the principles of natural evolution. GA operates on a population of candidate solutions and iteratively improves them through genetic operators such as selection, crossover, and mutation. GA is particularly effective for combinatorial and non-convex optimization problems, making it well suited for optimal recloser placement in distribution systems.

#### 3.2.3.2 Optimization Problem Formulation

##### Decision Variables

The decision variables represent the locations of auto-reclosers on feeder sections. Each decision variable is discrete and selected from a predefined set of candidate locations.

$$X=[x_1,x_2,\dots,x_k] \quad (3.1)$$

where  $x_i$  denotes the feeder section where the  $i^{\text{th}}$  auto-recloser is installed.

##### Objective Function

The optimization objective is formulated to incorporate both reliability improvement and economic feasibility. The objective function is defined as:

$$\begin{aligned} \text{Maximize profit (f)} &= (R_E) - (C_R + T_{MC}) & (3.2) \\ &= \text{Revenue} - \text{Expenditure} \end{aligned}$$

$$= (\text{Saving due to reduction in ENS}) - (\text{Investment cost} + \text{Maintenance cost})$$

Where;

$R_E$  is the net present worth of revenue earned over the life time of recloser.

$C_R$  is Capital investment of recloser and Installation cost

$T_{MC}$  is the net present worth of maintenance cost over the life time of recloser.

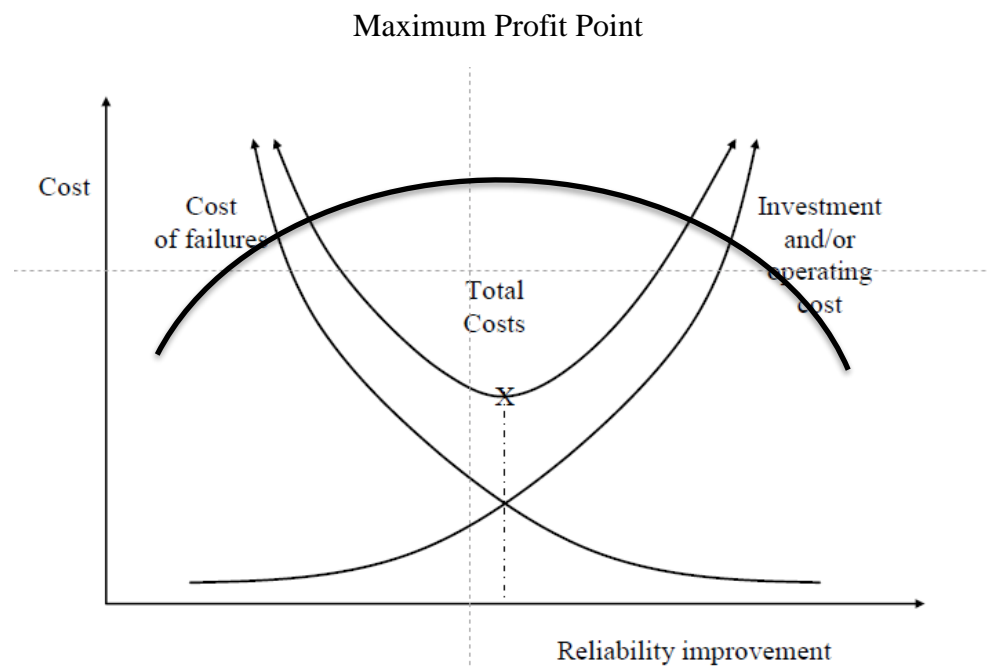


Figure 3.2 Reliability Cost/profit worth Graph

### Constraints

The optimization problem is subject to the following constraints:

1. Radial network constraint: The feeder must remain radial.
2. Installation constraint: Auto-reclosers can only be installed at predefined candidate locations.
3. Quantity constraint: The maximum number of auto-reclosers is limited.

4. Coordination constraint: Protection coordination with downstream devices must be maintained.

### **3.2.3.3 Chromosome Representation**

In GA, each candidate solution is represented as a chromosome. A chromosome consists of multiple genes, where each gene corresponds to a recloser location.

Example representation:

Chromosome=[10,18,27]

This chromosome indicates that auto-reclosers are installed on feeder sections 10, 18, and 27.

### **3.2.3.4 Initialization of Population**

The initial population is generated randomly while satisfying all problem constraints. Each chromosome represents a feasible recloser placement configuration. Random initialization ensures diversity in the solution space and improves the likelihood of obtaining a global optimum.

### **3.2.3.5 Fitness Evaluation**

The fitness of each chromosome is evaluated using the objective function. For each candidate solution:

1. Reliability indices (SAIFI, SAIDI, EENS) are computed.
2. Outage cost reduction is calculated using the Value of Lost Load (VOLL).
3. Recloser costs are incorporated.
4. The net benefit or total cost is used as the fitness value.

Chromosomes with better reliability improvement and higher economic benefit receive higher fitness values.

### **3.2.3.6 Crossover and Mutation**

- Crossover is applied to exchange genetic material between parent chromosomes, generating new offspring solutions. Single-point or uniform crossover is used.
- Mutation introduces random changes to chromosome genes with a low probability, maintaining population diversity and preventing premature convergence.

### **3.2.3.7 Termination Criteria**

The GA process is terminated when one of the following conditions is met:

- The maximum number of generations is reached.
- The improvement in fitness value between successive generations becomes negligible.

The best chromosome obtained at termination represents the optimal recloser placement solution.

The figure given below describes the optimization of recloser placement using Genetic Algorithm (GA).

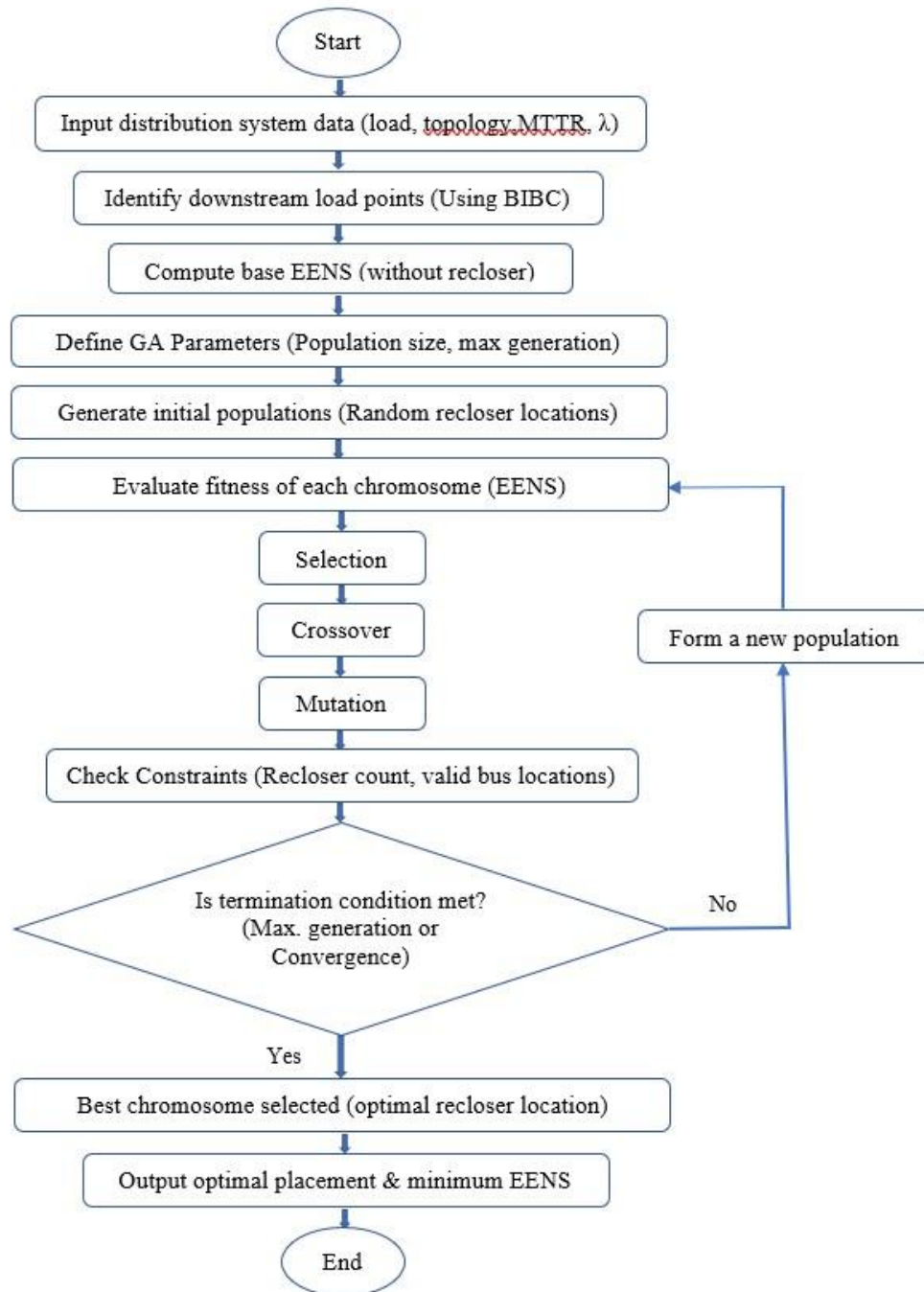


Figure 3.3 Flowchart for Optimum recloser placement using GA

### **3.2.4 Cost-Benefit Analysis**

Cost–benefit analysis (CBA) is conducted to evaluate the economic feasibility of installing auto-reclosers in distribution systems by comparing the economic benefits obtained from reliability improvement with the associated investment and operating costs. In this study, CBA is used to support decision-making for optimal recloser placement and to quantify the economic impact of reliability enhancement in rural and urban feeders.

#### **3.2.4.1 Basis of Cost–Benefit Analysis**

The cost–benefit analysis in this study follows the principles of economic analysis, where benefits are measured in terms of reduction in customer interruption costs rather than direct financial profit to the utility. The analysis considers the long-term expected performance of the distribution system.

#### **Benefit Assessment**

The primary benefit of installing auto-reclosers is the reduction in outage duration and frequency, leading to a decrease in Expected Energy Not Supplied (EENS). The annual economic benefit is calculated as:

$$\text{Economic Benefit} = \Delta\text{EENS} \times \text{VOLL}$$

Where;

- $\Delta\text{EENS}$  = Reduction in expected energy not supplied (kWh/year)
- $\text{VOLL}$  = Value of Lost Load (currency/kWh)

The Value of Lost Load represents the monetary value associated with unsupplied energy and reflects customer inconvenience, loss of productivity, and social impact caused by power interruptions.

