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An Explicit Formula Based Estimation Method for Reliability of Urban Feeder in Kathmandu valley

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A thesis submitted to the Department of Electrical Engineering in partial fulfillment of
the requirements for the degree of
Master of Science in Power System Engineering

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CERTIFICATE OF APPROVAL

The undersigned, certify that they have reviewed and hereby recommend to the esteemed Institute of Engineering for acceptance, a thesis titled **"An Explicit Formula Based Estimation Method for Reliability of Urban Feeder in Kathmandu valley"** submitted by Mr. Rajesh Kumar Pandey in partial fulfillment of the requirements for the degree of Master of Science in Power System Engineering.

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ABSTRACT

An innovative approach to reliability assessment in the planning phase of medium-voltage distribution systems is presented in this study. The method introduces a novel technique for estimating reliability indices, enabling their expression through explicit formulas while accommodating various network topologies. Initially, typical feeder structures are identified within the candidate area using a combination of tree edit distance and hierarchical clustering algorithms. Subsequently, for each typical network structure, a reliability evaluation model is established, incorporating factors such as fault isolation, load restoration, and the impact of reliability enhancement equipment, formulated through regression analysis. The feasibility and effectiveness of the proposed reliability assessment algorithm are validated through test cases, demonstrating its capability to achieve rapid and accurate reliability index calculations with minimal data requirements. This approach offers a systematic and efficient means of assessing distribution system reliability during the planning process, ensuring adaptability to diverse network configurations. Finally, this approach is implemented for Baneshwor 11 kV feeder distribution system.

Index terms : Tree edit distance, reliability estimation, Correlation agglomerative hierarchical clustering(ACH), MATLAB, Regression analysis, medium voltage distribution Feeder.

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LIST OF ABBREVIATIONS

SYMBOLS	DEFINITION
β	Customer Identification factor or normalized Customer
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
DS	Distribution system
DSS	Distribution Substation
EENS	Expected energy not supplied
RBTS	Roy Billinton Test System
IEEE	Institute of Electrical and Electronics Engineers
TED	Tree Edit Distance
MTBF	Mean Time Between Failure
MTTF	Mean time between failures
MTTR	Mean time to repair
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
TTR	Times to Failure

CHAPTER 1. INTRODUCTION

1. 1. Background

The distribution systems are the final link between the bulk power system and customers, and the most customer interruptions occur due to failures in the distribution systems zone. Reliability evaluation plays a crucial role in distribution systems for several reasons that is:

a) **Customer Satisfaction**: Reliable electricity supply is essential for customers. It ensures uninterrupted service, minimizing disruptions in daily activities, business operations, and essential services such as healthcare and emergency response.

b) **Economic Impact**: Power outages can result in significant economic losses for businesses and industries due to production downtime, loss of revenue, and damage to equipment. Reliable distribution systems help mitigate these losses by minimizing downtime.

c) **Safety**: Reliable distribution systems contribute to public safety by ensuring the availability of electricity for critical services such as hospitals, fire stations, and law enforcement agencies. Additionally, reliable systems reduce the risk of accidents and injuries associated with power outages.

d) **Quality of Life**: Reliable electricity supply enhances the quality of life for individuals by supporting essential services such as heating, cooling, lighting, and communication. It also facilitates the use of technologies that improve comfort and convenience, such as home appliances and electronic devices.

e) **Resilience**: In the face of natural disasters, extreme weather events, or other emergencies, reliable distribution systems are crucial for maintaining essential services, supporting emergency response efforts, and facilitating recovery and rebuilding efforts.

f) **Energy Efficiency**: Reliable distribution systems enable the efficient use of energy resources by minimizing losses associated with power interruptions and ensuring optimal operation of equipment and infrastructure.

Overall, reliability evaluation in distribution systems is essential for ensuring the continuity of electricity supply, promoting economic development, safeguarding public safety, and enhancing the quality of life for individuals and communities. In Nepal

Distribution system at peak Demand time the Interruption of Supply is a greater number of times which means there is no good reliability of system. So, the low reliability is due tomany causes like lengthy 11 kV feeders, feeders are not upgraded according to demand, must of the lines are overhead etc. Currently, there has been no study conducted by the Nepalese government or NEA on the reliability of Nepal's distribution system, nor is there an official body authorized to oversee its reliability. However, going forward, both the Nepalese government and NEA aspire to set forth standards for ensuring the reliability of Nepal's distribution system. So there is many classical method to estimate the reliability of Distribution network system such as Approximate evaluation algorithms for Reliability indices of Distribution network but these method not give highly accurate data for Reliability indices of Distribution network,these method need more data to calculate the Reliability and also other method do not consider the whole topology of network, This thesis begins by exploring an explicit formula-based method for estimating the reliability of distribution networks, specifically focusing on the IEEE RBTS bus system. It then proceeds to compare these reliability indices with approximate evaluation algorithms for distribution network reliability. The study further examines the reliability indices derived from the explicit formula-based method in the context of the 11 kV Baneshwor feeder Distribution system and compares them with those from the IEEE RBTS system. This research aims to optimize distribution network planning by addressing the challenges posed by network topology and other related factors.

The algorithms that mentioned involve analyzing the network topology, which can be challenging due to its unknown nature in the planning model. This complexity is compounded by segmented switches and other elements, making analytical and simulation methods more difficult to apply.

The explicit formula that mentioned in the thesis seems promising as it aims to evaluate the reliability index of a large-scale distribution network based on its specific structural characteristics. By avoiding detailed analysis after failure, it likely streamlines the process. However, it seems that this formula might not be perfectly continuous and differentiable due to the presence of judgment statements, and there may be significant errors due to numerous assumptions on feeders.

Developing an improved explicit estimation algorithm for the reliability index could address these limitations. Such an algorithm would likely aim to reduce errors by refining assumptions and minimizing the impact of judgment statements on the continuity and differentiability of the formula. Additionally, it might incorporate more accurate modelling techniques to better represent real-world distribution network scenarios.

1.1.1 Reliability analysis of distribution Network.

Reliability indices in power distribution systems encompass measurements for individual components, load points, and the entire network. Key components such as power transformers, transmission cables, bus-bars, circuit breakers, and disconnectors are critical, with their operational statuses closely monitored. These components are characterized by failure rates (λ) and repair rates (μ). From these rates, two additional reliability indices, Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR), can be calculated to further assess system reliability.

Mean Time to Failure (MTTF) refers to the average time a component or system operates before experiencing a failure. It is a measure of reliability indicating the expected lifespan under normal operating conditions.

Mean Time to Repair (MTTR) is the average time required to repair a failed component or system and restore it to operational status. MTTR is a crucial metric in assessing maintainability and downtime management within a system or network.

These metrics, MTTF and MTTR, are essential for evaluating and improving the reliability and availability of complex systems, including power distribution networks.

The System Average Interruption Frequency Index (SAIFI) is a metric used to measure the average number of interruptions experienced by a customer or a specific group of customers for a definite period, typically per year. It provides insight into the power outages frequency within a distribution system.

The System Average Interruption Duration Index (SAIDI) indicates the average length of time that customers or groups of customer experience power interruptions over a given period, typically on an annual basis. This index evaluates the reliability of the power supply by measuring the average duration that customers are without electricity during outages.

Together, SAIFI and SAIDI are essential reliability indices in power distribution systems, providing valuable information for utilities and regulators to improve service quality and customer satisfaction

1.1.2 System Reliability indices

The thesis will provide a concise overview of system reliability indices, which serve as key indicators of power supply reliability. These indices assess the distribution grid's ability to meet demand and manage interruptions effectively. Among them, the Expected Energy Not Supplied (EENS) is an important index used to measure load reliability. Specifically, the focus of this thesis centers on two widely recognized indices: the System Average Interruption Frequency Index (SAIFI) and the System Average Interruption Duration Index (SAIDI). These indices are crucial for evaluating power outage frequency and duration within distribution networks, and they are calculated using established formulas for accurate reliability assessment.

$$S_F = \sum_{k=1}^{N_E} N_E \, \lambda_k (\beta_{AK} U_A + \beta_{BK} U_B + \beta_{CK} U_C) \qquad (1)$$

$$S_D = \sum_{k=1}^{N_E} N_E \, \lambda_k (\beta_{AK} T_A + \beta_{BK} T_B + \beta_{CK} T_C) \qquad (2)$$

Where ,

S_F is System Average Interruption Frequency Index (SAIFI)

S_D is System Average Interruption Duration Index (SAIDI)

The failure rate of the *kth* type of equipment $=\lambda_k$

N_E Represents amounts of Equipment

β is Customer identification factor (Total customer affected After failure of k_{th} type Equipment)

T_A , T_B and T_c Represents the time which explain in table 1

U_A , U_B and U_c are 0-1 Variables which denotes the power failure status respectively.

Table 1: Timing representation of different Scenario

TYPE	Outage Time	Location
A	$T_A = T_{dw} + T_g$	Customer fall in Up-stream part of Failure point
B	$T_B = T_{dw} + T_g + T_z$	Customer fall in Down-stream part of Failure point and transferred.
C	$T_C = T_{dw} + T_g + T_x$	Customer fall in Down-stream part of Failure point and not transferred, Failed user in failure point.

The outage time of various users, represents as T_A , T_B and T_c.
The time required to locate failures, isolate them, transfer the load., and failure repairing time represents as T_{dw}, T_n, T_g , T_z and T_x respectively.
The network topology and load distribution is mainly influenced on β calculation, so it is complex to calculate β, due to which S_D is not expressed by explicit formula.

1.1.3 Reliability Analysis method

Explicit Formula Based Estimation Method is used to calculate Reliability Distribution Network. The core aim of this thesis is to calculate the value of β is Customer identification factor.

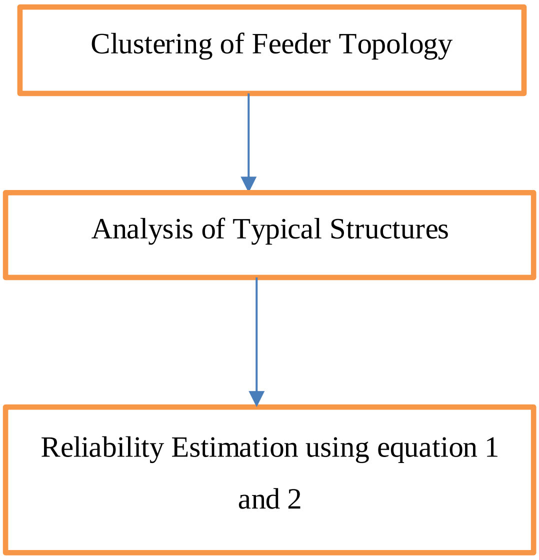

Figure 1.1: General outline reliability calculation method

The calculation of reliability indices involves utilizing a function derived from regression analysis, which incorporates considerations such as fault isolation and load transfer. This method is highly effective in accurately determining reliability indices across diverse network topologies, making it a robust tool in reliability assessment.

1.1.4 Reliability test system

The IEEE-RBTS (IEEE Reliability Test System) indeed played a significant role in the 1970s and beyond in facilitating reliability analysis for generation and transmission systems. However, when it comes to distribution systems, its applicability and convenience diminish somewhat. Here’s why:

1. **Scale and Complexity**: Distribution systems typically involve a larger number of components (such as distribution lines, transformers, switches) compared to generation and transmission systems. The IEEE-RBTS was designed with a focus on the generation and transmission aspects, often modeling fewer components and simpler configurations than what is typical in distribution networks.
2. **Modeling Detail**: Distribution systems require more detailed modeling of individual components due to the diverse nature of loads, the variability in local conditions, and the network topology. The IEEE-RBTS, while useful for bulk power systems, may lack the granularity needed to capture these complexities effectively.
3. **Data Availability**: Reliability analysis for distribution systems often requires more localized and specific data on outage frequencies, load profiles, and equipment performance at a smaller scale. The data used for the IEEE-RBTS may not be readily applicable or available at the distribution level.
4. **Simulation Requirements**: Distribution systems often require simulation tools that can handle varying voltage levels, protection schemes, and interaction with customer installations (like distributed generation). The IEEE-RBTS was not explicitly designed to simulate these interactions or the operational dynamics of distribution networks.
5. **Reliability Indices**: The indices and metrics used to measure reliability in distribution systems may differ from those used in transmission and generation

contexts. For instance, customer interruption indices (such as SAIDI, SAIFI) are critical for distribution reliability analysis but are not typically emphasized in the IEEE-RBTS.

In summary, while the IEEE-RBTS is invaluable for analyzing reliability in generation and transmission contexts, its applicability to distribution systems is limited due to the scale, complexity, and modeling requirements specific to distribution networks. Researchers and engineers typically use other tools and methodologies tailored to the unique challenges and characteristics of distribution system reliability analysis.

In summary, while the IEEE-RBTS system evolved to address distribution system reliability concerns, comparison with methods like approximate evaluation algorithms and explicit formula-based estimation highlights trade-offs between computational intensity, accuracy, and applicability to specific distribution network contexts like the Baneshwor 11 kV feeder. Each method offers distinct advantages depending on the depth of analysis and resources available for reliability assessment in distribution systems.

1.1.5 Data in distribution System reliability

Reliability analysis heavily relies on accurate input data, which is often complex, incomplete, and occasionally erroneous when sourced from grid data. Ensuring high-quality data is crucial but can be costly and challenging to obtain. The accuracy of output results in reliability analysis is inherently limited by the precision of input data. Therefore, engineers and scientists must appreciate the significance of precise data and grasp effective data analysis techniques.

Fundamental data on component failures such as failure rates, repair rates, and occasionally maintenance rates form the core inputs for reliability analysis. Coupled with essential parameters specific to the distribution network, these data enable engineers to conduct reliability assessments and derive system reliability indices.

In this thesis, for step work Data is used from Standard IEEE 33 bus RBTS system and then for Reliability analysis of Baneshwor distribution System the data is collected from Related NEA Distribution Centre that is Baneshwor Distribution Centre.

1.1.6 Reliability in Distribution Systems

Ensuring the reliability of the distribution system is essential for maintaining a continuous and high-quality electricity supply to consumers. Various reliability indices are highlighted in the literature, including the System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI) and System Average Interruption Frequency Index (SAIFI). These indices are widely used to evaluate the performance and reliability of distribution systems. Research has underscored the need to enhance these indices to meet the growing demand for reliable power supply. All above reliability indices are useful but in this thesis paper we focus on System Average interruption frequency index (SAIFI), System Average interruption duration Index (SAIDI).

1.1.7 Reliability Hierarchical Clustering of network topology

The reliability calculation of distribution feeders, such as analytical techniques, simulation-based approaches etc considered the system is simple radial feeder and the existed is uniformly distributed but in actual practices things are not so. The literature also highlights following limitation associated with analytical and simulation -based approaches:

Limitations of Analytical Techniques:

Simplifying Assumptions: Analytical techniques often rely on simplifying assumptions about the distribution feeder's topology, load characteristics, and operating conditions. These assumptions may not fully capture the complexity and variability of real-world scenarios, leading to inaccuracies in the reliability estimates.