## **Cost Assessment**

The cost component of the analysis includes all expenditures related to auto-recloser installation and operation. The total annual cost is calculated as:

- Capital cost of auto-recloser
- Installation cost
- Operation and maintenance (O&M) cost

The capital cost is annualized over the service life of the device using an appropriate discount rate. The total annual cost is expressed as:

$$C_{\text{recloser}} = C_{\text{capital}} + R_{\text{installation}} + C_{\text{O\&M}}$$

## **Net Economic Benefit**

The net economic benefit is determined by subtracting the annualized recloser cost from the economic benefit:

$$\text{Net Benefit} = \text{Economic Benefit} - C_{\text{recloser}}$$

A positive net benefit indicates that the installation of auto-reclosers is economically justified and beneficial from a system and societal perspective.

## **Comparative Analysis of Rural and Urban Feeders**

Cost-benefit analysis is performed separately for rural and urban feeders to account for differences in:

- Load density
- Failure rates
- Repair times
- Value of Lost Load

This comparison highlights the varying economic effectiveness of auto-recloser installation in different distribution environments.

### **Assumptions and Limitations**

The following assumptions are adopted in the cost–benefit analysis:

1. VOLL is constant for a given feeder type.
2. Load demand remains unchanged during the study period.
3. Recloser performance is ideal and consistent.
4. Inflation and tariff variations are neglected.

These assumptions are standard in distribution system economic studies and do not significantly affect comparative results.

## **4. RESULT AND DISCUSSION**

### **4.1 Introduction**

This chapter presents and discusses the results obtained from the implementation of the proposed methodology for optimal recloser placement in rural and urban power distribution feeders of Nepal. The results are derived from reliability assessment, genetic algorithm-based optimization, and cost-benefit analysis carried out on selected real distribution feeders. The performance of the system is evaluated using standard reliability indices, including SAIFI, SAIDI and Expected Energy Not Supplied (EENS).

Initially, the base-case reliability performance of the selected feeders is analyzed without the installation of reclosers to establish a reference for comparison. Subsequently, the optimal locations and number of reclosers are determined using the proposed optimization approach (GA), and the resulting improvements in reliability and economic performance are evaluated. A comparative analysis between rural and urban feeders is also presented to highlight the impact of feeder characteristics on reliability improvement and investment justification.

### **4.2 Geographic Overview from GIS Mapping**

Birgunj is a metropolitan city in Parsa District of Madhes Pradesh in southern Nepal. Birgunj is one of the largest cities in Nepal and the largest in Madhesh Province. almost all of the land in birgunj are flat terrain and densely populated with fewer coverage of forest.

Feeder-4 under Birgunj DC is one of the 11 kV urban feeder from 66/11 kV, 48 MVA Birgunj Substation. This feeder cover about 28 km of distribution area. The GIS mapping of the feeder is shown figure 4.1.

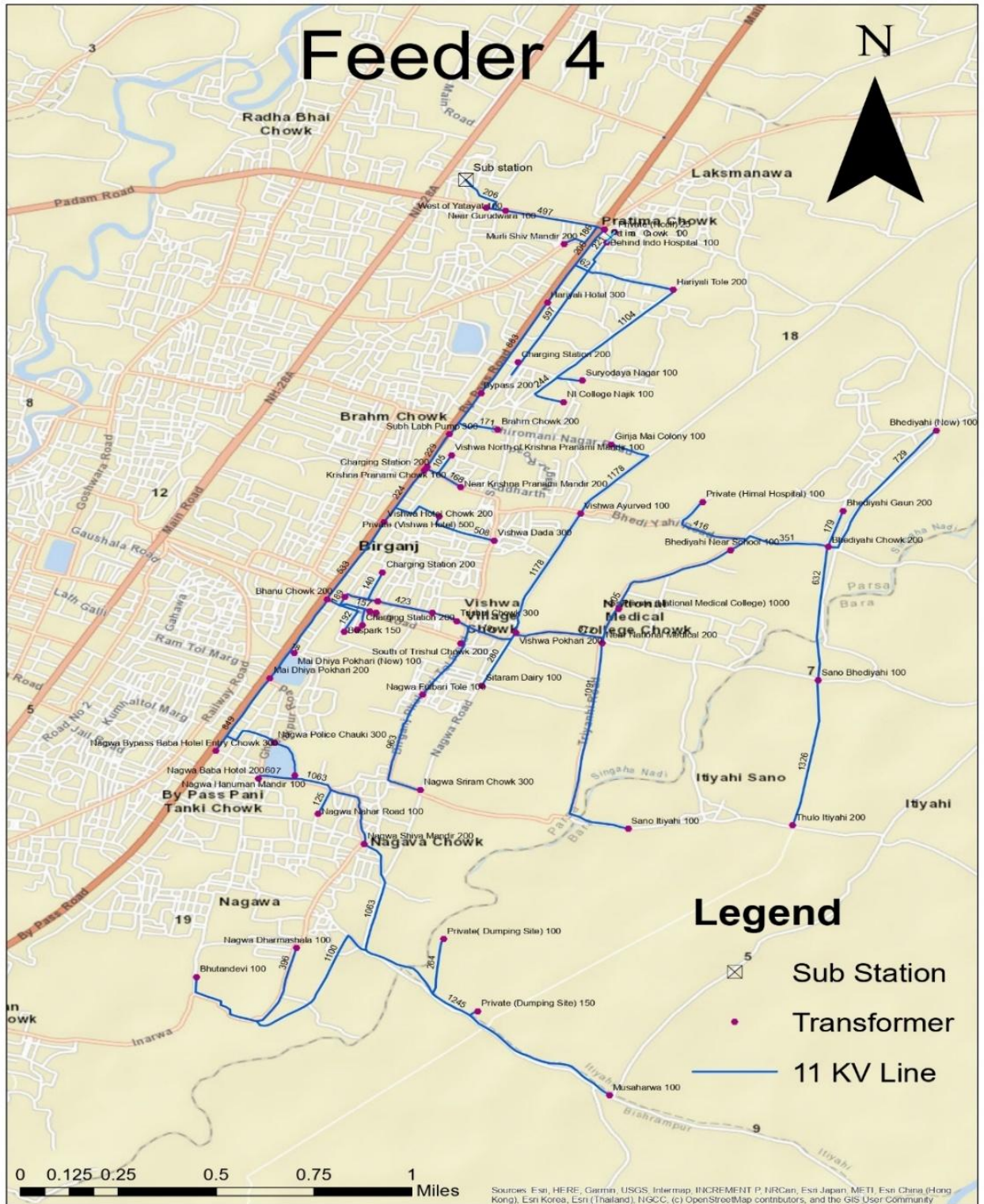


Figure 4.1 GIS Mapping of 11 kV Feeder-4 of Birgunj Substation, Parsa

Gorkha district is a part of Gandaki Province located in northern Nepal. Gorkha is fourth largest district of the country with most of the area cover by hill and mountains. This is sparsely populated district with most of forest area.

Khoplang feeder Under Gorkha DC is one of the rural feeder form 33/11 kV, 8 MVA Gorkha Substation. This feeder distributed in about 114 km distance. The GIS Mapping of the feeder is shown below;

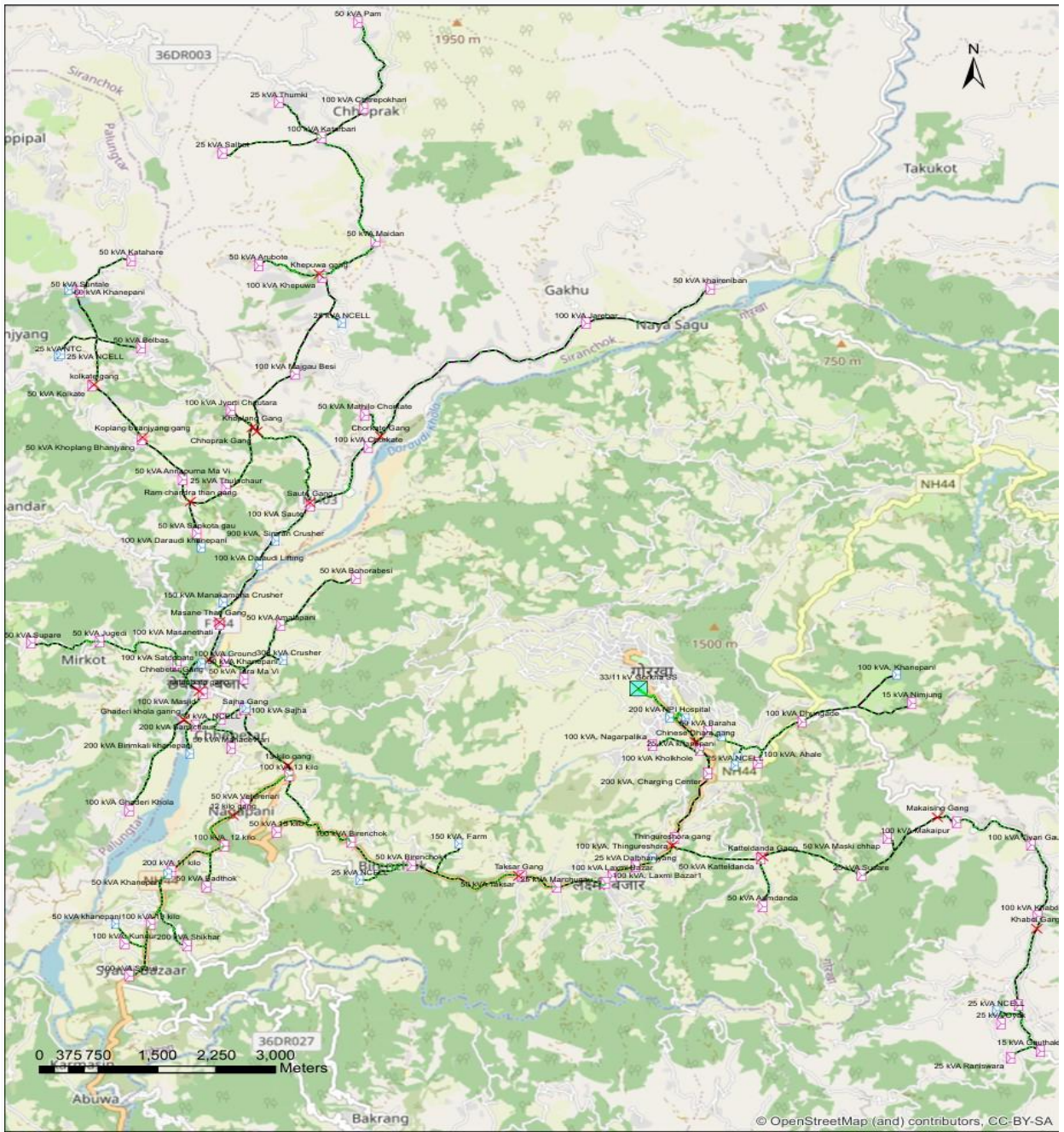


Figure 4.2 GIS Mapping of 11 kV Khoplang feeder under Gorkha Substation, Gorkha

### 4.3 Tripping data Analysis

Three years' tripping data of the feeders are taken from log book of respective substation. Both momentary and sustained tripping are considered. The tripping frequency and the duration of urban and rural feeders are presented in graphical form.

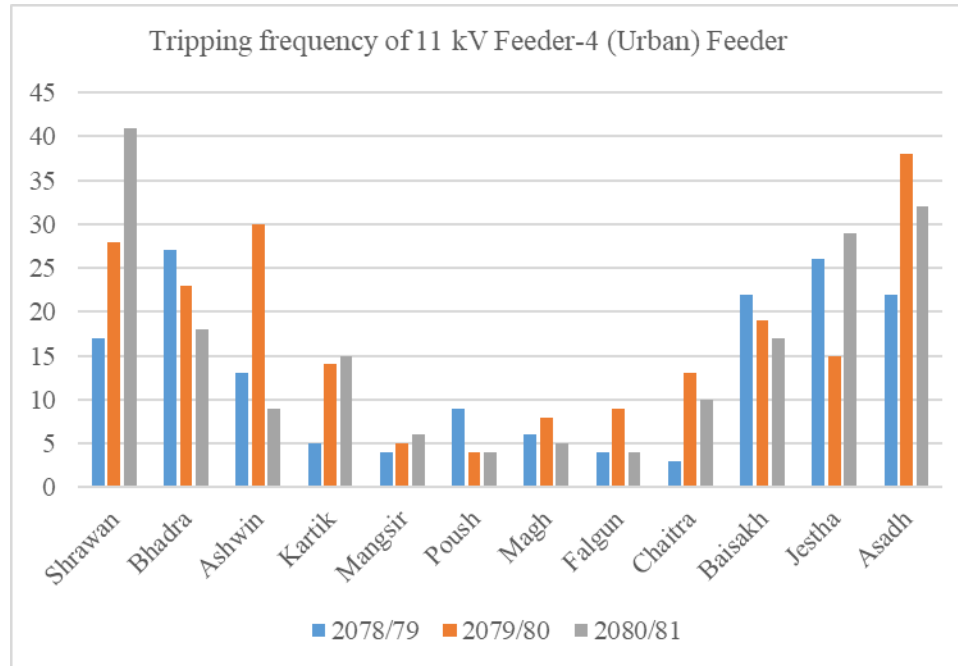


Figure 4.3 Three years' tripping frequency of 11 kV feeder-4 (Urban feeder)

Figure 4.3 illustrates the monthly tripping frequency of the 11 kV Feeder-4 (Urban Feeder) for three consecutive fiscal years: 2078/79, 2079/80, and 2080/81.

From the figure, it is evident that the tripping frequency varies significantly across months and years, indicating both seasonal influence and year-to-year variation in feeder performance. In all three years, higher tripping frequencies are observed during the monsoon and early summer months, particularly Shrawan, Bhadra, Asadh, and Jestha. For instance, in 2080/81, the tripping frequency peaks in Shrawan and Asadh, suggesting a strong impact of adverse weather conditions such as heavy rainfall, moisture ingress, vegetation contact, and lightning on the urban distribution system.

Conversely, the lowest tripping frequencies occur during the winter months, especially Mangsir, Poush, Magh, and Falgun, across all three years. This reduction can be attributed to stable weather conditions, lower load fluctuations, and minimal environmental disturbances, resulting in improved feeder reliability during this period.

A comparative analysis among the three years shows that 2079/80 and 2080/81 generally experience higher tripping incidents than 2078/79, particularly during peak months. This trend may indicate increasing load demand, aging infrastructure, or insufficient preventive maintenance in recent years.

Overall, the figure highlights that the reliability of the 11 kV Urban Feeder-4 is strongly season-dependent, with monsoon and summer months posing the highest risk of outages. These findings emphasize the need for use of proper protective devices, targeted maintenance activities, vegetation management, and system upgrades before high-risk seasons to reduce tripping frequency and enhance supply reliability.

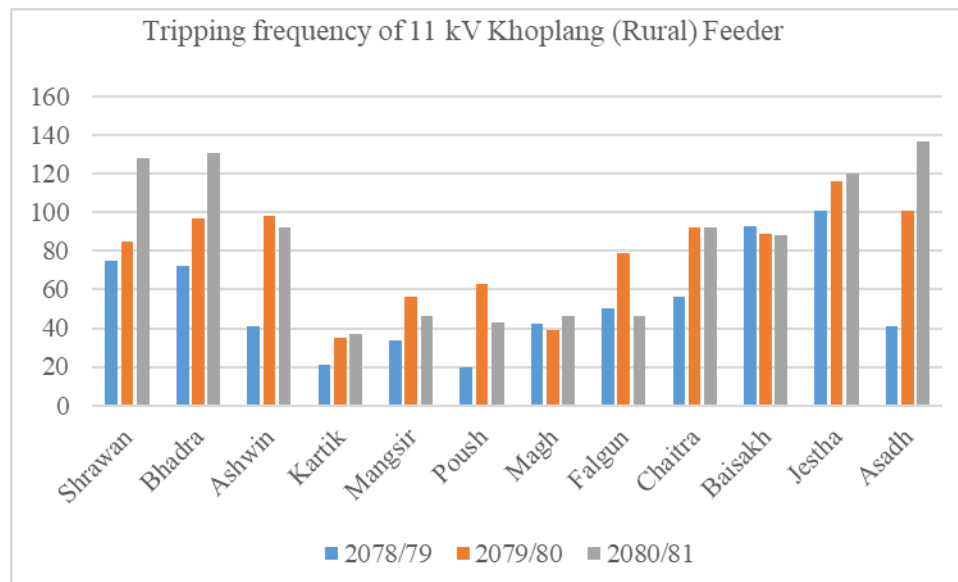


Figure 4.4 Three years' tripping frequency of 11 kV Khoplang (Rural) feeder

Figure 4.4 presents the monthly tripping frequency of the 11 kV Khoplang (rural) feeder for three fiscal years: 2078/79, 2079/80, and 2080/81. The figure clearly demonstrates substantial seasonal variation as well as higher overall tripping levels compared to urban feeders, which is characteristic of rural distribution systems.

The highest tripping frequencies are observed during the monsoon and pre-monsoon months, particularly Shrawan, Bhadra, Jestha, and Asadh, across all three years. In 2080/81, the feeder experienced extreme tripping levels, with peaks exceeding 130–140 incidents in Bhadra and Asadh. This sharp increase can be attributed to heavy rainfall, strong winds, lightning, vegetation encroachment, longer line lengths, and limited protection coordination, which are common challenges in rural networks.

In contrast, the winter months (Kartik to Magh) show relatively lower tripping frequencies, although the values remain significantly higher than those observed in the urban feeder. This indicates that, even during favorable weather conditions, the rural feeder is more vulnerable due to exposed overhead lines, difficult terrain, and limited maintenance access.

A year-wise comparison reveals a progressive increase in tripping frequency from 2078/79 to 2080/81, with 2080/81 recording the highest number of trips in almost all months. This trend suggests increasing system stress, possibly due to aging infrastructure, expansion of rural electrification, and insufficient preventive maintenance.

Overall, the figure highlights that the 11 kV Khoplang (rural) feeder exhibits high susceptibility to seasonal and environmental factors, resulting in frequent interruptions and reduced supply reliability. The findings emphasize the necessity for enhanced vegetation management, strengthening of line structures, improved protection systems, and periodic maintenance planning, especially before the monsoon season, to improve the reliability of rural power distribution.

#### **4.4 Basic Reliability Indices Calculation of Feeders**

Table 4.2 presents the calculated basic reliability parameters of the 11 kV Khoplang rural feeder over three consecutive years (2078/79–2080/81). The analysis is based on recorded outage data and is used to estimate key reliability parameters required for further reliability assessment and optimization studies.

Table 4.1 Basic Reliability parameter calculation of 11 kV Khoplang (Rural) feeder

Year	Total Hours in a year (H)	FOI (No. of Failure (NF))	IT (Outage) hrs	Failure Rate ( $\lambda_a=NF/H$ )	MTTR (D=IT/NF)
2078/79	8760	646	74.30	0.07	0.12
2079/80	8760	950	115.77	0.11	0.12
2080/81	8760	1006	93.55	0.11	0.09
<b>Average</b>		<b>867.33</b>	<b>94.54</b>	<b>0.10</b>	<b>0.11</b>

The feeder experienced 646 failures in 2078/79, which increased to 950 in 2079/80 and further to 1006 in 2080/81. This increasing trend suggests growing stress on the rural network, possibly due to aging infrastructure, extended feeder length, and increased exposure to environmental conditions.

The Interruption Time (IT) increased from 74.30 hours in 2078/79 to 115.77 hours in 2079/80, followed by a reduction to 93.55 hours in 2080/81. The reduction in outage duration in the final year, despite a higher number of failures, indicates improved fault clearing or restoration practices, such as quicker repair or switching operations.

The Failure Rate ( $\lambda_a$ ), varies from 0.07 failures/hour in 2078/79 to 0.11 failures/hour in the subsequent two years, with an average value of 0.10 failures/hour. This relatively high failure rate reflects the vulnerability of rural feeders to frequent interruptions.

The Mean Time to Repair (MTTR), remains relatively consistent across the study period, with values ranging from 0.09 to 0.12 hours and an average of 0.11 hours. This indicates that although the feeder experiences frequent failures, the restoration time per outage is relatively short, likely due to the predominance of temporary faults.

The average values of failure rate and MTTR obtained from this analysis are used as representative reliability parameters for the Khoplang feeder in subsequent reliability analysis.

Similarly, the table 4.3 presents the basic reliability parameters calculated for the 11 kV Feeder-4 (urban) over three consecutive years (2078/79–2080/81).

Table 4.2 Basic Reliability parameter calculation of 11 kV Feeder-4 (Urban) Feeder

Year	Total Hours in a year (H)	FOI (No. of Failure (NF))	IT (Outage) hrs	Failure Rate ( $\lambda_a=NF/H$ )	MTTR ( $D=IT/NF$ )
2078/79	8760	158	16.32	0.02	0.10
2079/80	8760	206	15.05	0.02	0.07
2080/81	8760	216	17.72	0.02	0.08
<b>Average</b>		<b>193.33</b>	<b>16.36</b>	<b>0.02</b>	<b>0.09</b>

The feeder experienced 158 failures in 2078/79, which increased moderately to 206 and 216 failures in the subsequent years. Despite this increase, the failure frequency is significantly lower than that observed in the rural feeder, reflecting the more compact structure and better protection coverage of the urban distribution network.

The Interruption Time (IT) values remain relatively consistent, ranging from 15.05 to 17.72 hours across the three years, with an average of 16.36 hours. This consistency suggests effective fault management and faster restoration practices in the urban feeder, likely supported by better accessibility, shorter line sections, and higher operational priority.