Limited Scope: Analytical techniques may be limited in their ability to model certain aspects of distribution feeders, such as non-linear loads, distributed generation, voltage regulation devices, and dynamic system behavior. This can restrict their applicability to specific types of feeders or operating conditions.

Complexity: Some analytical techniques, such as Markov models or state-space approaches, can become computationally complex, especially for large-scale distribution networks with multiple feeders and complex topologies. This complexity may hinder their practical implementation and scalability.

Data Requirements: Analytical techniques often require detailed data on feeder topology, component failure rates, load profiles, and other parameters. Obtaining accurate and reliable data for these inputs can be challenging, particularly for older or poorly documented distribution networks.

Sensitivity to Model Parameters: Analytical techniques are sensitive to the assumptions and parameters used in the model. Small changes in model inputs or assumptions can lead to significant variations in the reliability estimates, making it difficult to assess the robustness of the results.

Limitations of Simulation-Based Approaches:

a) **Computational Intensity**: Simulation-based approaches, such as Monte Carlo simulations or time-domain simulations, can be computationally intensive, especially for large-scale distribution networks or long-duration studies. This can result in long simulation times and resource-intensive computations.

b) **Model Complexity**: Developing accurate simulation models for distribution feeders requires detailed representations of network components, load behaviors, and operational constraints. Managing the complexity of these models and ensuring their validity and accuracy can be challenging.

c) **Data Requirements**: Simulation-based approaches rely on extensive data inputs, including feeder topology, load profiles, equipment characteristics, and system parameters. Obtaining and maintaining these data sets can be resource-intensive and may require access to proprietary or confidential information.

d) **Model Calibration and Validation**: Simulation models need to be calibrated and validated against real-world data to ensure their accuracy and reliability. This process can be time-consuming and may require access to field measurements, historical outage data, or other sources of empirical data.

e) **Scalability**: Scaling simulation models to larger distribution networks or longer time horizons can be challenging due to computational limitations and memory constraints. This may limit the applicability of simulation-based approaches to certain types of studies or analyses.

In summary, both analytical techniques and simulation-based approaches have their limitations when applied to reliability estimation in distribution feeders. So in proposed method the to consider the complexity of network topology characterization of feeder should consider, all whole feeder should be breakdown in 4 type of structure.

1.1.8 Simulation and Case Study of Real Feeder

Simulation studies play a important role in reliability calculation of distribution feeder. In first step explicit formula-based Reliability estimation used to calculate Reliability of 33 bus of reliability test system called IEEE-33 Bus RBTS system and to calculate the reliability of real system in this thesis for case study Baneshwor 11 kV feeder is taken whose relevant data was collected from NEA, Baneshwor distribution center.

1. 2. Problem Statement

The main motive of this research is to estimation reliability of the distribution networkby using an improved explicit estimation algorithm to show the suitability of the proposed method in obtaining accurate reliability index for diversified network topology. Calculating the value of β, the consumer identification factor, is complex due to its dependence on network topology and load distribution, which prevents S_D from being expressed by a straightforward formula. In the analytical method, the calculation of β is simplified by assuming a simple radial feeder with a uniformly distributed load. However, in practice, feeders are not simple radial structures, and loads are not uniformly distributed, leading to errors. To minimize these errors, the 'simple radial feeder structure' is replaced by several typical feeder topologies, and the parameter β is formulated accordingly.

1. 3. Objectives

The primary goal of the thesis proposal is to calculate the reliability of a distribution network by utilizing enhanced explicit estimation algorithms.

- ✓ In first Step Reliability estimation of Standard IEEE 33 Bus distribution Network using Improved explicit estimation algorithms.
- ✓ In Second Step Reliability estimation of Baneshwor 11 kV feeder using Improved explicit estimation algorithms.

1. 4. Scope

- Feeder Topology Clustering
- Feeder Topology Characterization
- Topology difference measurement
- Hierarchical clustering
- Planning and policy recommendations.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

The distribution systems serve as the crucial link between the bulk power system and customers, with most customer interruptions stemming from failures within these systems. Various classical methods exist to estimate the reliability of distribution networks, such as approximate evaluation algorithms for reliability indices. However, these methods often fail to provide highly precise data on the reliability indices of distribution networks.

This literature review endeavors to explore a wide array of existing research articles that delve into the estimation of distribution network reliability. Despite efforts, many studies have encountered difficulties in achieving precise results, especially when dealing with intricate and diverse distribution networks. By delving deeply into pertinent literature, this review aims to provide a comprehensive understanding of the current state of research, pinpoint areas where gaps exist, and underscore critical aspects that warrant focus for the proposed thesis. Understanding these nuances will be essential for advancing the field and addressing challenges in network reliability assessment effectively.

[1]-[3]: The mathematical framework for explicit reliability indices of distribution systems has been developed, encompassing factors such as equipment count, failure rates, and normalized customer loads. This paper also elaborates on four distinct topological configurations.

In [11], how different three types of case considered for each equipment has been studied and also general concept of T_A, T_B, T_C has been studied.

In [6], how tree edit distance minimal path has been set in given topological structure. The mapping of topology and how isomorphic condition is full-filled is considered.

In [8],[9] in these research paper describes about Reconfiguration of Distribution system network for reliability enhancement using optimization tools. In this paper also describe about how four types of clusters obtained for distribution system using optimization tools.

In [5] and [10] : These paper describes about the approximate evaluation and monte-carlo simulation for the reliability indices calculation of distribution system but these methods only considered the simple radial structure of feeder.

So, for the any complex topology feeder network these methods not Calculate more accurate result. So, for estimation of reliability indices for complex topological distribution system network in this thesis explicit formula-based reliability estimation method is used. In this method all cases that should happen during fault condition of distribution feeder is considered. Thus, this method is preferred for the estimation of reliability indices of complex topology distribution network in this thesis.

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CHAPTER 3. METHODOLOGY

3.1 Introduction

This chapter focuses on estimating reliability indices using an explicit formula-based approach. The primary objective is to determine the β value, which represents the customer identification factor. To achieve accurate and efficient β calculation with minimal input data, the study introduces feeder topology clustering and the TED method. Subsequently, using the calculated β value, the thesis will estimate the reliability indices of IEE RBTS and assess the reliability of the Baneshwor feeder.

3.2 Data processing

Data processing aims to obtain a comprehensive and accurate dataset for subsequent analysis. Contacted distribution center (NEA, Baneshwor Distribution Center) to collect the necessary data. In cases where data is missing, fill in the missing values by using data from the same hour one week prior and then calculate the average value. This approach ensures that the dataset is complete and suitable for thorough analysis.

3.3 Feeder Topology Clustering

3.3.1 Feeder Topology Characterization

In generally Distribution feeder design as a "closed-loop design and open-loop operation" principle is a common approach used in the design and operation of medium-voltage distribution networks worldwide. This principle dictates that distribution feeders are built with closed-loop configurations, but during normal operation, these loops are opened by opening switches. As a result, the feeder behaves like a tree or radial structure.

In summary, both analytical techniques and simulation-based approaches have them limitations when applied to reliability estimation in distribution feeders

It looks like the focus here is on differentiating between the load transfer capabilities and failure isolation of various network topologies, particularly by examining sectional devices such as those installed in the branch boxes of underground cables or overhead lines. The process concentrates on the connections between the main line and the branch box.

For instance, let's consider a typical ring structure cable feeder. In this case, the topology characterization process results in two topological structures: A and B.

- **Topological Structure A**: This represents the original line topology, likely including the main line and branch boxes, as well as any connections or branching points along the feeder.
- **Topological Structure B**: This represents the characterization result, which may involve simplifying or abstracting the original topology to focus specifically on the connections between the main line and the branch boxes. This characterization aims to highlight the key structural features related to failure isolation and load transfer capabilities.

The characterization process may involve analyzing the connectivity patterns, the arrangement of sectional devices, and the redundancy or alternative pathways within the feeder network. By focusing on the connections between the main line and the branch boxes, the characterization aims to provide insights into how different topological configurations affect the network's ability to isolate faults and transfer loads in the event of disruptions.

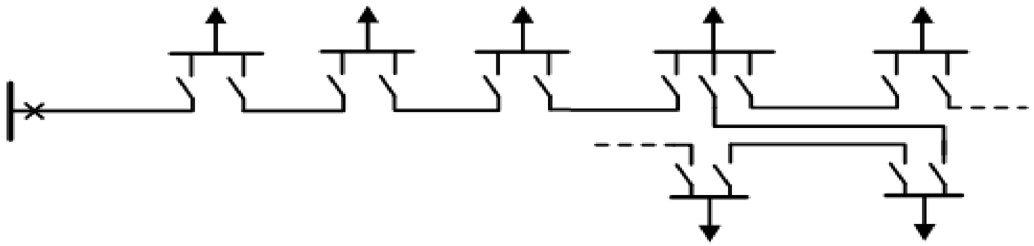


Fig: A

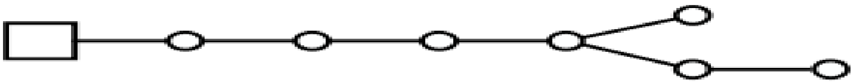


Fig: B

Figure 2.1: Topological characterization result

Fig. 2.1 likely illustrates the differences between the original line topology (A) and the characterized topology (B), highlighting any modifications or simplifications made during the characterization process. This visualization can help researchers and practitioners understand the structural differences between the two topologies and how they may impact the feeder's reliability and resilience.

3.3.2 Topology difference measurement

Tree Edit Distance (TED) is a computational algorithm designed to assess the similarity or dissimilarity between two hierarchical structures represented as trees. It achieves this by determining the smallest sequence of node edit operations required to transform one tree into another. These operations typically involve inserting, deleting, or substituting nodes. TED provides a robust method for quantifying the structural differences within complex hierarchical data, offering valuable insights into their comparative analysis.

3.3.2.1 Tree edit distance (TED)

The Tree Edit Distance (TED) algorithm is utilized to quantify the disparity between two trees by identifying the smallest sequence of node edit operations necessary to transform one tree into another at minimal cost.

Here's how the Tree Edit Distance algorithm typically works:

a. **Input**: The algorithm takes two input trees, often referred to as the source tree and the target tree, which are the trees to be compared.
b. **Node Edit Operations**: The TED algorithm defines a set of nodes edit operations that can be applied to the source tree to transform it into the target tree. These operations typically include:
    - Insertion: Adding a new node to the source tree.
    - Deletion: Removing a node from the source tree.
    - Substitution: Modifying a node in the source tree to match a node in the target tree.
    - Relabeling: Changing the label of a node in the source tree.
c. **Cost Assignment**: Each node edit operation is associated with a cost, representing the effort or distance required to perform the operation. The TED algorithm assigns costs to these operations based on various factors, such as the structural similarity between nodes or the semantic meaning of labels.
d. **Dynamic Programming**: The TED algorithm employs dynamic programming techniques to efficiently compute the minimum cost sequence of node edit operations. By breaking down the problem into smaller subproblems and storing intermediate results, the algorithm avoids redundant computations and finds the optimal solution.
e. **Optimal Alignment**: The TED algorithm produces an optimal alignment

between the nodes of the source tree and the nodes of the target tree, along with the corresponding edit operations and their costs. This alignment represents the most cost-effective transformation from the source tree to the target tree.

f. **Output**: The output of the TED algorithm is typically the minimum edit distance or cost required to transform the source tree into the target tree, along with the sequence of edit operations that achieve this transformation.

Overall, the Tree Edit Distance algorithm is a powerful tool for comparing and analyzing tree structures, allowing for the quantification of similarity or dissimilarity between hierarchical data representations. It finds applications in diverse domains where tree-like structures are prevalent, providing valuable insights into the relationships and differences between complex data sets.

In the context provided, where *Cd* and *Ci* are assigned values of 1 while *Cc* is assigned a value of 0, it seems like these variables are being used to represent costs associated with different types of nodes edit operations in the Tree Edit Distance (TED) algorithm. Here's what these variables likely represent:

- *Cd*: This could represent the cost associated with a deletion operation. In the context of tree editing, a deletion operation would involve removing a node from the source tree to transform it into the target tree. Assigning a cost of 1 to *Cd* means that performing a deletion operation incurs a unit cost.
- *Ci*: This could represent the cost associated with an insertion operation. In tree editing, an insertion operation involves adding a new node to the source tree to match the structure of the target tree. Assigning a cost of 1 to *Ci* indicates that performing an insertion operation also incurs a unit cost.
- *Cc*: This could represent the cost associated with a relabeling operation. In some versions of the TED algorithm, relabeling operations involve changing the label of a node in the source tree to match the label of a corresponding node in the target tree. However, in this context, *Cc* is assigned a value of 0, which might imply that relabeling operations are not allowed or are considered to have zero cost.

By assigning costs to different types of nodes edit operations, the TED algorithm can determine the minimum cost sequence of operations required to transform one tree into another. This allows for a quantitative comparison of tree structures based on the costs of the edit operations needed to align them, providing insights into their structural similarity or dissimilarity.

Expanding tree structures to ensure they have the same number of nodes before applying the Tree Edit Distance (TED) algorithm is a practical approach to address the issue of different-sized feeders potentially impacting the TED result. By ensuring uniformity in the number of nodes, you create a fair basis for comparison between the tree structures.

Here's a breakdown of the approach:

a. **Topology Characterization**: Initially, each feeder's topology is characterized, resulting in tree structures with varying numbers of nodes. This variation might occur due to differences in the feeder's size, complexity, or configuration.

b. **Expanding Tree Structures**: To standardize the comparison process, all tree structures are expanded by inserting additional nodes. These nodes are inserted following the sequence of node IDs, ensuring that the expanded trees have the same number of nodes.

c. **Uniform Node Numbers**: After expansion, all feeder tree structures have an equal number of nodes. This step ensures that the TED algorithm is applied to trees of comparable size, mitigating the impact of size discrepancies on the TED result.

d. **TED Implementation**: With the expanded tree structures, the TED algorithm is implemented to compute the tree edit distance between pairs of trees. The algorithm identifies the minimum cost sequence of node edit operations required to transform one tree into another.

e. **Result Interpretation**: The TED results obtained from the expanded tree structures provide a fair comparison of the structural differences between feeders, independent of their original sizes. This standardized approach facilitates meaningful analysis and decision-making based on the TED distances calculated.

By expanding the tree structures to have uniform node numbers before applying the TED algorithm, ensure that the resulting TED distances accurately reflect the structural dissimilarities between the feeders, without being influenced by variations in their sizes.