The Failure Rate ( $\lambda_a$ ), remains constant at approximately 0.02 failures per hour for all years. This low and stable failure rate highlights the higher reliability of the urban feeder compared to the rural feeder.

The Mean Time to Repair (MTTR), varies between 0.07 and 0.10 hours, with an average value of 0.09 hours. The relatively low MTTR indicates that outages in the urban feeder are restored quickly, which can be attributed to improved infrastructure, better maintenance practices, and ease of fault localization.

The average values of failure rate and MTTR obtained from this table are used as representative reliability parameters for the urban feeder in subsequent reliability analysis.

#### 4.5 Modeling of Feeder in ETAP and Base case reliability analysis

The base case ETAP modeling of the 11 kV urban feeder and rural feeder is carried out to establish the existing operating and reliability condition of the system before the

installation of additional auto-reclosers. This base case serves as a reference scenario against which the impacts of optimal recloser placement are evaluated.

Both feeders are modeled in ETAP using actual feeder data, including line lengths, transformer ratings, connected loads, and the number of consumers supplied by each section. The feeder is represented as a radial distribution network, consistent with its normal operating configuration, with the supply originating from the substation bus and extending downstream to various load points. Existing protective devices, such as circuit breakers are modeled at their actual locations to reflect the current protection scheme.

Load data are assigned to the corresponding buses based on connected load information and aggregated consumer data. The load model assumes steady-state operation under normal conditions, and the total connected load of the feeder is matched with field data to ensure model accuracy. Line and transformer parameters are utility records to closely represent real system characteristics.

For reliability assessment, the base case ETAP model incorporates the calculated reliability parameters, including failure rates and mean time to repair (MTTR), derived from historical outage data of the feeders. These parameters are assigned to the respective feeder sections and components. Using ETAP's reliability assessment module, key reliability indices such as SAIFI, SAIDI, CAIDI, and Expected Energy Not Supplied (EENS) are evaluated for the base case scenario.

### 4.5.1 Base case of Feeder-4 (Urban)

Using the calculated parameters, the base case ETAP modeling of feeder-4 is shown below;

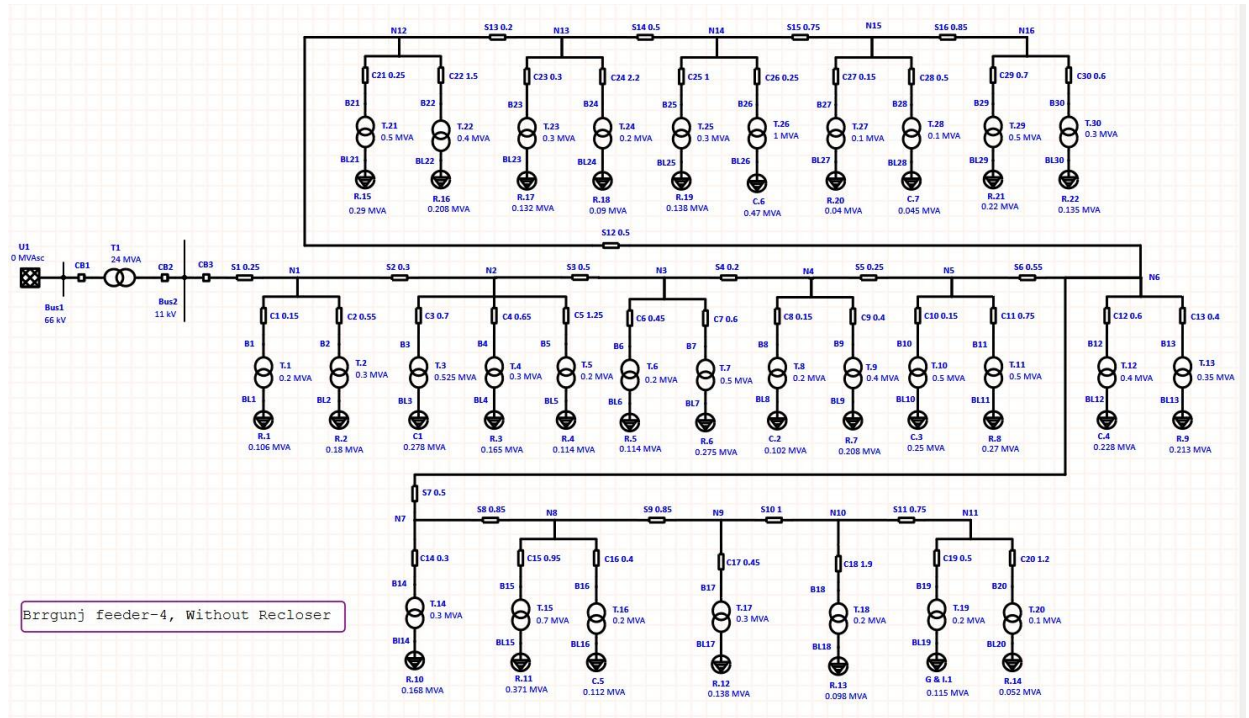


Figure 4.5 ETAP Model of Feeder-4 (Urban) Feeder (Base Case)

The base case reliability indices of feeder-4 (Urban), obtained from above model are:

SAIDI	12.6748 hr./customer yr
SAIFI	2.5977 freq./customer yr
CAIDI	4.879 hr./cust. Interruption
EENS	57357 kWh/yr

## 4.5.2 Base case of Khoplang Feeder (Rural)

The base case ETAP modeling of Khoplang feeder is shown below;

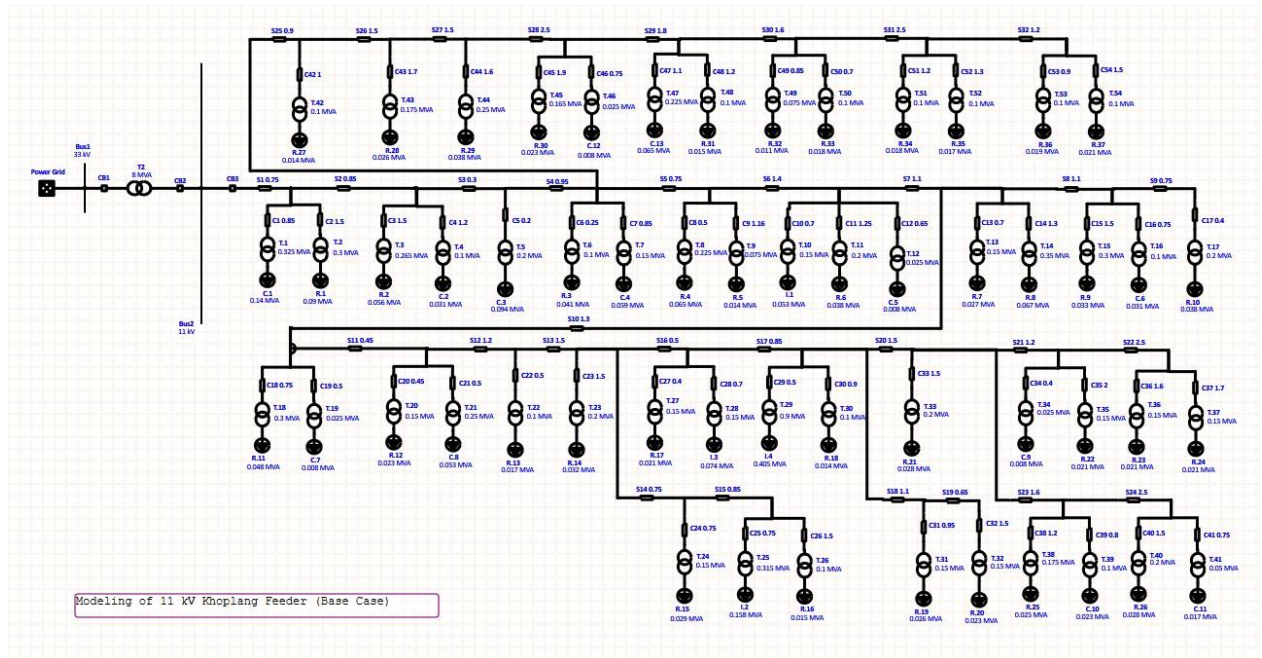


Figure 4.6 ETAP Model of Khoplang (Rural) Feeder (Base Case)

The base case reliability indices of Khoplang (Rural) Feeder obtained from above model are:

SAIDI	77.06 hr./customer yr
SAIFI	12.7309 freq./customer yr
CAIDI	6.053 hr/cust. Interruption
EENS	151.696 kWh/yr

The base case ETAP results obtained are used as a reference for comparison with optimized recloser placement scenarios discussed in subsequent sections

## 4.6 Optimum recloser placement using GA

Genetic Algorithm is used for optimal placement of recloser and to improve reliability indices. The base case EENS and EENS with variation of number of recloser is obtained from GA optimization using MATLAB coding.

### 4.6.1 Optimum recloser for Feeder-4 (Urban Feeder)

The EENS obtained with different number of recloser using GA for Feeder-4 (Urban) feeder is shown below.

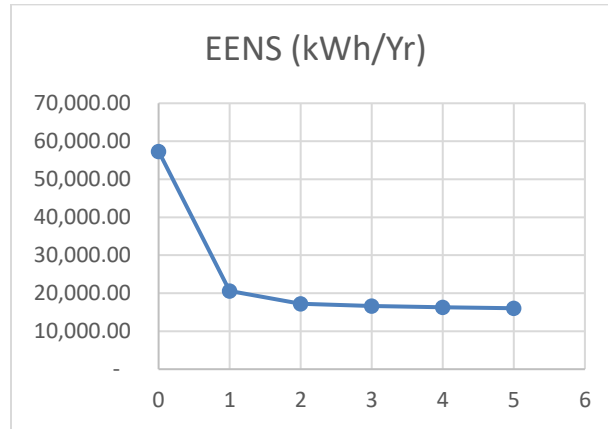


Figure 4.7 Graph EENS Vs Number of Recloser for Feeder-4 (Urban Feeder)

Figure 4.10 illustrates the variation of Expected Energy Not Supplied (EENS) with the number of reclosers installed on Feeder-4. A significant reduction in EENS is observed with the installation of the first recloser, indicating substantial reliability improvement. Further addition of reclosers results in diminishing marginal improvement, and the EENS curve begins to flatten after the installation of two reclosers. Beyond this point, additional reclosers provide negligible reduction in EENS while increasing investment cost. Therefore, the optimum number of reclosers for Feeder-4 is identified as two and their location is branch 16 and 40.