3.3.3 Estimation method for network reliability

Equations (1) and (2) likely pertain to a mathematical model or algorithm described in the thesis. Without specific context, provide a general explanation of how one might calculate the parameter β quickly and then obtain its expression through regression analysis.

a. **Calculate β for Typical Topologies**: The first step involves selecting typical topologies or scenarios relevant to the problem domain. These topologies represent common configurations or conditions encountered in practice. For example, in the context of electrical power systems, typical topologies might include radial feeders, meshed networks, or looped configurations.

b. **Sectional Analysis**: Each typical topology is divided into sections or segments based on relevant criteria. For instance, in an electrical power system, sections might correspond to individual branches, nodes, or substations.

c. **Calculate β for Each Section**: Within each section of the typical topology, calculate the parameter β using Equations (1) and (2) or any other relevant equations from the paper. This calculation involves analyzing the characteristics of the section, such as its impedance, load distribution, or operational parameters.

d. **Regression Analysis**: Once β values have been calculated for various sections of the typical topology, perform regression analysis to obtain an expression for β. Regression analysis involves fitting a mathematical model to the data (in this case, the calculated β values) to find the relationship between the independent variables (section characteristics) and the dependent variable (β).

e. **Obtain Expression for β**: The regression analysis yields an expression that relates the parameter β to the relevant characteristics of the sections within the typical topology. This expression provides a predictive model for estimating β based on the inputs associated with a given section.

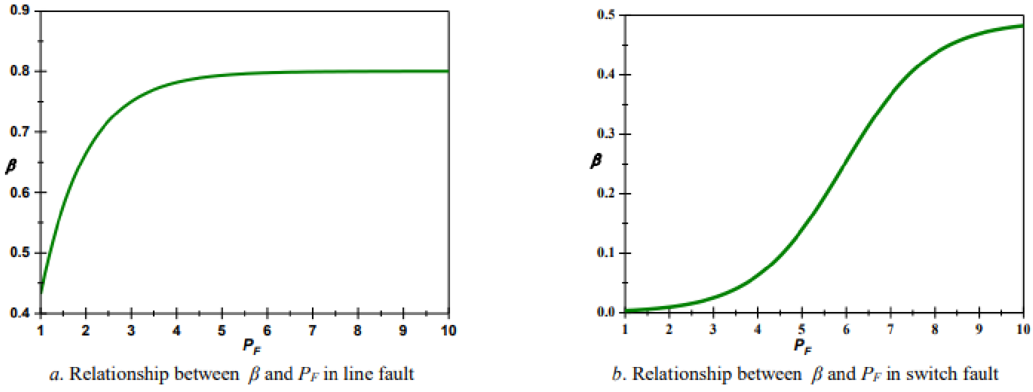
f. **Use of Improved Estimation Algorithm**: The obtained expression for β can then be used within the improved estimation algorithm to quickly calculate β for arbitrary topologies or scenarios. Instead of performing detailed calculations for each topology, the algorithm can utilize the regression-derived expression to estimate β based on the characteristics of the sections involved.

In calculation of β following condition should be considered:

a. Analysis of failure isolation capability

The provided text describes the establishment of a functional relationship between the fault isolation capability parameter βAk and the number of feeder segments (PF) through regression analysis. Three different functional forms are considered: linear, exponential, and sigmoid functions. The choice of the function is based on the observed behavior of βAk with respect to PF.

From reference paper [2] relationship between β and $\boldsymbol{P_F}$



a. Relationship between *β* and P_F in line fault

b. Relationship between *β* and P_F in switch fault

Figure 2.2: Between β and $\boldsymbol{P_F}$

From above two figure following equations are concluded

F(x)=ae^{-bx}+c ....(3)

F(x)= (ax+b)/(x+c) ………………………(4)

F(x)= a$(1+\frac{b}{x})^x$ ....(5)

Let's break down the key points mentioned in the text:

I. **βAk and Fault Isolation Capability**: The parameter βAk represents the fault isolation capability, and it becomes stronger as βAk increases. In practical scenarios, βAk typically ranges between 0 and 1. The fault isolation capability improves with an increasing number of feeder segments (PF), leading to a stronger βAk until it reaches a certain limit.

II. **Regression Analysis for Functional Relationship**: Fig. 2(a) presumably shows the relationship between βAk and PF. Regression analysis is applied to establish a functional relationship between βAk and PF. Three different functional forms are considered: linear (Equation 3), exponential (Equation 4), and a more complex sigmoid function (Equation 5).

III. **Constraint and Selection of Regression Function**: The constraint $0 \le f(x) \le 1$ ensures that the resulting function remains within the valid range for βAk. The regression function with the highest correlation coefficient is selected as the formula for βAk, denoted as βAk = f1(PF).

IV. **Switch Failure Scenario**: In situations where a switch failure occurs and the circuit breaker fails to isolate the fault or transfer the load, the change trend of βAk with PF is similar to a sigmoid function, as observed in Fig. 2(b). Therefore, a sigmoid function is introduced into the regression analysis to model this behavior (Equation 5).

Overall, the text outlines the process of establishing a functional relationship between βAk and PF using regression analysis, considering different functional forms based on the observed behavior of βAk in different scenarios. The resulting regression function provides a predictive model for estimating βAk based on the number of feeder segments.

b. Analysis of load transfer capability

In this section we discussing the impact of adding tie-lines to feeders in a power distribution system. These tie-lines allow for the transfer of customers to reserve generation in the event of a failure. This introduces a new parameter, P_z (the transfer rate), which affects the load factor β_{3k}. Since β_{3k} is influenced by both power factor (P_F) and transfer rate (P_z), it becomes a multiple regression problem. To simplify the problem, we're considering two common conditions for P_z: 0% (no transfer capacity) and 100% (full transfer capacity). By doing this, we can focus the regression analysis on the relationship between P_F and β_{3k}, as the other variable (P_z) is fixed. Using this approach, you can develop a linear function that connects the two extreme conditions (P_F, 0%) and (P_F, 100%), allowing you to adapt to other P_z conditions. After that drive a relation between β_{3k} and P_F through the regression analysis.

c. Analysis of load transfer capability

The benefits of distribution automation terminals in improving fault identification and reducing fault clearance time in power distribution networks. When distribution automation terminals are installed along the feeder, they play a crucial role in quickly identifying fault locations and facilitating rapid fault clearance. This leads to improvements in two key parameters:

I. $\boldsymbol{T_{dw}}$: Downstream Fault Detection Time - With automation terminals in place, the time taken to detect faults downstream ($\boldsymbol{T_{dw}}$) is significantly reduced.

II. **β**: Load Factor - The presence of automation terminals also rectifies the load factor (β), likely by minimizing disruptions and optimizing power flow within the network.

In a closed single-loop network with dual power supply, protection mechanisms are employed to isolate fault segments while maintaining power supply to the rest of the network.

- $\boldsymbol{T_{dw}}$, $\boldsymbol{T_{dn}}$, $\boldsymbol{T_{g}}$, and $\boldsymbol{T_{z}}$ (presumably representing various fault detection and clearance times) are set to 0 during calculations. This adjustment enhances the reliability of the distribution network by minimizing downtime and ensuring continuous power supply to unaffected sections.

3.4 Algorithms of Method Implementation

This pseudo-code outlines the implementation steps for the proposed method based on the analysis provided:

```
I.    Set the value of $\boldsymbol{P_F}$, $\boldsymbol{P_{DE}}$ $\boldsymbol{N_E}$, $\boldsymbol{P_{DE}}$, $\boldsymbol{P_Z}$, $\boldsymbol{P_{Ds}}$, T, $\boldsymbol{ux}$ etc.
II.   Input the topology structure of selected candidate feeder.
III.  Compute the Topology characterization of selected candidates' feeder.
IV.   Using TED method Differentiate each type with rest one.
V.    Using Agglomerative hierarchical clustering algorithm (AHCA) each cluster are merged in "Bottom up'' approach.
VI.   Generate different four type of cluster of feeders.
VII.  Calculate the value of β for every type clustered feeder structure of all three different condition.
VIII. Now using equation 1 and 2 calculate the of value of SAIFI and SAIDI.
```

3.4.1 Flow chart representation of Method Implementation

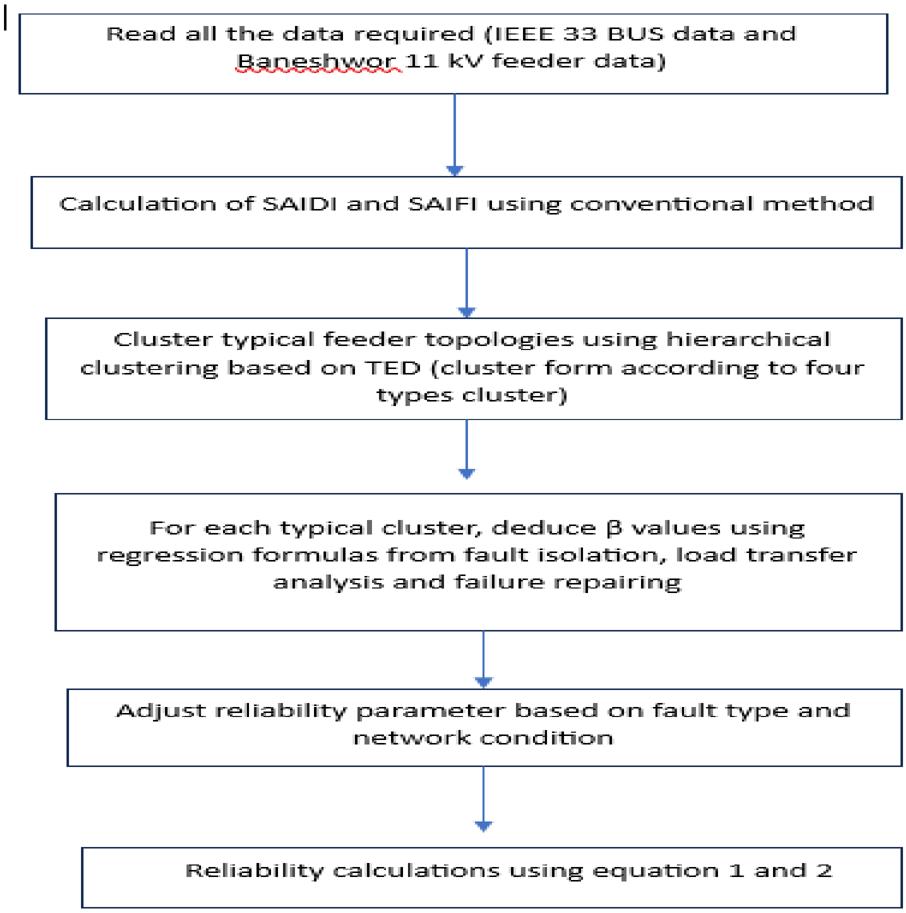


Figure 3.1: Flow chart representation of Method Implementation

In first Step Initialize parameters (e.g., feeder topology, failure data) means input the bus data, line data total number equipment, failure rate and reliability related data.

In Second step Extract feeder topology structures focusing on fault isolation and load transfer and Cluster typical feeder topologies using hierarchical clustering based on TED distance. Using TED method all topology made same number of nodes by insertion, deletion, substitution and relabeling.

In third step for each feeder, deduce β values using regression formulas derived from fault isolation, load transfer analysis and failure repairing.

In fourth step Adjust reliability parameters based on fault type and network conditions that means each type of topology there are 15 number of values of β because in this study 5 type of equipment is considered and for each equipment three types of customers is exist.

In fifth and final step Calculate reliability indices (SAIFI, SAIDI) using derived formulas for network evaluation and planning that is from equation 1 and 2.

3.5 Classification of Main feeder into clustered feeder structure

In first Step Standard IEEE RTS distribution Network is taken using above method of feeder clustering, it seems that the algorithm successfully clusters the feeders into distinct types based on their characteristics, possibly considering factors such as topology, capacity, and connectivity within the distribution network. The effectiveness and feasibility of the algorithm are demonstrated through the successful clustering of the real-world distribution network data. The clustering results depicted in Figure 3 likely provide insights into the structure and organization of the feeders within the distribution network.

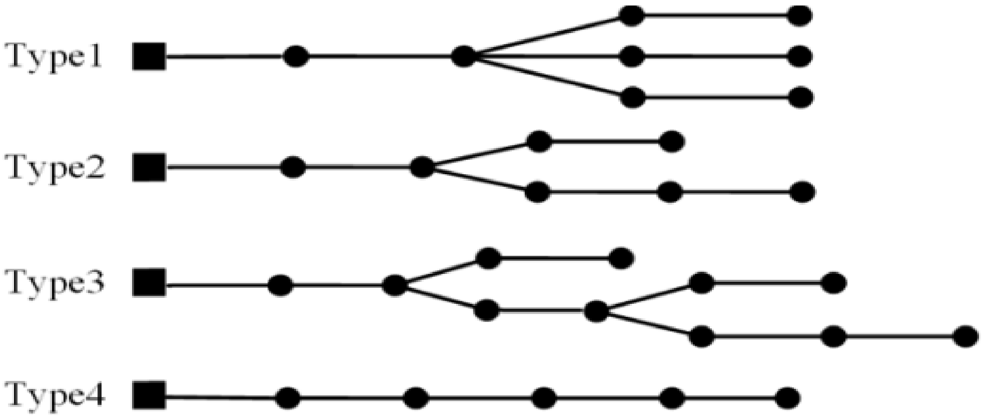


Figure3.2: Typical topology of each clustered feeder Structure

In Standard IEEE 33 bus system RTS distribution Network this method is used and *Cd* and *Ci* are assigned values of 1 while *Cc* is assigned a value of 0. After using Tree edit distance AHCA method network is clustered in above four types. The proportion of the four types of feeders is distributed as follows: 13% for type 1, 21% for type 2, 16% for type 3, and 50% for type 4. This distribution indicates that while type 4 feeders constitute the largest portion with 50%, the other types also contribute significantly to the overall distribution of feeders.

Let's break down what this distribution means:

1. **Type 4 (50%)**: This type comprises the majority of the feeders, representing the largest proportion. It indicates that a significant portion of the distribution network exhibits characteristics or features associated with type 4 feeders.
2. **Type 2 (21%)**: Type 2 feeders constitute a substantial portion of the distribution network but are less prevalent than type 4 feeders. They represent a significant segment of the network and may exhibit distinct characteristics or topology compared to other types.
3. **Type 3 (16%)**: Type 3 feeders represent a moderate proportion of the distribution network. While they are less common than type 4 and type 2 feeders, they still contribute significantly to the overall distribution network.
4. **Type 1 (13%)**: Type 1 feeders constitute the smallest proportion of the distribution network, representing the least prevalent type among the four. However, they still play a role in the overall network and may have specific characteristics or attributes that differentiate them from other types.

Overall, this distribution suggests that the distribution network comprises a diverse mix of feeder types, with type 4 feeders being the most prevalent. Understanding the distribution of feeder types is valuable for network planning, optimization, and maintenance, as it provides insights into the network's structure, characteristics, and potential areas for improvement.

3.6 Reliability analysis of distribution network

Reliability is the probability of a system that it performs satisfactorily for the period of time under the set of operating conditions. Reliability of the distribution network closely related to the satisfaction level of customers. For evaluation of the reliability indices of the distribution network, data of failure rate (λ_j), repair rate (μ), average outage duration rate (U_j), and number of consumers of the buses of the distribution network (N_i) is taken from the reference paper no.

$$SAIFI = \frac{\sum \lambda_j N_j}{\sum N_j}$$

$$SAIDI = \frac{\sum U_j N_j}{\sum N_j}$$

$$CAIDI = \frac{\sum U_j N_j}{\sum \lambda_j N_j}$$

$$ENS = \sum L_j U_j$$

$$AENS = \frac{L_j U_j}{\sum N_j}$$

SAIFI, CAIDI, SAIDI, ENS, and AENS are critical indices used to assess the reliability and performance of a power distribution system:

1. **SAIFI (System Average Interruption Frequency Index)**: quantifies the average number of power interruptions encountered by a customer during a specified timeframe, offering insights into the frequency of interruptions across the system.
2. **SAIDI (System Average Interruption Duration Index)**: Represents the average duration of interruptions per customer served over a given period, illustrating the reliability of the system in terms of interruption duration.
3. **CAIDI (Customer Average Interruption Duration Index)**: Calculates the average duration of interruptions for customers who experience at least one interruption during a year, providing insight into the typical outage duration for affected customers.
4. **ENS (Energy Not Supplied)**: Quantifies the total energy not delivered by the system during interruptions, serving as an indicator of energy deficiency or outage impact.
5. **AENS (Average Energy Not Supplied)**: Reflects the average amount of energy not supplied by the system over a specific time period, offering a measure of the average load curtailment or energy shortfall experienced by customers.

These indices collectively provide a comprehensive view of the reliability, outage characteristics, and energy shortfall within a distribution network, aiding in performance evaluation and improvement planning.

The component failure model is represented by a two-state Markov model, distinguishing between a failure state and a working state, as depicted in Figure 3.3. Here, λ signifies the failure rate of the component, while μ denotes its repair rate.

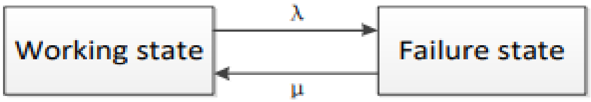


Figure 3.3: Two state failure model.

CHAPTER 4. RESULTS AND DISCUSSION

4.1 Reliability estimation of IEEE Standard 33 Bus system

In first step estimate the reliability of IEEE standard 33 bus whose bus data, line data, tie line data and data for reliability calculation is presented in annex. The single line diagram of IEEE 33 bus is presented below.

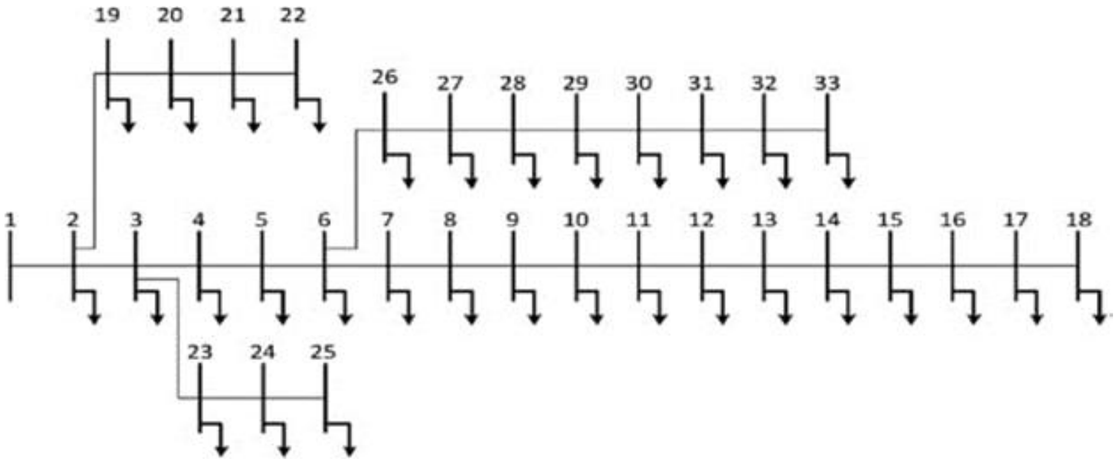


figure 4. 1 single diagram of IEEE 33 bus

Now for reliability calculation first step is to calculated value of β here we set the value of cost node delete and cost of node insertion is 1 and cost of node replacing/substitution is 0(i.e C_d, C_c is 1 and C_c is 0). After that we apply TED based hierarchical clustering algorithm above system can be clustered into 4 types.

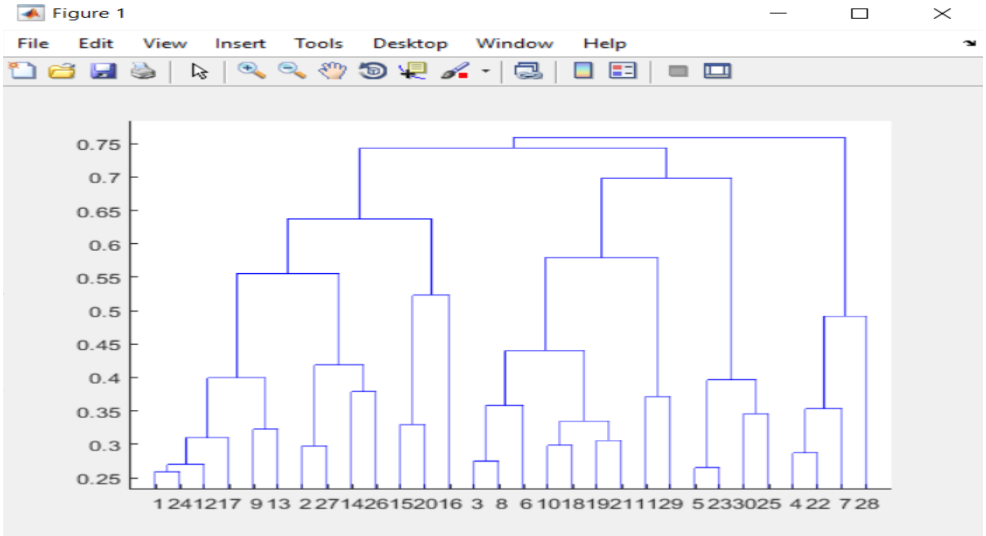


figure 4. 2: type 1 cluster, dendrogram of IEEE 33 Bus

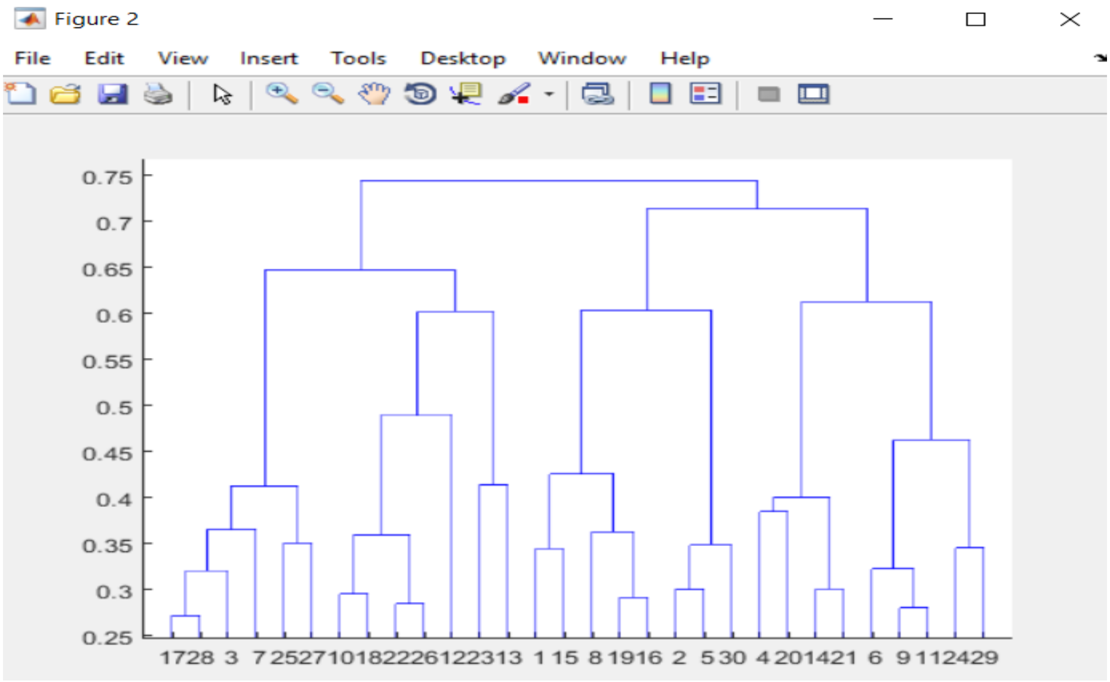


figure 4. 3: type 2 cluster, dendrogram of IEEE 33 BUS

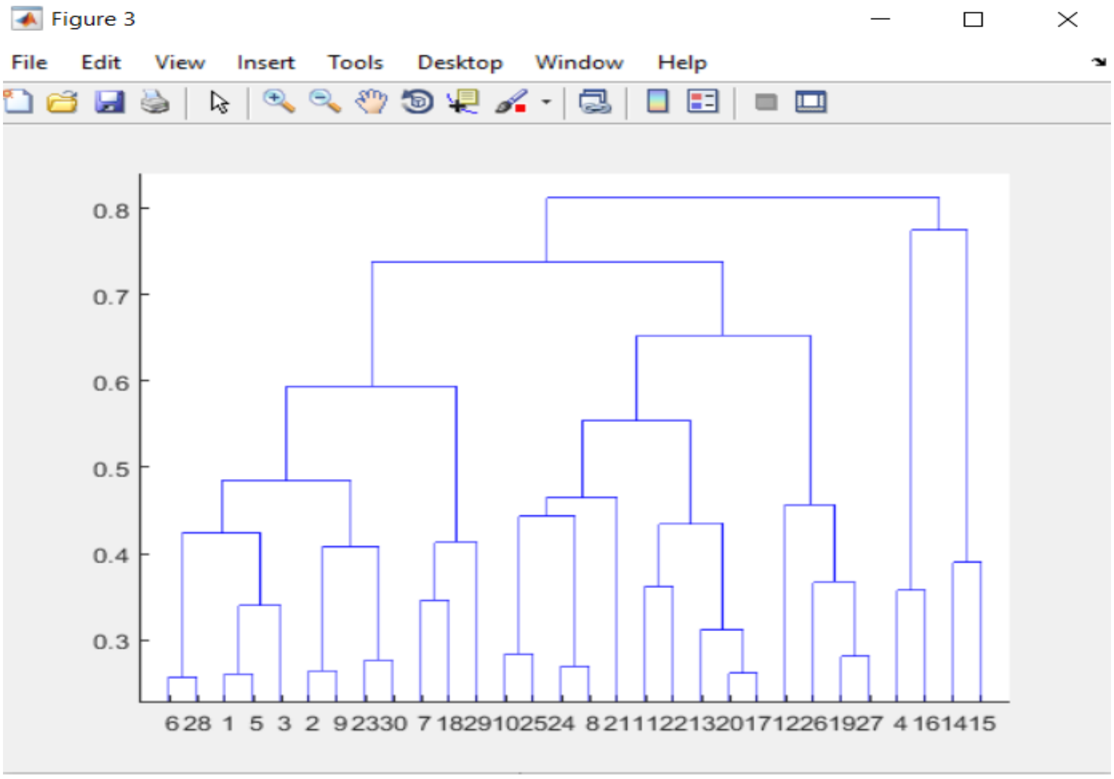


figure 4. 4: type 3 cluster, dendrogram of IEEE 33 Bus

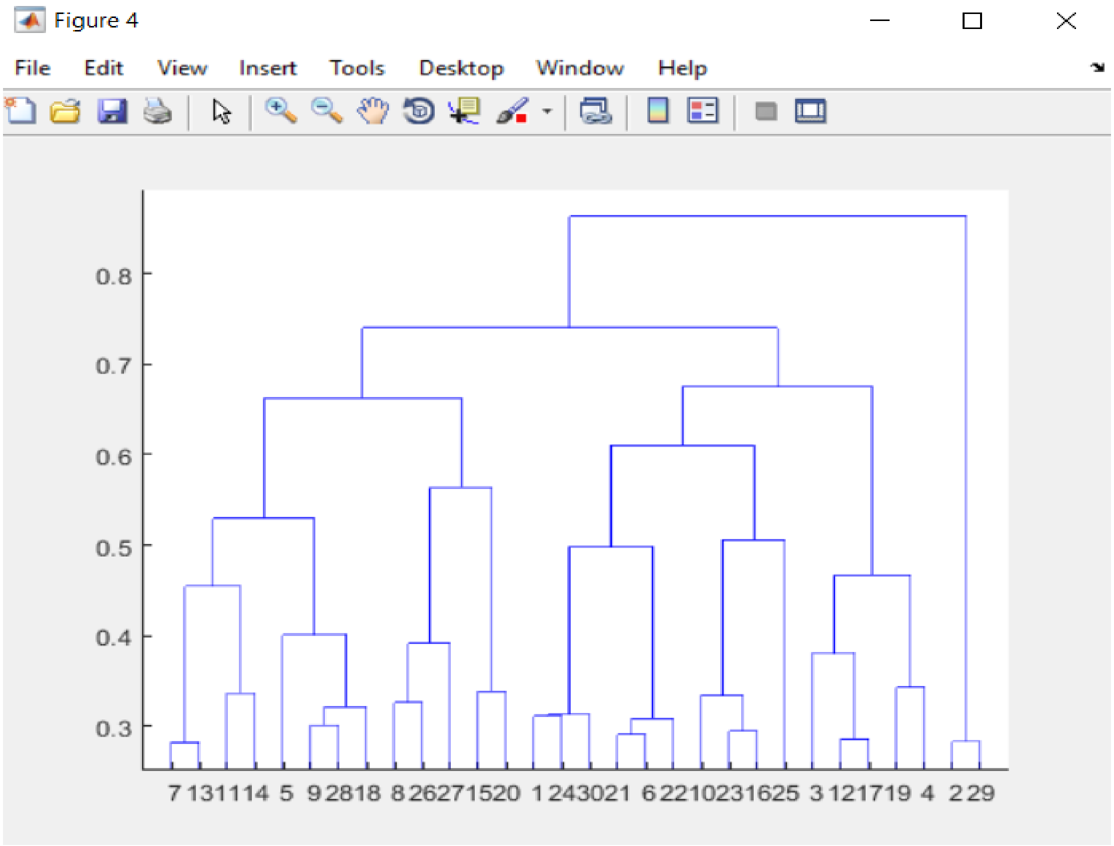


figure 4. 5: type 4 cluster, dendrogram of IEEE 33 Bus

From above method it can be indicates that although the majority of the feeders belong to the "simple radial structure" (type 4), comprising 50% of the total, there are still significant numbers of feeders classified as "big branch structure" (type 2) at 21%, and "multiple branch structure" (type 1 and 3) at 13% and 16%, respectively.