The ETAP Model with optimal Recloser placement at urbane feeder is given below and simulation is carried out;

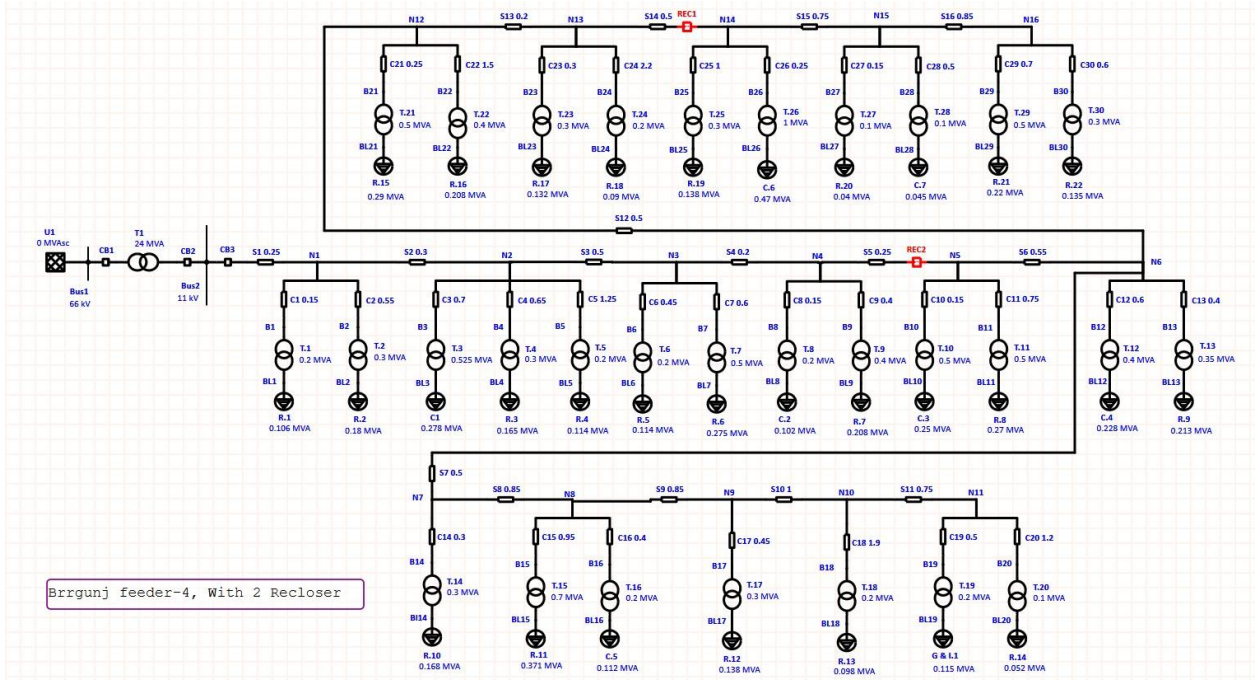


Figure 4.8 ETAP Modeling of Feeder-4 (urban feeder) with 2 Recloser

The reliability indices of base case and with placement of optimum recloser is shown below;

Table 4.3 Reliability indices of feeder-4 (Base case and with optimum recloser)

Reliability Indices	Unit	Base Case	With 2 Recloser	% Improved
SAIDI	hr./Cust. Yr	12.6748	5.1618	59.28
SAIFI	Int./Cust. Yr	2.5977	1.6656	35.88
CAIDI	hr./Cust. Intr.	4.879	3.099	36.48
EENS	kWh/yr	57357	22981	59.93

Table 4.3 presents a comparison of key reliability indices of Feeder-4 (urban) under the base case condition and after the installation of two auto-reclosers.

The System Average Interruption Duration Index (SAIDI) decreases significantly from 12.6748 hr/customer-year in the base case to 5.1618 hr/customer-year with the installation of two reclosers, representing an improvement of 59.28%. This substantial reduction

indicates that reclosers effectively reduce the total duration of customer interruptions by enabling faster fault isolation and restoration.

The System Average Interruption Frequency Index (SAIFI) is reduced from 2.5977 interruptions/customer-year to 1.6656 interruptions/customer-year, corresponding to an improvement of 35.88%. This shows that the presence of reclosers limits the number of customers affected by each fault by sectionalizing the feeder and isolating faulted sections.

The Customer Average Interruption Duration Index (CAIDI) decreases from 4.879 hours/interruption to 3.099 hours/interruption, yielding an improvement of 36.48%. The reduction in CAIDI reflects quicker restoration per interruption due to the automatic operation of reclosers, which minimizes manual intervention.

The Expected Energy Not Supplied (EENS) shows a substantial reduction from 57,357 kWh/year in the base case to 22,981 kWh/year after installing two reclosers, resulting in an improvement of 59.93%. This significant decrease highlights the effectiveness of reclosers in reducing outage-related energy losses, which directly translates into economic benefits.

#### 4.6.2 Optimum recloser for Khoplang (Rural Feeder)

The EENS obtained with different number of recloser using GA for Khoplang (Rural) feeder is shown below.

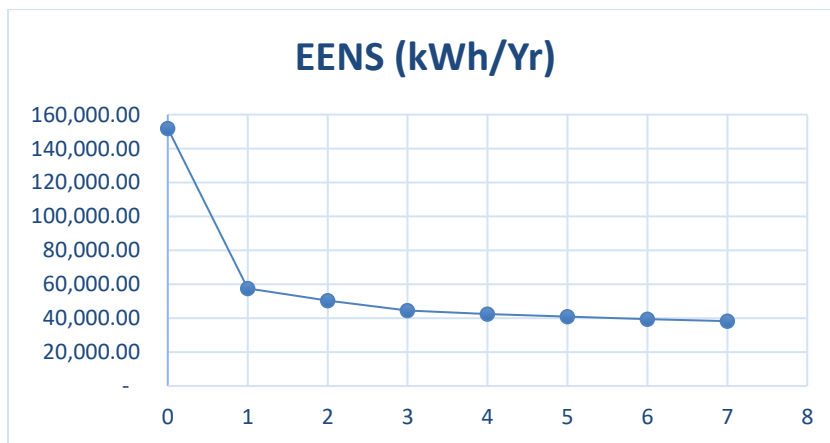


Figure 4.9 EENS Vs Number of Recloser for Khoplang (Rural) Feeder

Figure 4.13 illustrates the variation of Expected Energy Not Supplied (EENS) with respect to the number of auto-reclosers installed on the Khoplang rural feeder, as obtained using the genetic algorithm (GA)-based optimization approach.

A significant reduction in EENS is observed with the installation of the first recloser, where EENS decreases sharply. As the number of reclosers increases, EENS continues to decrease; however, the rate of reduction becomes progressively smaller. Beyond four reclosers, the EENS curve becomes nearly flat, indicating that the installation of additional reclosers results in negligible improvement in reliability. Therefore, the optimum number of reclosers for Khoplang feeder is identified as four and their location are at branch 29,39,47 and 77 respectively.

The ETAP Model with optimum number of recloser is shown below;

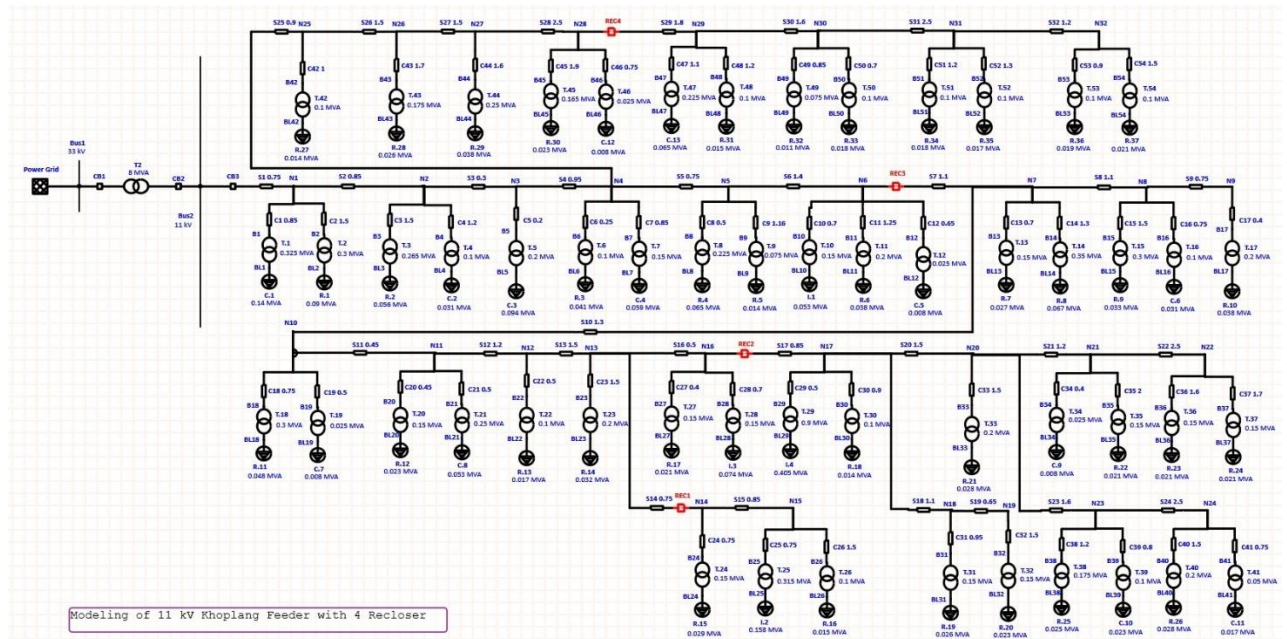


Figure 4.10 ETAP Modeling of Khoplang (Rural) Feeder with 4 recloser

The reliability indices of base case and with placement of optimum recloser is shown below;

Table 1.4 Reliability indices of Khoplang (Rural) Feeder (base case and using optimum recloser)

<b>Reliability Indices</b>	<b>Unit</b>	<b>Base Case</b>	<b>With 4 Recloser</b>	<b>% Improved</b>
SAIDI	hr./Cust. Yr	77.06	33.4307	56.62
SAIFI	Int./Cust. Yr	12.7309	6.7504	46.98
CAIDI	hr./Cust. Intr.	6.053	4.952	18.19
EENS	kWh/yr	151696	70433	53.57

Table 4.5 presents a comparison of key reliability indices of the Khoplang (rural) feeder under the base case condition and after the installation of four optimally placed auto-reclosers.

The System Average Interruption Duration Index (SAIDI) is reduced significantly from 77.06 hr./customer-year in the base case to 33.4307 hr./customer-year with four reclosers, corresponding to an improvement of 56.62%. This substantial reduction indicates that reclosers effectively reduce the overall duration of customer interruptions by enabling faster isolation of faulted sections and quicker restoration of supply.

The System Average Interruption Frequency Index (SAIFI) decreases from 12.7309 interruptions/customer-year to 6.7504 interruptions/customer-year, representing an improvement of 46.98%. This reduction demonstrates that the installation of reclosers limits the number of customers affected during fault events by sectionalizing the long rural feeder.