This distribution suggests a diversity in the topology of the distribution network. While the simple radial structure is predominant, the presence of big branch and multiple branch structures implies that there are variations in the network configuration. Furthermore, the mention that these structures are more common in overhead lines provides additional context regarding their physical characteristics and potential operational considerations.

Now the value of β can be calculate different four type of cluster and for Cluster system contains five different equipment in system so there are five values of β. So, each value of β (i.e normalized customer identification) should consider three different Scenario. Since there are 15 values of β for each cluster. So, three different Scenario are:

Scenario	**Outage Time**	**Location**	**Action**
A	$T_A = T_{dw} + T_g$	Customer fall in Up-stream part of Failure point	failure locating time, failure isolating time
B	$T_B = T_{dw} + T_g + T_z$	Customer fall in Down-stream part of Failure point and transferred.	failure locating time, failure isolating time, load transfer time.
C	$T_C = T_{dw} + T_g + T_x$	Customer fall in Down-stream part of Failure point and not transferred, Failed user in failure point.	failure locating time, failure isolating time, load transfer time, and failure repairing time.

Using regression analysis is used to calculate the value of β.

Table 4 .1 Value of β four different types of clusters for three different scenarios

Topological structure type	type of Equipment	Scenario A	Scenario B	Scenario C
Type 1	CB	0.2736	0.8584	0.8069
	Transformer	0.0657	0.4602	0.0527
	BB	0.1175	1	0.1306
	BR	0.2194	0.6864	0.4536
	DS	0.2741	0.2114	0.0689
Type 2	CB	0.45	0.4975	0.4951
	Transformer	0.3156	0.4986	0.4970
	BB	0.4124	0.4962	0.4925
	BR	0.1843	0.4044	0.3184
	DS	0.1325	0.3575	0.2519
Type 3	CB	0	0.9999	0.9491
	Transformer	0	0.3739	0.7724
	BB	0.7155	0.8856	0.2004
	BR	0.4446	0.4809	0.001
	DS	0.0	1.0	0.0093
Type 4	CB	0.1328	0.3070	0
	Transformer	0.4099	0.3070	0
	BB	0.0068	0.4826	0.3653
	BR	0.5790	0.1345	0.0089

	DS	0.0875	0.0	0.1701

Now using Eq. 1 and 2 value of SAIFI and SAIDI calculated

Table 4.2 Value of SAIFI and SAIDI for different cluster

Topological structure type	Value of SAIFI	Value of SAIDI
Type 1	4.2086	23.8454
Type 2	4.3423	23.117
Type 3	4.2744	20.7164
Type 4	4.6506	21.5791

Table 4.3 Comparison of errors of reliability indices on different type.

Type	Average Errors of SAIDI		Errors on SAIFI in proposed algorithm
	Reference [4]	Proposed algorithm	
Type 1	21.32%	8.333%	7.6923%
Type 2	15.74%	5.00%	4.7619%
Type 3	16.89%	5.8824%	6.25%
Type 4	3.12%	1.9608%	2%

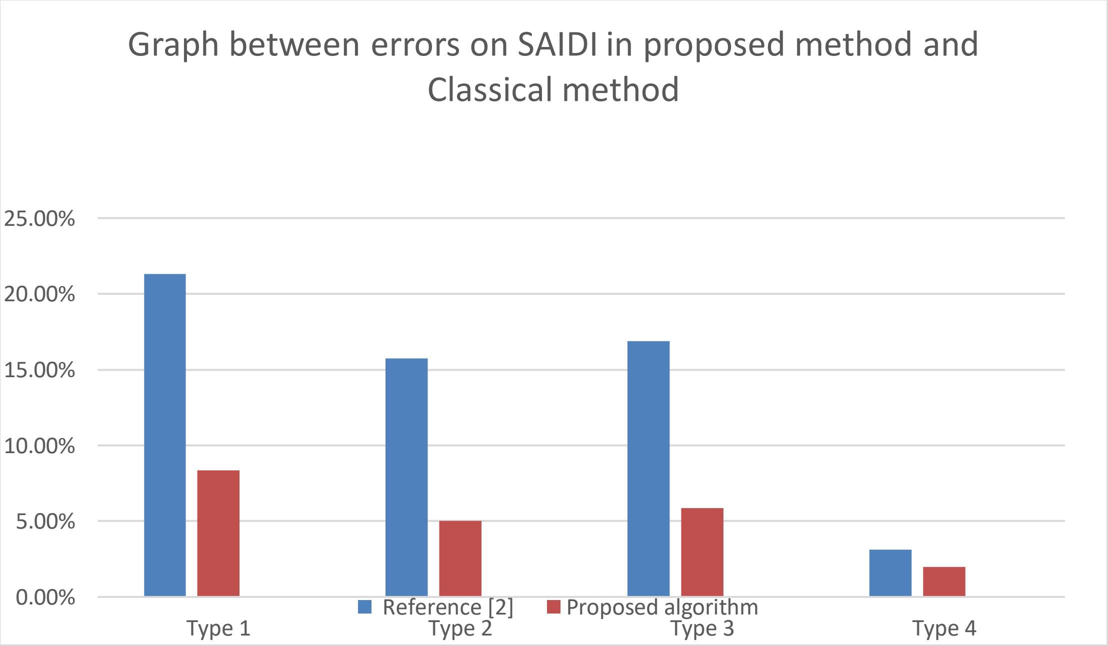


Figure 4.6: Graph between errors on SAIDI in proposed method and classical method

From above table 4.3 and fig 4.1 Graph clearly seen that in type one topology the errors percentage is 8.333% and in Reference [4] or in approximate method error is seen 21.32 % similarly type four topology the errors percentage is 1.9608% and in Reference [4] or in approximate method error is seen 3.12 % , type two topology the errors percentage is 5 % and in Reference [4] or in approximate method error is seen 15.74 % and for type three topology the errors percentage is 5.8824 % and in Reference [4] or in approximate method error is seen 16.89 %. The error in type four topological structure greatly reduced and it contains different branches so this method calculates more accurate value of SAIDI and SAIFI in difficult topology. In type four topology the error is seen closer in each algorithm because of simplicity in network topology.

4.2 Reliability estimation of 11 kV Baneshwor feeder

The analysis utilizes real system data from Nepal Electricity Authority (NEA) for the 11 kV Baneshwor feeder, encompassing 25 distribution transformers. The study incorporates scheduled and unscheduled outages from September 2022 to September 2023. Figure 4.7 illustrates the feeder diagram, with yellow dotted spots indicating transformers.

Figure 4.7: GIS mapping of Baneshwor feeder diagram

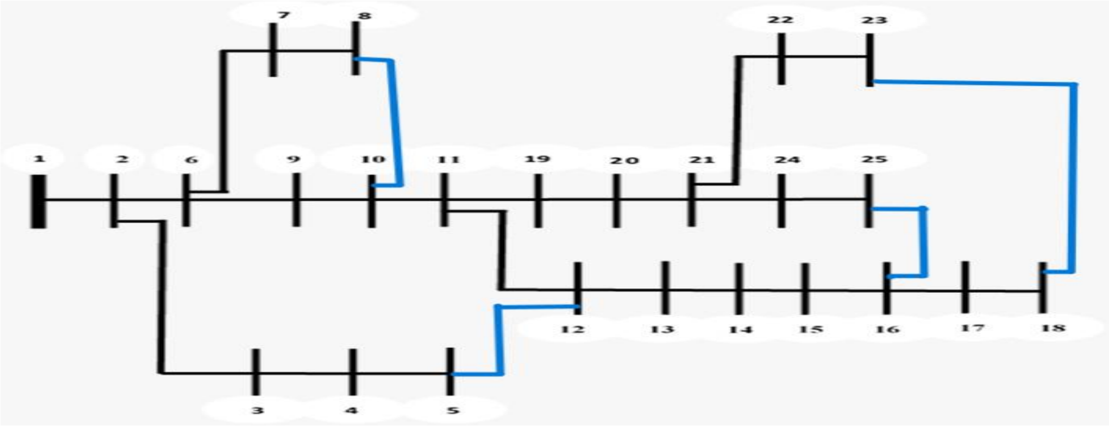


figure 4.8 Single line diagram of Baneshwor Feeder with Tie-ine

From figure 4.7 GIS mapping of Baneshwor feeder (topology) figure 4.8 is derived in this figure clearly seen that there are four different tie lines.

Now for reliability calculation first step is to calculated value of β here we set the value of cost node delete and cost of node insertion is 1 and cost of node replacing/substitution is 0(i.e C_d, C_c is 1 and C_c is 0). After that we apply TED based hierarchical clustering algorithm above system can be clustered into 4 types.

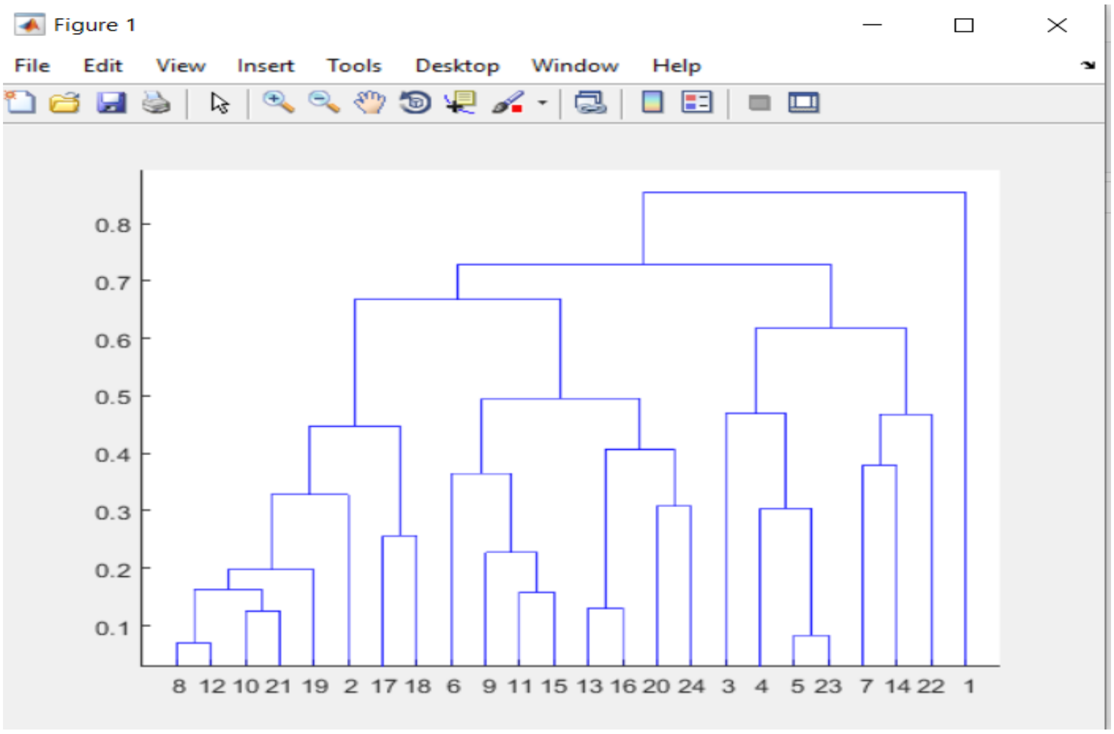


figure 4. 9: type 1 cluster, dendrogram of Baneshwor feeder

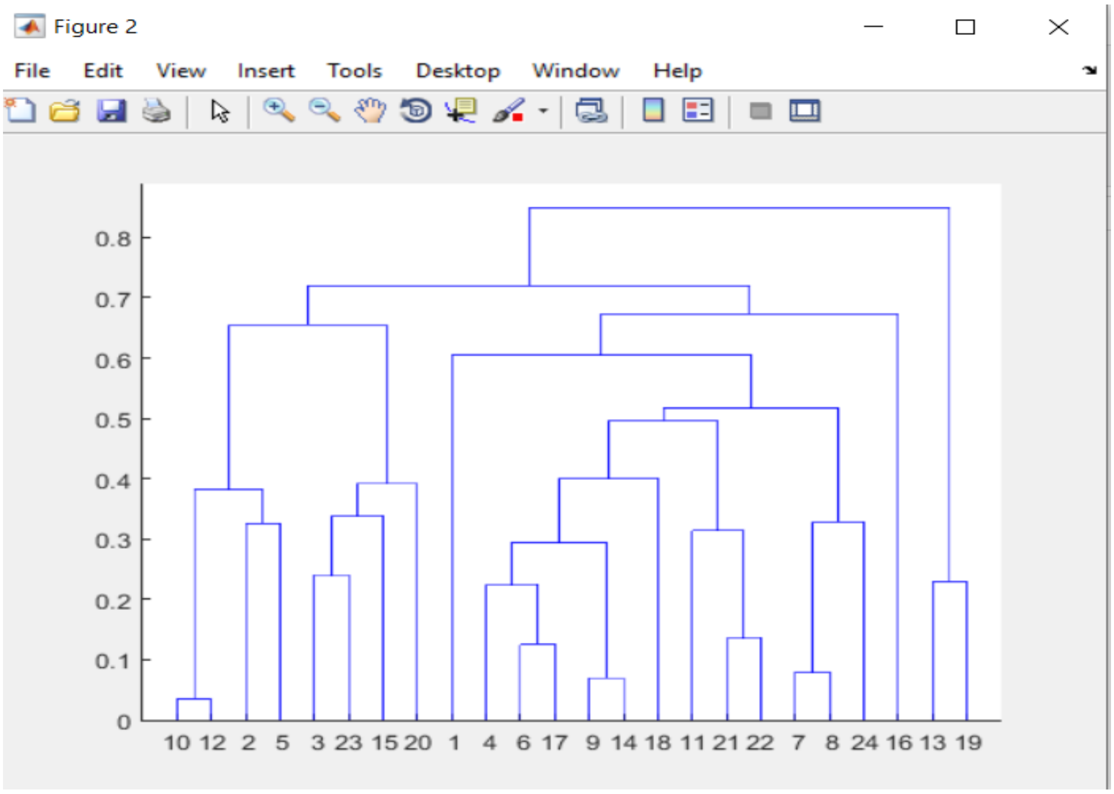


figure 4.10: type 2 cluster, dendrogram of Baneshwor Feeder

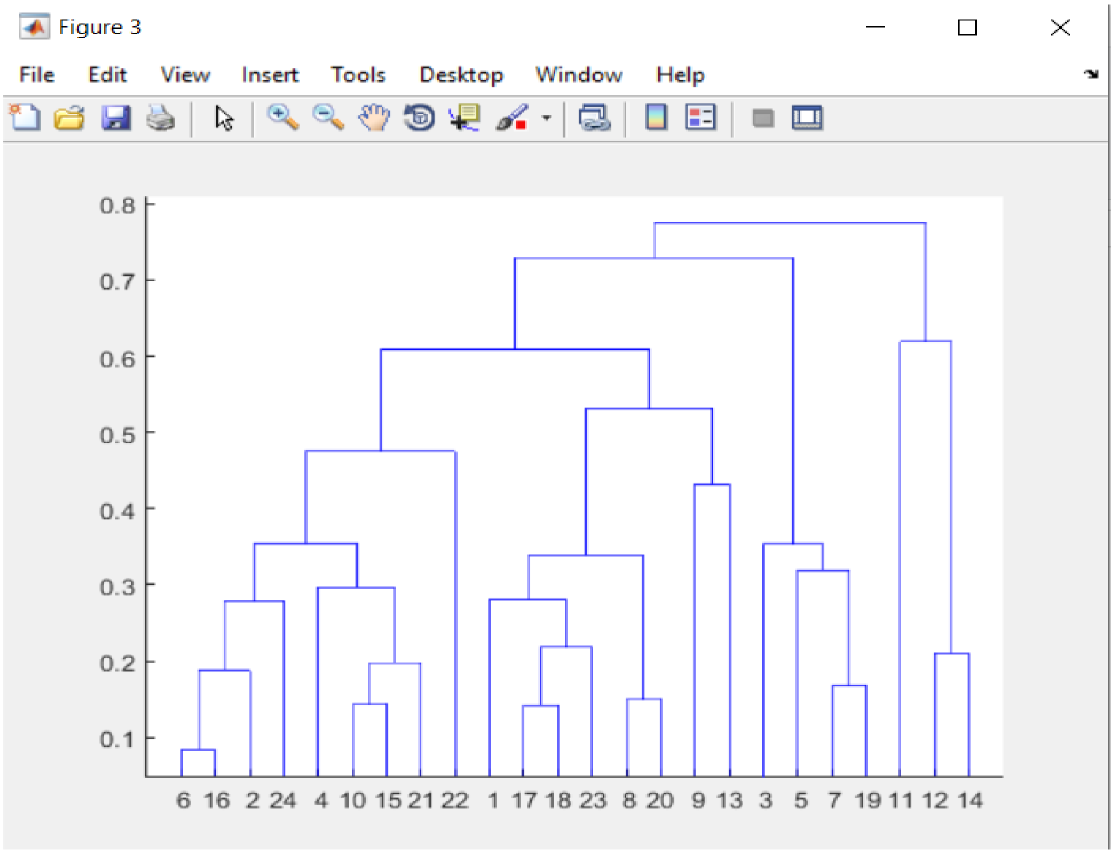


figure 4.11: type 3 cluster, dendrogram of Baneshwor feeder

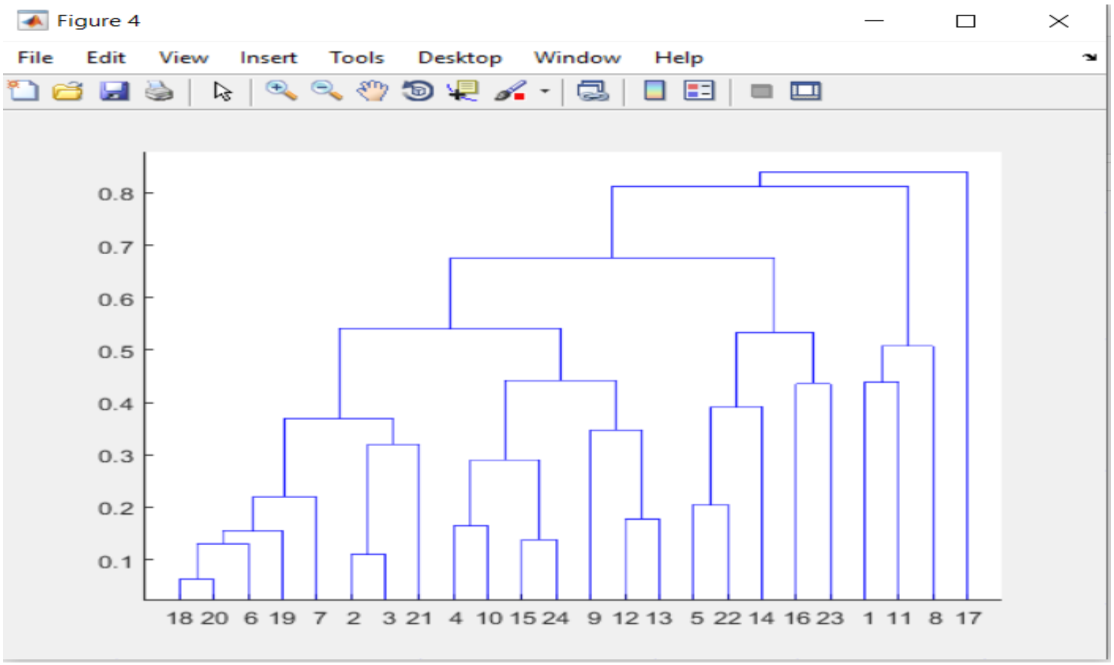


figure 4.12: type 4 cluster, dendrogram of Baneshwor feeder

Now using TED based hierarchical clustering algorithm the obtain result can be indicates that although the majority of the feeders belong to the "simple radial structure" (type 4), comprising 45% of the total, there are still significant numbers of feeders classified as "big branch structure" (type 2) at 25%, and "multiple branch structure" (type 1 and 3) at 13% and 17%, respectively.

This distribution suggests a diversity in the topology of the distribution network. While the simple radial structure is predominant, the presence of big branch and multiple branch structures implies that there are variations in the network configuration. Furthermore, the mention that these structures are more common in overhead lines provides additional context regarding their physical characteristics and potential operational considerations.

Now the value of β can be calculate different four type of cluster and for Cluster system contains five different equipment in system so there are five values of β. So each value of β (i.e normalized customer identification) should consider three different Scenario. Since there are 15 values of β for each cluster.

Table 4 .4 Value of β four different types of clusters for three different scenarios

Topological structure type	type of Equipment	Scenario A	Scenario B	Scenario C
Type 1	CB	0.4314	0.4959	0.4932
	Transformer	0.4109	0.4980	0.4954
	BB	0.4087	0.4953	0.4915
	BR	0.1757	0.3835	0.3034
	DS	0.1297	0.3522	0.2576
Type 2	CB	0.4313	0.4966	0.4911
	Transformer	0.4028	0.4980	0.4960
	BB	0.4113	0.4938	0.4900
	BR	0.1677	0.3448	0.2774
	DS	0.1351	0.3568	0.2774
Type 3	CB	0.422	0.4982	0.4918
	Transformer	0.3855	0.4989	0.4952
	BB	0.3963	0.4939	0.4908
	BR	0.1738	0.4447	0.2895
	DS	0.1152	0.4196	0.2315
Type 4	CB	0.3939	0.5036	0.4887
	Transformer	0.3552	0.4967	0.4934

	BB	0.3696	0.4938	0.4974
	BR	0.1201	0.6012	0.4326
	DS	0.1188	0.2898	0.1867

Now using Eq. 1 and 2 value of SAIFI and SAIDI calculated

Table 4.5 Value of SAIFI and SAIDI for different cluster

Topological structure type	Value of SAIFI	Value of SAIDI
Type 1	3.5587	16.3813
Type 2	3.7010	15.7513
Type 3	4.0820	16.0663
Type 4	3.9409	15.4649

Table 4.6 Comparison of calculation errors under reliability

Type	Average Errors on SAIDI when calculated from Proposed algorithm	Errors on SAIFI in proposed algorithm
Type 1	-8.3333%	7.6923%
Type 2	-4.1667%	4.0001%
Type 3	-6.2500%	-5.8824%
Type 4	-2.2727%	-2.2222%

CHAPTER 5. CONCLUSION

In the realm of analytical and simulation analyses aimed at optimizing network topology A variable that remains unknown during the planning phase the complexity and non-linearity of distribution network planning are notably heightened. Consequently, these approaches proof most suitable for simple radial feeders. However, for extensive and highly intricate topological networks, an enhanced explicit method emerges from various network templates, meticulously addressing the intricacies of power failure scenarios.

The explicit method of reliability estimation is mainly focus on the calculation of β(normalized customer) so that the value of reliability indices SAIDI and SAIFI is more accurate in compare to analytical and simulation method.

In result and discussion seen that for IEEE 33 Bus the value of β (i.e. the normalized customer) is calculated by considering all the condition after feeder failure and for all four different feeder topology Cluster, calculated value of reliability index SAIDI using explicit formula has negative error value that means the value obtained from this method is more accurate in compare to analytical and simulation method. Further this method is more accurate in highly branched and complex network which is seen from the result that for type one topology error in proposed algorithms is 8.33% while in classical method error is 21.32% and simple radial feeder error in both method is very closer. Thus, this method calculates reliability indices more accurately for complex network in compare to other method.

Similarly, when this method in applied in 11 kV Baneshwor feeder for type 1 cluster the error value for SAIDI is -8.33% and for type 4 cluster is -2.2727%. Thus, this method also gives less error in SAIDI value for real feeder, when network has complex and for simple radial structure value calculated is closer to classical method.

From both Case study it is seen that the Calculated value of Reliability indices is more accurate when Explicit method is applied in compare to the classical method and this method is more acceptable for complex distribution network.

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ANNEX 1

IEEE 33 Bus System data

```
bKVA=1000; %1MVA
bKV=12.66;    %11KV
tolerance=0.0001;

% end of initialization FOR LOADFLOW

%ldata_o= [ Ln    sn    rn      r         x      ]
 ldata_o= [  1   1    2    0.270435    0.04327
2   2   3   0.078943    0.012631
3   3   4   0.018322    0.002932
4   1   5   0.254363    0.040698
5   5   6   0.093484    0.014957
6   6   7   0.014485    0.002318
7   5   8   0.103181    0.016509
8   8   9   0.034248    0.00548
9   9   10  0.08203 0.013125
10  10  11  0.062751    0.01004
11  11  12  0.078789    0.012606
12  12  13  0.080989    0.012958
13  13  14  0.06445 0.010312
14  14  15  0.126942    0.020311
15  15  16  0.044617    0.007139
16  16  17  0.005125    0.00082
17  10  18  0.039221    0.006275
18  18  19  0.019964    0.003194
19  19  20  0.036199    0.005792
20  20  21  0.02261 0.003618
21  21  22  0.029138    0.004662
22  20  23  0.166372    0.02662
23  23  24  0.021167    0.003387
24  24  25  0.044702    0.007152
  ];


 %tldata_o=[ tln    tsn    trn      tr         tx      ]  TIE LINE DATA
 tldata_o=[ 33    21     8    2.0000    2.0000
            34     9    15    2.0000    2.0000
            35    12    22    2.0000    2.0000
            36    18    33    0.5000    0.5000
            37    25    29    0.5000    0.5000 ];




%  busdata=[ Bn     BP      BQ     NC     ]
   busdata=[  1 0    0    0
2   100 0.00085 0.00052678
3   100 0.00085 0.00052678
4   200 0.0017  0.00105356
5   200 0.0017  0.00105356
6   100 0.00085 0.00052678
7   200 0.0017  0.00105356
8   200 0.0017  0.00105356
9   200 0.0017  0.00105356
10  200 0.0017  0.00105356
11  100 0.00085 0.00052678
```

```
12  250 0.00213 0.00131695
13  200 0.0017  0.00105356
14  200 0.0017  0.00105356
15  100 0.00085 0.00052678
16  200 0.0017  0.00105356
17  100 0.00085 0.00052678
18  200 0.0017  0.00105356
19  100 0.00085 0.00052678
20  100 0.00085 0.00052678
21  200 0.0017  0.00105356
22  300 0.00255 0.00158034
23  200 0.0017  0.00105356
24  100 0.00085 0.00052678
25  100 0.00085 0.00052678
];
%Reliability Parameters
%RI=[  Lf1     Rf1
rdata=[ 0.1       20 ;%CB
        0.05882  144 ;%TRF
        0.0045    24 ;%BB
        0.13       5 ;%BR
        0.20       5 ];%SW
```