The Customer Average Interruption Duration Index (CAIDI) is reduced from 6.053 hours/interruption to 4.952 hours/interruption, yielding an improvement of 18.19%. The relatively smaller improvement in CAIDI compared to SAIDI suggests that reclosers have a greater impact on reducing the extent of outages rather than significantly shortening repair time per interruption, which is influenced by accessibility and field repair conditions in rural areas.

The Expected Energy Not Supplied (EENS) shows a notable reduction from 151,696 kWh/year in the base case to 70,433 kWh/year with four reclosers, corresponding to an improvement of 53.57%. This reduction highlights the effectiveness of reclosers in minimizing energy losses due to outages and improving the overall service continuity of the rural feeder.

#### 4.7 Cost Analysis.

Following assumptions are made for Cost–benefit analysis (CBA) to evaluate the economic feasibility of installing auto-reclosers in distribution systems by comparing the economic benefits obtained from reliability improvement with the associated investment and operating costs.

Assumptions;

- Capital cost of Recloser : Rs, 5,60,000.00
- Installation cost : Rs. 55,000.00
- O & M Cost (Urban feeder) : Rs. 7,500.00 per year
- O & M Cost (Rural feeder) : Rs. 11,000.00 per year
- Useful life : 15 years
- Discounting rate : 8%

Table 4.5 Cost Benefit Analysis of Feeder-4 (Urban) and Khoplang (Rural) Feeder

<b>Descriptions</b>	<b>Unit</b>	<b>Urban (Feeder-4) Feeder</b>	<b>Rural (Khoplang) Feeder</b>	<b>Remarks</b>
Base Case EENS	kWh/yr	57,357.00	151,696.00	
EENS with optimal recloser	kWh/yr	22,981.00	70,433.00	
Annual Energy Saving	kWh/yr	34,376.00	81,263.00	
Avg. per unit Cost	Rs.	9.63	8.23	
Annual Benefit	Rs.	331,040.88	668,794.49	
BCR		2.09	2.02	
Payback period	Years	3.72	3.68	

Table 4.5 presents the cost–benefit analysis of optimal auto-recloser placement for the selected urban (Feeder-4) and rural (Khoplang) distribution feeders. The analysis is based on the reduction in Expected Energy Not Supplied (EENS) achieved through optimal recloser installation and the corresponding monetary benefits.

For the urban feeder (Feeder-4), the base-case EENS is 57,357 kWh/year, which is reduced to 22,981 kWh/year after installing optimally placed reclosers. This results in an annual energy saving of 34,376 kWh/year. Considering an average per-unit energy cost of Rs. 9.63 per kWh, the annual economic benefit obtained from reduced energy not supplied is Rs. 331,040.88.

Similarly, for the rural feeder (Khoplang), the base-case EENS of 151,696 kWh/year is reduced to 70,433 kWh/year after optimal recloser placement, yielding an annual energy saving of 81,263 kWh/year. With an average per-unit energy cost of Rs. 8.23 per kWh, the corresponding annual benefit is Rs. 668,794.49. The higher energy saving in the rural feeder is attributed to its longer feeder length and higher base-case outage exposure.

The Benefit–Cost Ratio (BCR) is found to be 2.09 for the urban feeder and 2.02 for the rural feeder. Since the BCR values are greater than unity in both cases, the investment in auto-reclosers is economically justified for both feeders. The slightly higher BCR for the urban feeder indicates better economic efficiency per unit investment, largely due to higher load density and greater outage cost per unit energy.

The payback period for the investment is 3.72 years for the urban feeder and 3.68 years for the rural feeder. These relatively short payback periods demonstrate that the capital investment in recloser installation can be recovered within a reasonable time frame, making the proposed solution financially attractive.

### 1.10 Analysis of Urban and Rural Feeder

Based on the available data of feeders the table below shows the analysis of Urban and Rural Distribution Feeders along with effectiveness of recloser placement based on economic feasibility analysis of both feeder.

Table 4.6 Analysis of Feeder-4 (Urban) Feeder

S.N.	Descriptions	Unit	Feeder-4 (Urban)
1	Feeder Length	km	28
2	Connected Load	kVA	10325
3	Average Load	kVA	5376
4	Consumer Connected	Nos.	4709
5	Load Density	kVA/Cons.	1.14
6	Avg. Tripping frequency	failure/yr	193.00
7	Avg. Tripping duration	hr	16.00
8	EENS (Reduction)	kWh	34,376.00
9	Average per unit Cost	NRs.	9.63
10	Annual benefit with recloser	Rs.	331,040.88
11	Optimum no. of recloser	Nos.	2
12	B/C Ratio		2.09
13	Payback Period	Years	3.72

Table 4.6 presents the technical parameters, reliability indices, and economic evaluation of 11 kV Feeder-4 (Urban Feeder). The feeder has a total length of 28 km and supplies power to 4,709 consumers with a connected load of 10,325 kVA. The average operating load is 5,376 kVA, indicating moderate utilization of the feeder capacity.

The load density of the feeder is 1.14 kVA per consumer, which reflects a relatively compact and concentrated urban load pattern. From a reliability perspective, the feeder experiences an average tripping frequency of 193 failures per year with a corresponding average annual outage duration of 16 hours. These values indicate frequent interruptions, which negatively affect supply reliability and consumer satisfaction in the urban area.

With optimal placement of recloser in feeder-4 (urban) feeder the Expected Energy Not Supplied (EENS) is reduced by 34,376 kWh per year. Considering the average per unit

energy cost of NRs. 9.63, the annual economic benefit of NRs. 331,040.88 will be achieved.

Economic analysis shows that the optimum number of reclosers required is two, which provides the best balance between cost and reliability improvement. The resulting Benefit–Cost (B/C) ratio of 2.09 indicates that the investment is economically viable, as the benefits significantly outweigh the costs. Furthermore, the payback period is approximately 3.72 years, which is acceptable for distribution system investments.

Overall, the analysis demonstrates that installation of reclosers on Feeder-4 (Urban) can substantially improve reliability and reduce energy not supplied, while also being technically justified and economically attractive. The results support the recommendation for recloser deployment as an effective reliability enhancement measure for urban distribution feeders.

Table 4.7 Analysis of Khoplang (Rural) Feeder

S.N.	Descriptions	Unit	Khoplang Feeder (Rural)
1	Feeder Length	km	114
2	Connected Load	kVA	9220
3	Average Load	kVA	2309
4	Consumer Connected	Nos.	7446
5	Load Density	kVA/Cons.	0.31
6	Avg. Tripping frequency	failure/yr	867.00
7	Avg. Tripping duration	hr	95.00
8	EENS (Reduction)	kWh	81,263.00
9	Average per unit Cost	NRs.	8.23
10	Annual benefit with recloser	Rs.	668,794.49
11	Optimum no. of recloser	Nos.	4
12	B/C Ratio		2.02
13	Payback Period	Years	3.68

Table 4.7 presents the technical parameters, reliability indices, and economic evaluation of the 11 kV Khoplang rural feeder. The feeder has a total length of 114 km, which is

significantly longer than typical urban feeders, and supplies electricity to 7,446 consumers. The connected load is 9,220 kVA, while the average operating load is 2,309 kVA, indicating relatively low utilization of installed capacity.

The load density of the feeder is 0.31 kVA per consumer, which reflects a sparsely distributed rural load pattern. Such low load density generally leads to higher exposure of overhead lines and increased vulnerability to environmental disturbances, thereby affecting feeder reliability.

Reliability analysis shows that the feeder experiences a very high average tripping frequency of 867 failures per year, along with an average annual outage duration of 95 hours. These values indicate poor reliability performance, which is characteristic of long rural feeders with extensive line exposure, difficult terrain, vegetation encroachment, and limited access for fault rectification.

With optimal placement of recloser in Khoplang (rural) feeder Energy Not Supplied (EENS) is reduced by 81,263 kWh per year. Considering the average per unit energy cost of NRs. 8.23, the annual economic benefit of NRs. 668,794.49 will be achieved.

Economic assessment indicates that the optimum number of reclosers required is four, which is higher than that of the urban feeder due to the greater feeder length and higher fault incidence. The calculated Benefit–Cost (B/C) ratio of 2.02 confirms that the investment in recloser installation is economically justified. Additionally, the payback period of 3.68 years demonstrates that the investment can be recovered within an acceptable timeframe.

Overall, the analysis reveals that the 11 kV Khoplang (rural) feeder suffers from severe reliability issues, but also offers significant scope for reliability improvement and economic gain through the strategic installation of reclosers. The results strongly support the implementation of recloser-based protection schemes to enhance supply continuity and reduce outage-related losses in rural distribution systems.

## 5 CONCLUSION AND RECOMMENDATION

### 5.1 CONCLUSION

This thesis investigated the optimal placement of auto-reclosers in rural and urban power distribution feeders of Nepal with the objective of enhancing system reliability and evaluating economic feasibility. Two practical 11 kV distribution feeders were selected for the study: Feeder-4 representing an urban feeder and Khoplang feeder representing a rural feeder.

Analytical reliability modeling based on historical outage data was employed to evaluate base-case reliability indices. The results indicated that the rural feeder suffers from significantly higher interruption frequency and duration due to its longer feeder length, lower load density, and greater exposure to environmental conditions. Standard reliability indices, including SAIFI, SAIDI, CAIDI, and Expected Energy Not Supplied (EENS), were used to quantify the reliability performance of both feeders.

A Genetic Algorithm-based optimization framework was developed to determine the optimal number and locations of auto-reclosers. The optimization results showed that two reclosers are optimal for the 11 kV feeder-4 (urban feeder), while four reclosers are required for the 11 kV Khoplang (rural) feeder to achieve a balanced trade-off between reliability improvement and investment cost. The optimal placement resulted in substantial reductions in reliability indices, with SAIDI and EENS reductions exceeding 50% in both feeders.

A comprehensive cost–benefit analysis was conducted using reduced EENS as the primary economic benefit indicator. The analysis yielded benefit–cost ratios greater than 2.0 and payback periods of less than four years for both feeders, confirming that the investment in auto-reclosers is economically justified. Although the Khoplang (rural) feeder achieved higher absolute reliability improvement, the Feeder-4 (urban feeder) demonstrated slightly better economic efficiency due to higher load density.

## 5.2 RECOMMENDATION

Based on the findings of this research, the following recommendations are made:

1. **Implementation of Auto-Reclosers:**

Distribution utilities in Nepal are recommended to implement optimal auto-recloser placement, particularly in long radial feeders, to significantly improve reliability and reduce outage durations.

2. **Differentiated Planning for Rural and Urban Feeders:**

Rural and urban feeders should be planned separately due to their distinct structural and load characteristics. Rural feeders generally require a higher number of reclosers, while urban feeders provide higher economic returns per unit investment.

3. **Strengthen data collection and monitoring**

Utilities should maintain accurate records of fault locations, interruption durations, and equipment health. This enables improved modeling accuracy and enhances the effectiveness of optimization-based planning.

4. **Use of Analytical Reliability Modeling:**

Utilities are encouraged to adopt analytical reliability modeling techniques for planning studies, as they are computationally efficient and suitable for radial distribution systems.

5. **Integration of Economic Evaluation:**

Reliability improvement projects should be evaluated using cost–benefit analysis to ensure financial feasibility and optimal allocation of limited investment resources.

6. **Future Research Directions:**

Future studies may extend this work by considering normally closed ring or meshed distribution systems, incorporation of distributed generation, time-varying load models, and advanced protection schemes with communication-assisted reclosers.

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## **7 APPENDICES**

## Appendix 1: Tripping data of 11 kV Urban (feeder-4) and Rural (Khoplang) Feeder

Table 1: Tripping Data of 11 kV Feeder-4 and Khoplang Feeder(Fiscal year 2078/79)

S.N.	Month	F/Y: 2078/79				Remarks
		Frequency of Interruption		Duration		
		Urban Feeder (Feeder-4)	Rural Feeder (Khoplang)	Urban Feeder (Feeder-4)	Rural Feeder (Khoplnag)	
1	Shrawan	17	75	85	449	
2	Bhddra	27	72	162	496	
3	Ashwin	13	41	65	256	
4	Kartik	5	21	16	139	
5	Mangsir	4	34	10	254	
6	Poush	9	20	150	169	
7	Magh	6	42	30	216	
8	Falgun	4	50	9	390	
9	Chaitra	3	56	10	427	
10	Baisakh	22	93	180	436	
11	Jestha	26	101	134	993	
12	Asadh	22	41	128	233	
	<b>Total</b>	<b>158</b>	<b>646</b>	<b>979</b>	<b>4458</b>	

Table 2: Tripping Data of Feeder-4 and Khoplang (Fiscal year 2079/80)

S.N.	Month	F/Y: 2079/80				Remarks
		Frequency of Interruption		Duration		
		Urban Feeder (Feeder-4)	Rural Feeder (Khoplnag)	Urban Feeder (Feeder-4)	Rural Feeder (Khoplnag)	
1	Shrawan	28	85	132	545	
2	Bhddra	23	97	125	647	
3	Ashwin	30	98	79	765	
4	Kartik	14	35	64	267	
5	Mangsir	5	56	18.00	353	
6	Poush	4	63	6.00	311	
7	Magh	8	39	25	343	
8	Falgun	9	79	28	449	
9	Chaitra	13	92	67	674	
10	Baisakh	19	89	79	822	
11	Jestha	15	116	76	986	
12	Asadh	38	101	204	784	
	<b>Total</b>	<b>206</b>	<b>950</b>	<b>903</b>	<b>6946</b>	

Table 3: Tripping Data of Feeder-4 and Khoplang (Fiscal year 2080/81)

S.N.	Month	F/Y: 2080/81				Remarks
		Frequency of Interruption		Duration		
		Urban Feeder (Feeder-4)	Rural Feeder (Khoplnag)	Urban Feeder (Feeder-4)	Rural Feeder (Khoplnag)	
1	Shrawan	67	128	324	661	
2	Bhadra	18	131	90	757	
3	Ashwin	9	92	55	467	
4	Kartik	15	37	72	204	
5	Mangsir	6	46	17	188	
6	Poush	4	43	10	307	
7	Magh	5	46	25	224	
8	Falgun	4	46	11	406	
9	Chaitra	10	92	51	448	
10	Baisakh	17	88	96	422	
11	Jestha	29	120	149	639	
12	Asadh	32	137	163	890	
	<b>Total</b>	<b>216</b>	<b>1006</b>	<b>1063</b>	<b>5613</b>	

## Appendix 2: Loading and Consumer Detail of feeders

Table 4 : Loading Status and consumer details of Feeder-4 (Urban Feeder)

S.N.	Load Point	Connected load kVA	Load Factor	Lumped load (kVA)	Bus/ Node	Category	No. of Consumer	Remarks
1	L1	200	0.53	106	N1	Residential	95	
2	L2	300	0.6	180	N1	Residential	126	
3	L3	525	0.53	278.25	N2	Commercial	3	
4	L4	300	0.55	165	N2	Residential	155	
5	L5	200	0.57	114	N2	Residential	106	
6	L6	200	0.57	114	N3	Residential	127	
7	L7	500	0.55	275	N3	Residential	285	
8	L8	200	0.51	102	N4	Commercial	1	
9	L9	400	0.52	208	N4	Residential	257	
10	L10	500	0.5	250	N5	Commercial	1	
11	L11	500	0.54	270	N5	Residential	335	
12	L12	400	0.57	228	N6	Commercial	2	
13	L13	350	0.61	213.5	N6	Residential	196	
14	L14	300	0.56	168	N7	Residential	275	
15	L15	700	0.53	371	N8	Residential	446	
16	L16	200	0.56	112	N8	Commercial	1	
17	L17	300	0.46	138	N9	Residential	235	
18	L18	200	0.49	98	N10	Residential	190	
54	L19	250	0.46	115	N11	Government	2	
56	L20	100	0.52	52	N11	Residential	115	
26	L21	500	0.58	290	N12	Residential	268	
28	L22	400	0.52	208	N12	Residential	294	
30	L23	300	0.44	132	N13	Residential	179	
32	L24	200	0.45	90	N13	Residential	156	
34	L25	300	0.46	138	N14	Residential	205	
36	L26	1000	0.47	470	N14	Commercial	1	
37	L27	100	0.4	40	N15	Residential	95	
38	L28	100	0.45	45	N15	Commercial	1	
39	L29	500	0.44	220	N16	Residential	341	
42	L30	300	0.45	135	N16	Residential	216	
<b>Total</b>		<b>10325</b>					<b>4709</b>	

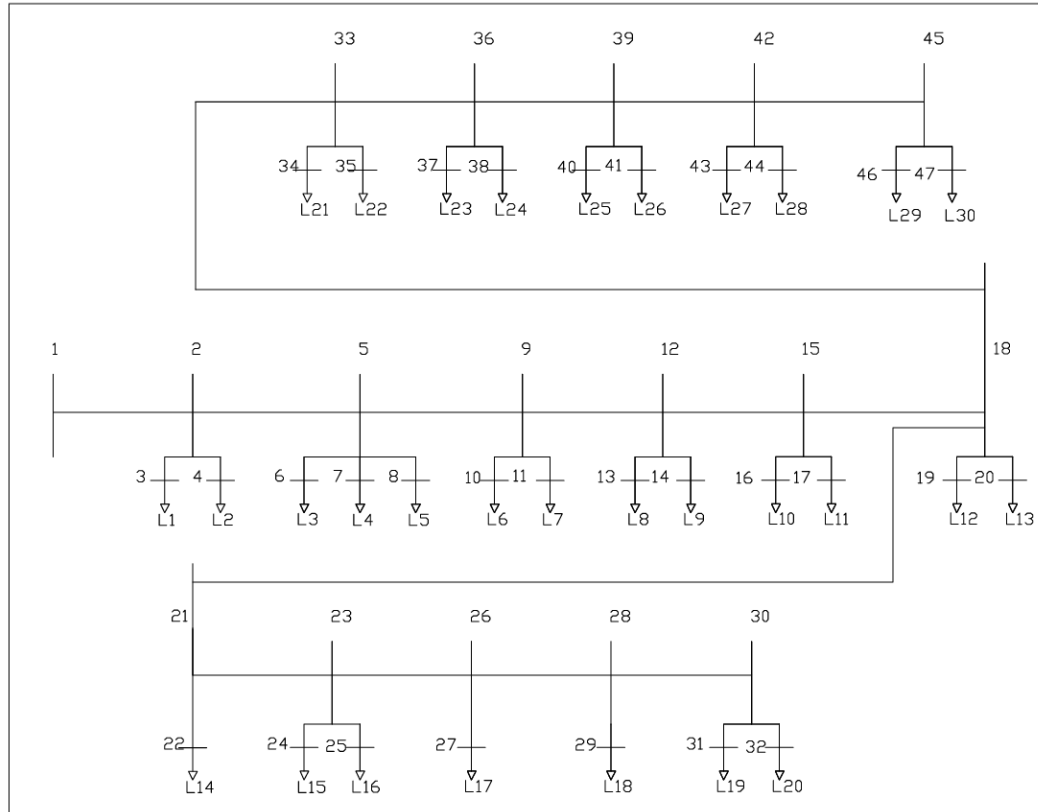
Table 5 : Loading Status and consumer details of Khoplang Feeder (Rural Feeder)

S.N.	Load Point	Connected load in kVA	Load Factor	Lumped load in MVA	Bus/Node	Category	No. of Consumer	Remarks
1	L1	325	0.43	0.140	N1	Commercial	3	
2	L2	300	0.30	0.090	N1	Residential	434	
3	L3	200	0.47	0.094	N3	Commercial	1	
4	L4	265	0.21	0.056	N2	Residential	424	
5	L5	100	0.31	0.031	N2	Commercial	1	
6	L6	100	0.41	0.041	N4	Residential	194	
7	L7	150	0.39	0.059	N4	Commercial	2	
8	L8	225	0.29	0.065	N5	Residential	351	
9	L9	75	0.19	0.014	N5	Residential	148	
10	L10	200	0.19	0.038	N6	Residential	332	
11	L11	150	0.35	0.053	N6	Industrial	1	
12	L12	25	0.31	0.008	N6	Commercial	1	
13	L13	150	0.18	0.027	N7	Residential	186	
14	L14	350	0.19	0.067	N7	Residential	337	
15	L15	300	0.11	0.033	N8	Residential	241	
16	L16	100	0.31	0.031	N8	Commercial	2	
17	L17	200	0.19	0.038	N9	Residential	316	
18	L18	300	0.16	0.048	N10	Residential	339	
19	L19	25	0.33	0.008	N10	Commercial	1	
20	L20	150	0.15	0.023	N11	Residential	201	
21	L21	250	0.21	0.053	N11	Commercial	1	
22	L22	100	0.17	0.017	N12	Residential	156	
23	L23	200	0.16	0.032	N13	Residential	238	
24	L24	150	0.19	0.029	N14	Residential	133	
25	L25	315	0.5	0.158	N15	Industrial	1	
26	L26	100	0.15	0.015	N15	Residential	138	
27	L27	150	0.14	0.021	N16	Residential	92	
28	L28	150	0.49	0.074	N16	Industrial	1	
29	L29	900	0.45	0.405	N17	Industrial	1	
30	L30	100	0.14	0.014	N17	Residential	81	
31	L31	150	0.17	0.026	N18	Residential	177	
32	L32	150	0.15	0.023	N19	Residential	153	
33	L33	200	0.14	0.028	N20	Residential	141	
34	L34	25	0.31	0.008	N21	Commercial	1	
35	L35	150	0.14	0.021	N21	Residential	242	
36	L36	150	0.14	0.021	N22	Residential	162	
37	L37	150	0.14	0.021	N22	Residential	131	