11 kV Baneshwor feeder System data

```
%ldata_o= [ Ln    sn    rn      r         x      ]
 ldata_o= [  1  1    2    0.270435    0.04327
2   2   3   0.078943    0.012631
3   3   4   0.018322    0.002932
4   1   5   0.254363    0.040698
5   5   6   0.093484    0.014957
6   6   7   0.014485    0.002318
7   5   8   0.103181    0.016509
8   8   9   0.034248    0.00548
9   9   10  0.08203 0.013125
10  10  11  0.062751    0.01004
11  11  12  0.078789    0.012606
12  12  13  0.080989    0.012958
13  13  14  0.06445 0.010312
14  14  15  0.126942    0.020311
15  15  16  0.044617    0.007139
16  16  17  0.005125    0.00082
17  10  18  0.039221    0.006275
18  18  19  0.019964    0.003194
19  19  20  0.036199    0.005792
20  20  21  0.02261 0.003618
21  21  22  0.029138    0.004662
22  20  23  0.166372    0.02662
23  23  24  0.021167    0.003387
24  24  25  0.044702    0.007152   ];
```

```
 %tldata_o=[ tln    tsn    trn      tr          tx      ]  TIE LINE DATA
 tldata_o=[ 25     5    12    2.0000    2.0000
            26     8    10    2.0000    2.0000
            27    16    25    2.0000    2.0000
            28    18    23    0.5000    0.5000 ];
```

```
%  busdata=[ Bn     BP      BQ     NC     ]
   busdata=[  1 0    0    0
2   0.00085 0.00052678  33
3   0.00085 0.00052678  33
4   0.0017  0.00105356  66
5   0.0017  0.00105356  66
6   0.00085 0.00052678  33
7   0.0017  0.00105356  66
8   0.0017  0.00105356  66
9   0.0017  0.00105356  66
10  0.0017  0.00105356  66
11  0.00085 0.00052678  33
12  0.00213 0.00131695  85
13  0.0017  0.00105356  66
14  0.0017  0.00105356  66
15  0.00085 0.00052678  33
16  0.0017  0.00105356  66
17  0.00085 0.00052678  33
18  0.0017  0.00105356  66
19  0.00085 0.00052678  33
20  0.00085 0.00052678  33
21  0.0017  0.00105356  66
22  0.00255 0.00158034  99
23  0.0017  0.00105356  66
24  0.00085 0.00052678  33
25  0.00085 0.00052678  33 ];

nbus=length(busdata);
P_elb=busdata(:,2)*mfol;
LF=0.5;

TrCB=rdata(1,2);
TrTRF=rdata(2,2);
TrBB=rdata(3,2);
TrBR=rdata(4,2);
TrSW=rdata(5,2);

FrCB=rdata(1,1);
FrTRF=rdata(2,1);
FrBB=rdata(3,1);
FrBR=rdata(4,1);
FrSW=rdata(5,1);

Tsw=1;
TtLn=1;

% Establish the incidence matrix
%data=loadcase(case33);
dim1=size(ldata_o);
mldata_o=ldata_o;
n1=dim1(1)+1;
ldata=ldata_o(1:dim1(1),2:dim1(2));
doc=ldata;
nhanh=37;
nut=33;
tmldata_all_o=[ldata_o;tldata_o];
mldata=ldata;
gbmldata_o=mldata_o;
fprintf('\n*********************************************************************
****************************************************');
```

```
fprintf('\n**********************************EXPLICIT RELIABILITY EVALUATION
IN DISTRIBUTION NETWORKS**********************************');
fprintf('\n*****************************************************************
***************************************************\n');
fprintf('\n*****************************************************************
***************************************************');
fprintf('\n*******************************************RELIABILITY EVALUATION
FOR BASE CASE STARTED*******************************************');
fprintf('\n*****************************************************************
***************************************************\n');

[sn rn lr lx s ne e p ncu uca ucd nbu ubd nmat BIBC BCBV ] =
fbase_conf_bibc_bcbv( mldata,nbus );
 zz=sum(nmat);


%[SAIFIb, SAIDIb, CIcb, COcb, CItrf, COtrf, CIbb, CObb, CIbr, CObr, CIsw,
COsw]=fDRI(ldata_o,busdata,rdata,cb,trf,bb,br,sw,Tsw);
[SAIFIb, SAIDIb]=fDRI()



ntln=5;
nbr=nbus-1;
cbpos=[1];
uscbpos=unique(sort(cbpos));
nCB=length(uscbpos);
swpos=zeros(1,nbr-nCB);
swpos([2:32])=1;
nsw=sum(swpos);
tln_pos=zeros(1,ntln);
tln_pos(1)=1;
sw_tln_pos=[swpos,tln_pos];

Ploadpu=busdata(:,2)/bKVA;
LR=busdata(:,4);
LF=LR/100;
Pload_Avg=Ploadpu.*LF;

Bus_CN = busdata(:,4);
ttyp=4;
[SAIFIa, SAIDIa] = fDRI_MAT(sw_tln_pos)
[Beta1  U1 Beta2  U2 Beta3  U3 Beta4  U4 Comp] =
fbeta_clc_all(sw_tln_pos,ttyp);
SAIFIc=zeros(1,ttyp);
SAIDIc=zeros(1,ttyp);
for i=1:NET

SAIFIc(1)=SAIFIc(1)+NE(i)*FOR(i)*(Beta1(i,1)*U1(i,1)+Beta1(i,2)*U1(i,2)+Beta
1(i,3)*U1(i,3));

SAIDIc(1)=SAIDIc(1)+NE(i)*FOR(i)*(Beta1(i,1)*TM(i,1)+Beta1(i,2)*TM(i,2)+Beta
1(i,3)*TM(i,3));
end

for i=1:NET

SAIFIc(2)=SAIFIc(2)+NE(i)*FOR(i)*(Beta2(i,1)*U2(i,1)+Beta2(i,2)*U2(i,2)+Beta
2(i,3)*U2(i,3));

SAIDIc(2)=SAIDIc(2)+NE(i)*FOR(i)*(Beta2(i,1)*TM(i,1)+Beta2(i,2)*TM(i,2)+Beta
2(i,3)*TM(i,3));
```

```
end

for i=1:NET

SAIFIc(3)=SAIFIc(3)+NE(i)*FOR(i)*(Beta3(i,1)*U3(i,1)+Beta3(i,2)*U3(i,2)+Beta
3(i,3)*U3(i,3));

SAIDIc(3)=SAIDIc(3)+NE(i)*FOR(i)*(Beta3(i,1)*TM(i,1)+Beta3(i,2)*TM(i,2)+Beta
3(i,3)*TM(i,3));
end

for i=1:NET

SAIFIc(4)=SAIFIc(4)+NE(i)*FOR(i)*(Beta4(i,1)*U4(i,1)+Beta4(i,2)*U4(i,2)+Beta
4(i,3)*U4(i,3));

SAIDIc(4)=SAIDIc(4)+NE(i)*FOR(i)*(Beta4(i,1)*TM(i,1)+Beta4(i,2)*TM(i,2)+Beta
4(i,3)*TM(i,3));
end

Comp
Beta1
U1
Beta2
U2
Beta3
U3
Beta4
U4
SAIFIa
SAIDIa
SAIFIc
SAIDIc
Err_SAIFI=zeros(1,ttyp);
Err_SAIDI=zeros(1,ttyp);
for typ=1:ttyp
    Err_SAIFI(typ)=(SAIFIa-SAIFIc(typ))/SAIFIa*100;
    Err_SAIDI(typ)=(SAIDIa-SAIDIc(typ))/SAIDIa*100;
end
Err_SAIFI
Err_SAIDI

toc
function [Beta1  U1 Beta2  U2 Beta3  U3 Beta4  U4 Comp] =
fbeta_clc_all(sw_tln_pos,ttyp)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here

    global Erf Erd



    Comp=zeros(1,ttyp);
    Comp(1)=10+randi(5);
    Comp(2)=20+randi(5);
    Comp(3)=15+randi(5);
    Comp(4)=100-sum(Comp(1:4));

    typ=1;
    Erf=0.01*(100/Comp(typ))*power(-1,randi(ttyp));
    Erd=0.01*(100/Comp(typ))*power(-1,randi(ttyp));
```

```
    [Beta1 U1] = fbeta_clc(sw_tln_pos);

    typ=2;
    Erf=0.01*(100/Comp(typ))*power(-1,randi(ttyp));
    Erd=0.01*(100/Comp(typ))*power(-1,randi(ttyp));
    [Beta2 U2] = fbeta_clc(sw_tln_pos);

    typ=3;
    Erf=0.01*(100/Comp(typ))*power(-1,randi(ttyp));
    Erd=0.01*(100/Comp(typ))*power(-1,randi(ttyp));
    [Beta3 U3] = fbeta_clc(sw_tln_pos);

    typ=4;
    Erf=0.01*(100/Comp(typ))*power(-1,randi(ttyp));
    Erd=0.01*(100/Comp(typ))*power(-1,randi(ttyp));
    [Beta4 U4] = fbeta_clc(sw_tln_pos);

end
function [Beta U] = fbeta_clc(sw_tln_pos)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here

    global ldata_o tldata_o busdata uscbpos FrCB FrTRF FrBB FrBR FrSW TrCB
TrTRF TrBB TrBR TrSW Tsw TtLn Bus_CN NE NET FOR TM SAIFIact SAIDIact nsw Erf
Erd


    nTln=size(tldata_o,1);
    nCB=length(uscbpos);
    nbus=length(busdata);




    ncb=1;
    ntrf=1;
    nbb=nbus;
    nbr=nbus-1;
    %nsw=length(sw);





    [SAIFIact, SAIDIact, CI_CB,
CO_CB,CI_TRF,CO_TRF,CI_BB,CO_BB,CI_BR,CO_BR,CI_SW,CO_SW,Amat_CB, Bmat_CB,
Cmat_CB,Amat_TRF,Bmat_TRF,Cmat_TRF,Amat_BB,Bmat_BB,Cmat_BB,Amat_BR,Bmat_BR,C
mat_BR,Amat_SW,Bmat_SW,Cmat_SW]=fDRI_MAT(sw_tln_pos);

    NET=5;
    NE=zeros(NET,1);
    NE(1)=ncb;
    NE(2)=ntrf;
    NE(3)=nbb;
    NE(4)=nbr;
    NE(5)=nsw;
    FOR=zeros(NET,1);
    FOR(1)=FrCB;
    FOR(2)=FrTRF;
    FOR(3)=FrBB;
    FOR(4)=FrBR;
    FOR(5)=FrSW;
```

```
    TM=zeros(NET,3);
    TM(1)=TrCB;
    TM(2)=TrTRF;
    TM(3)=TrBB;
    TM(4)=TrBR;
    TM(5)=TrSW;
    TM(:,2)=ones(NET,1)*Tsw;
    TM(:,3)=ones(NET,1)*(Tsw+TtLn);

    nvar=NET*3*2;
lb=[zeros(1,NET*(3+3)) ];
ub=[ones(1,NET*(3+3))];
options = optimoptions('particleswarm','SwarmSize',50,'HybridFcn',@fmincon);
[varval_opt,fobjval] = particleswarm(@fBU,nvar,lb,ub,options);

 U=zeros(NET,3);
Beta=zeros(NET,3);
for i=1:NET
    Beta(i,1:3)=varval_opt(3*(i-1)+1:3*i);
    U(i,1:3)=round(varval_opt(15+3*(i-1)+1:3*i+15));
end
  fuse00();
 % fuse01();

end
%function for FINDING THE CONTINUOUS PATHS(LATERALS OR TIESETS)
function [ncu,uca]=fcont_path(n,ne,e,p)
for i=1:1:ne
       x=e(i);
       ncu(i)=0;
       for k=1:1:n
           for m=1:1:n
                   if((m==p(x))||(p(x)==0))
                       ncu(i)=ncu(i)+1;
                       uca(i,ncu(i))=x;
                       x=p(x);
                       break;
                   end
               end
               if(x==0)
                   break;
               end
           end
end
end

function TED_distance = fcalculate_TED_distance(M1, M2)
    % Calculate Tree Edit Distance (TED) between two matrices M1 and M2

    % Get number of nodes (rows) and edges (columns) in each matrix
    n1 = size(M1, 1);
    n2 = size(M2, 1);

    % Initialize TED distance matrix
    D = zeros(n1 + 1, n2 + 1);

    % Initialize cost values for insertions, deletions, substitutions
    cost_insert = 1;
    cost_delete = 1;
    cost_substitute = 1;
```

```
    % Fill in TED distance matrix using dynamic programming approach
    for i = 1:n1+1
        D(i, 1) = i * cost_delete;
    end
    for j = 1:n2+1
        D(1, j) = j * cost_insert;
    end

    for i = 2:n1+1
        for j = 2:n2+1
            if isequal(M1(i-1, :), M2(j-1, :))
                cost_sub = 0; % No cost for matching nodes
            else
                cost_sub = cost_substitute; % Cost for substituting nodes
            end
            D(i, j) = min([D(i-1, j) + cost_delete, ...
                           D(i, j-1) + cost_insert, ...
                           D(i-1, j-1) + cost_sub]);
        end
    end

    % TED distance is the value in the bottom-right corner of the matrix
    TED_distance = D(n1+1, n2+1);
end

function [CI_BB,CO_BB,Amat_BB,Bmat_BB,Cmat_BB] =
fCI_CO_BB_CB_SW_Tln(sw_tln_pos)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here
    global ldata_o tldata_o busdata uscbpos FrCB FrTRF FrBB FrBR FrSW TrCB
TrTRF TrBB TrBR TrSW Tsw TtLn Bus_CN


    nTln=size(tldata_o,1);
    nCB=length(uscbpos);
    nbus=length(busdata);
    nbr=nbus-1;
    FOR=zeros(1,nbr);

    swpos=sw_tln_pos(1:nbr-nCB);

    nSW=sum(swpos);
    %Switch position correction
    cswpos=zeros(1,nbr);
    if(nSW>0)
        cnt=0;
        ind=0;
        for cbr=1:nbr
            cnt=sum(cbr==uscbpos);
            if(cnt>0)
                continue;
            else
                ind=ind+1;
                cswpos(cbr)=swpos(ind);
            end

        end
    end

    usswpos=find(cswpos);
    nSW=length(usswpos);
```

```
    tln_pos=find(sw_tln_pos(nbr-nCB+1:end));
    atldata_o=[];
    atldata_o=tldata_o(tln_pos,:);

    tmldata_o=[];

    %size(ldata_o)
    %size(atldata_o)
    tmldata_o=[ldata_o;atldata_o];


    [Amat_BB,Bmat_BB,Cmat_BB] =
fABCmat_CB_SW_Tlns_mdfd(nbus,tmldata_o,uscbpos,usswpos);

    FOR=FrBB*ones(1,nbr);


CI_BB=((FOR*Amat_BB)*Bus_CN)+((FOR*Bmat_BB)*Bus_CN)+((FOR*Cmat_BB)*Bus_CN);


CO_BB=(((FOR*TrBB)*Amat_BB)*Bus_CN)+(((FOR*Tsw)*Bmat_BB)*Bus_CN)+(((FOR*(Tsw
+TtLn))*Cmat_BB)*Bus_CN);




end
function [CI_BR,CO_BR,Amat_BR,Bmat_BR,Cmat_BR] =
fCI_CO_BR_CB_SW_Tln(sw_tln_pos)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here
    global ldata_o tldata_o busdata uscbpos FrCB FrTRF FrBB FrBR FrSW TrCB
TrTRF TrBB TrBR TrSW Tsw TtLn Bus_CN


    nTln=size(tldata_o,1);
    nCB=length(uscbpos);
    nbus=length(busdata);
    nbr=nbus-1;
    FOR=zeros(1,nbr);

    swpos=sw_tln_pos(1:nbr-nCB);

    nSW=sum(swpos);
    %Switch position correction
    cswpos=zeros(1,nbr);
    if(nSW>0)
        cnt=0;
        ind=0;
        for cbr=1:nbr
            cnt=sum(cbr==uscbpos);
            if(cnt>0)
                continue;
            else
                ind=ind+1;
                cswpos(cbr)=swpos(ind);
            end

        end
    end
```

```
    usswpos=find(cswpos);
    nSW=length(usswpos);

    tln_pos=find(sw_tln_pos(nbr-nCB+1:end));
    atldata_o=[];
    atldata_o=tldata_o(tln_pos,:);

    tmldata_o=[];

    %size(ldata_o)
    %size(atldata_o)
    tmldata_o=[ldata_o;atldata_o];


    [Amat_BR,Bmat_BR,Cmat_BR] =
fABCmat_CB_SW_Tlns_mdfd(nbus,tmldata_o,uscbpos,usswpos);

    FOR=FrBR*ones(1,nbr);


CI_BR=((FOR*Amat_BR)*Bus_CN)+((FOR*Bmat_BR)*Bus_CN)+((FOR*Cmat_BR)*Bus_CN);


CO_BR=(((FOR*TrBR)*Amat_BR)*Bus_CN)+(((FOR*Tsw)*Bmat_BR)*Bus_CN)+(((FOR*(Tsw
+TtLn))*Cmat_BR)*Bus_CN);




end
function [CI_CB,CO_CB,Amat_CB,Bmat_CB,Cmat_CB] =
fCI_CO_CB_CB_SW_Tln(sw_tln_pos)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here
    global ldata_o tldata_o busdata uscbpos FrCB FrTRF FrBB FrLn FrSW TrCB
TrTRF TrBB TrLn TrSW Tsw TtLn Bus_CN


    nTln=size(tldata_o,1);
    nCB=length(uscbpos);
    nbus=length(busdata);
    nbr=nbus-1;
    FOR=zeros(1,nbr);

    Amat_CB=zeros(nbr,nbus);
    Bmat_CB=zeros(nbr,nbus);
    Cmat_CB=zeros(nbr,nbus);

    Amat_CB(1,1:nbus)=ones(1,nbus);

    FOR(1)=FrCB;


CI_CB=((FOR*Amat_CB)*Bus_CN)+((FOR*Bmat_CB)*Bus_CN)+((FOR*Cmat_CB)*Bus_CN);


CO_CB=(((FOR*TrCB)*Amat_CB)*Bus_CN)+(((FOR*Tsw)*Bmat_CB)*Bus_CN)+(((FOR*(Tsw
+TtLn))*Cmat_CB)*Bus_CN);
```

```
end
function
[CI_CB_SW_Tln,CO_CB_SW_Tln,Amat_CB_SW_Tln,Bmat_CB_SW_Tln,Cmat_CB_SW_Tln] =
fCI_CO_CB_SW_Tln(sw_tln_pos)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here
    global ldata_o tldata_o busdata uscbpos FrCB FrTRF FrBB FrBR FrSW TrCB
TrTRF TrBB TrBR TrSW Tsw TtLn Bus_CN


    nTln=size(tldata_o,1);
    nCB=length(uscbpos);
    nbus=length(busdata);
    nbr=nbus-1;
    FOR=zeros(1,nbr);
    swpos=sw_tln_pos(1:nbr-nCB);

    nSW=sum(swpos);
    %Switch position correction
    cswpos=zeros(1,nbr);
    if(nSW>0)
        cnt=0;
        ind=0;
        for cbr=1:nbr
            cnt=sum(cbr==uscbpos);
            if(cnt>0)
                continue;
            else
                ind=ind+1;
                cswpos(cbr)=swpos(ind);
            end

        end
    end

    usswpos=find(cswpos);
    nSW=length(usswpos);

    tln_pos=find(sw_tln_pos(nbr-nCB+1:end));
    atldata_o=[];
    atldata_o=tldata_o(tln_pos,:);

    tmldata_o=[];

    %size(ldata_o)
    %size(atldata_o)
    tmldata_o=[ldata_o;atldata_o];


    [Amat_CB_SW_Tln,Bmat_CB_SW_Tln,Cmat_CB_SW_Tln] =
fABCmat_CB_SW_Tlns_mdfd(nbus,tmldata_o,uscbpos,usswpos);

    %Amat_CB_SW_Tln
    %Bmat_CB_SW_Tln
    %Cmat_CB_SW_Tln

    %{
    size(Amat_CB_SW_Tln)
```

```
    size(Bmat_CB_SW_Tln)
    size(Cmat_CB_SW_Tln)
    size(Fr_Ln)
    size(TrLn)
    size(Tsw)
    size(TtLn)
    %}

    FOR=ones(1,nbr)*FrBR;

CI_CB_SW_Tln=((FOR*Amat_CB_SW_Tln)*Bus_CN)+((FOR*Bmat_CB_SW_Tln)*Bus_CN)+((F
OR*Cmat_CB_SW_Tln)*Bus_CN);


CO_CB_SW_Tln=(((FOR*TrBR)*Amat_CB_SW_Tln)*Bus_CN)+(((FOR*Tsw)*Bmat_CB_SW_Tln
)*Bus_CN)+(((FOR*(Tsw+TtLn))*Cmat_CB_SW_Tln)*Bus_CN);




end
function [CI_SW,CO_SW,Amat_SW,Bmat_SW,Cmat_SW] =
fCI_CO_SW_CB_SW_Tln(sw_tln_pos)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here
    global ldata_o tldata_o busdata uscbpos FrCB FrTRF FrBB FrBR FrSW TrCB
TrTRF TrBB TrBR TrSW Tsw TtLn Bus_CN


    nTln=size(tldata_o,1);
    nCB=length(uscbpos);
    nbus=length(busdata);
    nbr=nbus-1;
    FOR=zeros(1,nbr);

    swpos=sw_tln_pos(1:nbr-nCB);

    nSW=sum(swpos);
    %Switch position correction
    cswpos=zeros(1,nbr);
    if(nSW>0)
        cnt=0;
        ind=0;
        for cbr=1:nbr
            cnt=sum(cbr==uscbpos);
            if(cnt>0)
                continue;
            else
                ind=ind+1;
                cswpos(cbr)=swpos(ind);
            end

        end
    end

    usswpos=find(cswpos);
    nSW=length(usswpos);

    tln_pos=find(sw_tln_pos(nbr-nCB+1:end));
    atldata_o=[];
    atldata_o=tldata_o(tln_pos,:);
```

```
    tmldata_o=[];

    %size(ldata_o)
    %size(atldata_o)
    tmldata_o=[ldata_o;atldata_o];


    [Amat_SW,Bmat_SW,Cmat_SW] =
fABCmat_CB_SW_Tlns_mdfd(nbus,tmldata_o,uscbpos,usswpos);

    FOR=FrSW*ones(1,nbr);


CI_SW=((FOR*Amat_SW)*Bus_CN)+((FOR*Bmat_SW)*Bus_CN)+((FOR*Cmat_SW)*Bus_CN);


CO_SW=(((FOR*TrSW)*Amat_SW)*Bus_CN)+(((FOR*Tsw)*Bmat_SW)*Bus_CN)+(((FOR*(Tsw
+TtLn))*Cmat_SW)*Bus_CN);




end
function [CI_TRF,CO_TRF,Amat_TRF,Bmat_TRF,Cmat_TRF] =
fCI_CO_TRF_CB_SW_Tln(sw_tln_pos)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here
    global ldata_o tldata_o busdata uscbpos FrCB FrTRF FrBB FrBR FrSW TrCB
TrTRF TrBB TrBR TrSW Tsw TtLn Bus_CN


    nTln=size(tldata_o,1);
    nCB=length(uscbpos);
    nbus=length(busdata);
    nbr=nbus-1;
    FOR=zeros(1,nbr);

    Amat_TRF=zeros(nbr,nbus);
    Bmat_TRF=zeros(nbr,nbus);
    Cmat_TRF=zeros(nbr,nbus);

    Amat_TRF(1,1:nbus)=ones(1,nbus);

    FOR(1)=FrTRF;


CI_TRF=((FOR*Amat_TRF)*Bus_CN)+((FOR*Bmat_TRF)*Bus_CN)+((FOR*Cmat_TRF)*Bus_C
N);


CO_TRF=(((FOR*TrTRF)*Amat_TRF)*Bus_CN)+(((FOR*Tsw)*Bmat_TRF)*Bus_CN)+(((FOR*
(Tsw+TtLn))*Cmat_TRF)*Bus_CN);



end
% function to find the configuration info of the system
function fconfig_display(sn,rn,s,e,ne,p,ncu,uca,ucd,nbu,ubd,ldata_o)
```