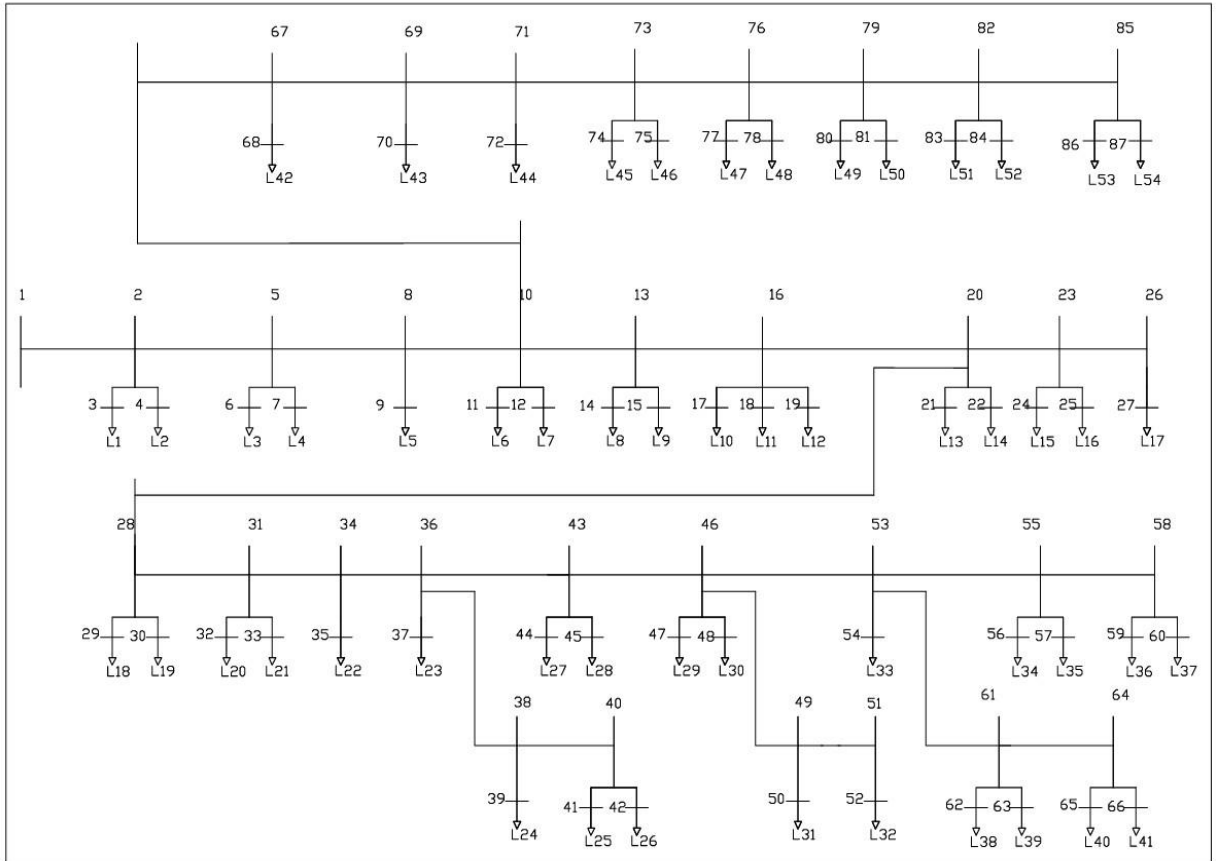
S.N.	Load Point	Connected load in kVA	Load Factor	Lumped load in MVA	Bus/Node	Category	No. of Consumer	Remarks
38	L38	175	0.14	0.025	N23	Residential	172	
39	L39	100	0.23	0.023	N23	Commercial	1	
40	L40	200	0.14	0.028	N24	Residential	179	
41	L41	50	0.33	0.017	N24	Commercial	2	
42	L42	100	0.14	0.014	N25	Residential	132	
43	L43	175	0.15	0.026	N26	Residential	216	
44	L44	250	0.15	0.038	N27	Residential	292	
45	L45	165	0.14	0.023	N28	Residential	214	
46	L46	25	0.31	0.008	N28	Commercial	1	
47	L47	225	0.29	0.065	N29	Commercial	2	
48	L48	100	0.15	0.015	N29	Residential	115	
49	L49	75	0.15	0.011	N30	Residential	116	
50	L50	100	0.18	0.018	N30	Residential	134	
51	L51	100	0.17	0.017	N31	Residential	136	
52	L52	100	0.17	0.017	N31	Residential	101	
53	L53	100	0.19	0.019	N32	Residential	126	
54	L54	100	0.21	0.021	N32	Residential	143	
<b>Total</b>		<b>9220</b>					<b>7446</b>	

### Appendix 3: Single Line Diagram of feeders

Single line diagram of Feeder-4 (Urban Feeder)



### Single line diagram of 11 kV Khoplang feeder (Rural Feeder)



#### Appendix 4: Cost Benefit analysis of feeders to incorporate Reclosers

Average per unit cost of is calculated using annual sales amount and annual sales unit of respective Distribution Center.

DC Name	Description	
Birgunj	Annual Sales amount (Rs.)	5,358,243,682.51
	Annual Sales Unit (kWh)	556,375,925.28
	Per Unit Cost (Rs/KWh)	9.63
Gorkha	Annual Sales amount (Rs.)	270,381,265.71
	Annual Sales Unit (kWh)	32,853,785.12
	Per Unit Cost (Rs/KWh)	8.23

#### Cost analysis of Feeder-4 (Urban feeder)

Here

$$EENS_{base} = 57357 \text{ kWh/yr}$$

$$EENS_{2R} = 22981 \text{ kWh/yr}$$

$$\text{Annual Energy Saving} = 34376 \text{ kWh}$$

$$\text{Annual Benefit (B}_{Urban}) = \text{Rs.}3,31,040.90$$

$$\text{Capital Cost of recloser (R}_{cap}) = \text{Rs. } 5,60,000$$

$$\text{Installation Cost (R}_{inst}) = \text{Rs. } 55,000$$

$$\text{O \& M Cost (R}_{om}) = \text{Rs.}7500 \text{ per year}$$

$$\text{Useful Life(n)} = 15 \text{ years}$$

$$\text{Discount Rate(i)} = 8\%$$

PV factor for 15 years and 8% discount rate is ( $PV_f$ ): 8.5595

$$\begin{aligned} \text{Present Value of Benefit (PV}_B) &= B_{Urban} * PV_f \\ &= \text{Rs.}(3,31,040.90 * 8.5595) \\ &= \text{Rs. } 28,33,537.36 \end{aligned}$$

$$\text{Present Value of O \& M (PV}_{om}) = R_{om} * PV_f$$

$$= \text{Rs.}(7500*8.5595)$$

$$= \text{Rs. } 64,196.09$$

$$\begin{aligned} \text{Total Present Value of Capital (PV}_{\text{Cap}}) &= 2 * (\text{R}_{\text{Cap}} + \text{R}_{\text{inst}} + \text{PV}_{\text{om}}) \\ &= \text{Rs. } 2 * (5,60,000 + 55,000 + 64196.09) \\ &= \text{Rs.}13,58,392.18 \end{aligned}$$

Now,

$$\begin{aligned} \text{Benefit Cost Ratio (B/C)}_{\text{Urban}} &= (\text{PV}_{\text{Cap}} / \text{PV}_{\text{B}}) \\ &= 28,33,537.36 / 13,58,392.18 \\ &= \mathbf{2.09} \end{aligned}$$

#### Calculation of Payback Period:

$$\begin{aligned} \text{Capital cost of recloser for urban feeder (Urban}_{\text{Ccost}}) &= \text{Rs. } 2*6,15,000 \\ &= \text{Rs. } 12,30,000 \end{aligned}$$

Then

$$\begin{aligned} \text{Payback Period for Feeder-4} &= (\text{Urban}_{\text{Ccost}} / \text{B}_{\text{Urban}}) \\ &= 12,30,000/3,31,040.90 \\ &= \mathbf{3.72 \text{ years}} \end{aligned}$$

#### Cost analysis of Khoplang feeder (Rural feeder)

Here

$$\text{EENS}_{\text{base}} = 151696 \text{ kWh/yr}$$

$$\text{EENS}_{4\text{R}} = 70433 \text{ kWh/yr}$$

$$\text{Annual Energy Saving} = 81263 \text{ kWh}$$

$$\text{Annual Benefit (B}_{\text{Rural}}) = \text{Rs.}6,68,794.49$$

$$\text{Capital Cost of recloser (R}_{\text{cap}}) = \text{Rs. } 5,60,000$$

$$\text{Installation Cost (R}_{\text{inst}}) = \text{Rs. } 55,000$$

$$\begin{aligned} \text{O \& M Cost (R}_{om}) &= \text{Rs.11,000 per year} \\ \text{Useful Life(n)} &= 15 \text{ years} \\ \text{Discount Rate(i)} &= 8\% \end{aligned}$$

PV factor for 15 years and 8% discount rate is ( $PV_f$ ): 8.5595

$$\begin{aligned} \text{Present Value of Benefit (PV}_B) &= B_{Rural} * PV_f \\ &= \text{Rs.}( 6,68,794.49 * 8.5595) \\ &= \text{Rs. } 57,24,532.18 \end{aligned}$$

$$\begin{aligned} \text{Present Value of O \& M (PV}_{om}) &= R_{om} * PV_f \\ &= \text{Rs.}(11000*8.5595) \\ &= \text{Rs. } 94,154.27 \end{aligned}$$

$$\begin{aligned} \text{Total Present Value of Capital (PV}_{Cap}) &= 4 * (R_{Cap} + R_{inst} + PV_{om}) \\ &= \text{Rs. } 4 * (5,60,000 + 55,000 + 94,154.27) \\ &= \text{Rs.} 28,36,617.06 \end{aligned}$$

Now,

$$\begin{aligned} \text{Benefit Cost Ratio (B/C)}_{Rural} &= (PV_{Cap} / PV_B) \\ &= 57,24,532.18 / 28,36,617.06 \\ &= 2.02 \end{aligned}$$

#### **Calculation of Payback Period:**

$$\begin{aligned} \text{Capital cost of recloser for Rural feeder (Rural}_{Ccost}) &= \text{Rs. } 4 * 6,15,000 \\ &= \text{Rs. } 24,60,000 \end{aligned}$$

Then

$$\begin{aligned} \text{Payback Period for Feeder-4} &= (\text{Rural}_{Ccost} / B_{Rural}) \\ &= 24,60,000 / 6,68,794.49 \\ &= 3.68 \text{ years} \end{aligned}$$

# Chij

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