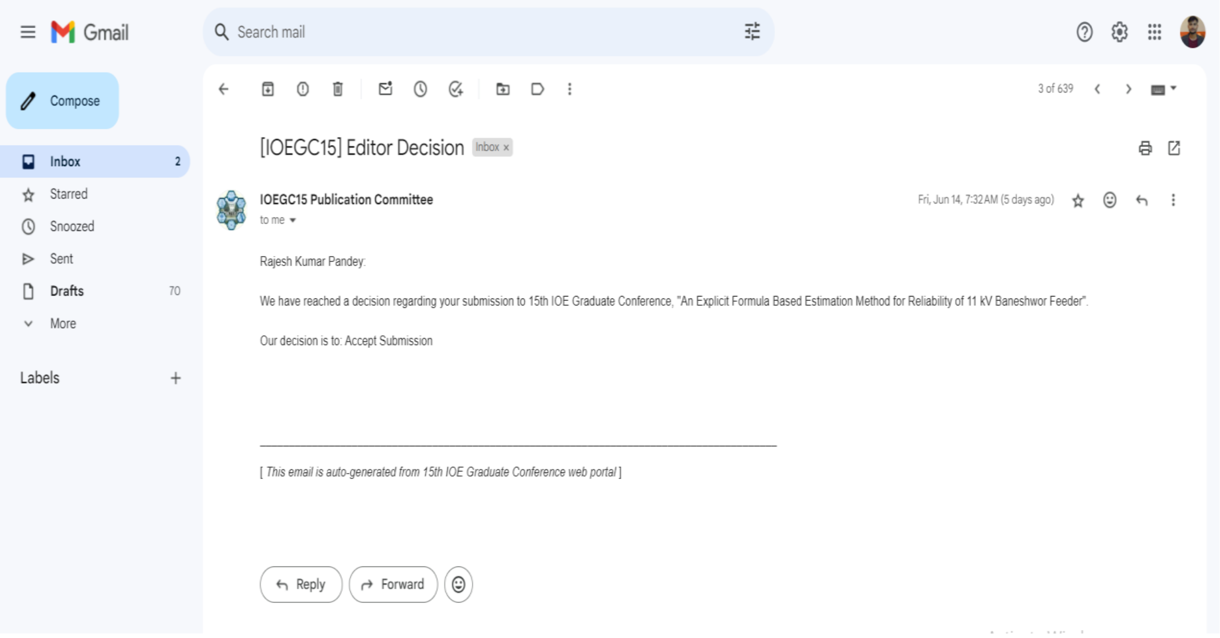
```
%sn=fsnodes(mldata);                        %SENDING NODES OF LINE
%rn=frnodes(mldata);                        %RECEIVING NODES OF LINE
%FINDING THE STARTING NODE OF NETWORK
%s=fssbus(n,rn);
fprintf('\nStarting node of the system : %d',s);

%fprintf('\n3**********************\n');
%FINDING THE ENDING NODES OF NETWORK
%[ne,e]=fendnodes(n,sn); %NE->NO OF LATERALS
                        %E->END NODE OF LATERALS

fprintf('\nEnding nodes of the system : ');
for i=1:1:ne
        fprintf('%d ',e(i));
end

%fprintf('\n4**********************\n');

%FINDING THE PRECEDENCE NODES
%p=fprecedencebus(n,s,sn,rn);
%{
fprintf('\nprecedence nodes :\nsn ->rn ');
for i=1:1:n
        fprintf('\n%d -> %d',p(i),i);
end

%}

%fprintf('\n5**********************\n');

%FINDING THE CONTINUOUS PATHS(LATERALS OR TIESETS) in ascending order (from
end bus to source end)

%[ncu,uca]=fcont_path(n,ne,e,p);  %NCU->NO OF COMPONENT(NODES) USED
                                 %UCA->USED NODES IN ASCENDING (RN-SN)
%Display of cua in screen
%{
fprintf('\n TOTAL NO. SUCCESS PATHS OR LATERALS = %d',ne);
for i=1:1:ne
    fprintf('\n %d SUCCESS PATH , nodes(a) : ',i);
    for j=1:1:ncu(i)
        fprintf('%d  ',uca(i,j));
    end
end

%}
%fprintf('\n6**********************\n');
%ARRANGING THE NODES OF LATERAL IN DESCENDING ORDER
fprintf('\n\n********LATERALS DETAILS IN TERMS OF NODES OR BUSES NUMBERS
FROM SOURCE TO ENDS i.e. DESCENDING ORDER ********\n');
%ucd=fuc_descening(ne,ncu,uca); % USED COMPONENTS IN DECENDING ORDER

fprintf('\n TOTAL NO. LATERALS FROM SOURCE END = %d',ne);
for i=1:1:ne
    fprintf('\n LATERAL %d  ,Nodes(Descending) : ',i);
    for j=1:1:ncu(i)
        fprintf('%d  ',ucd(i,j));
    end
end

%fprintf('\n7**********************\n');
```

```
%ARRANGING BRANCHES IN DESCENDING ORDER
fprintf('\n\n*********LATERALS DETAILS IN TERMS OF BRANCHES NUMBERS FROM
SOURCE TO ENDS i.e. DESCENDING ORDER***********\n');

%[nbu,ubd]=fub_descening(ne,ncu,ucd,rn); % NBU- NO OF BRANCH USED IN A
LATERAL
                                         % USED BRANCHES IN DECENDING ORDER

fprintf('\n TOTAL NO. LATERALS FROM SOURCE END = %d',ne);
for i=1:1:ne
    fprintf('\n LATERAL %d  ,Branches(Descending) : ',i);
    for j=1:1:nbu(i)
        fprintf('%d  ',ldata_o(ubd(i,j),1));
    end
end

end % end of main function definition

function [Plosspu,Qlosspu,tmpv,Iinjpu,Brinjpu,PBLpu,QBLpu,iter,maxerror] =
fdist_loadflow_bibc_bcbv( )
global ldata_o busdata bKVA bKV tolerance;


maxerror=1;

% end of initialization FOR LOADFLOW

dim=size(ldata_o);
n=dim(1)+1;
mldata=ldata_o(1:dim(1),2:dim(2));

[sn rn lr lx s ne e p ncu uca ucd nbu ubd nmat BIBC BCBV] =
fbase_conf_bibc_bcbv( mldata,n );
bp=busdata(:,2);
bq=busdata(:,3);



%%%%%%%%%%%%%%

bZ=bKV*bKV*1000/bKVA;
bppu=bp/bKVA;
bqpu=bq/bKVA;
lrpu=lr/(bZ);
lxpu=lx/(bZ);
BCBVpu=BCBV/bZ;
DLFpu=BCBVpu*BIBC;
% initialization
Plosspu=0;
Qlosspu=0;
PBLpu=zeros(n-1,1);
QBLpu=zeros(n-1,1);

iter=0;
tmpv0=ones(n,1);
tmpv=tmpv0;

%  end of initialization
while ((maxerror>tolerance)&&(iter<100))
```

```
    Plosspu=0;
    Qlosspu=0;
    iter=iter+1;
    Brinjpu=zeros(n-1,1);
    Pinjpu=zeros(n,1);
    Qinjpu=zeros(n,1);
    Pinjpu=bppu;
    Qinjpu=bqpu;
    Sinjpu=complex(Pinjpu(2:n),Qinjpu(2:n));
    Iinjpu=conj(Sinjpu./tmpv0(2:n));
    dltaV=DLFpu*Iinjpu;
    tmpv(2:n,1)=1-dltaV;
    nIinjpu=conj(Sinjpu./tmpv(2:n));
    Brinjpu=BIBC*nIinjpu;

    PBLpu=((abs(Brinjpu)).^2).*lrpu;
    QBLpu=((abs(Brinjpu)).^2).*lxpu;
    Plosspu=sum(PBLpu);
    Qlosspu=sum(QBLpu);

    v_err=abs(abs(tmpv0)-abs(tmpv));
    del_err=abs(angle(tmpv0)-angle(tmpv));
    maxr=max(v_err,del_err);
    maxerror=max(maxr);

    tmpv0=tmpv;
    Iinjpu=nIinjpu;

end % end of while


V_act=tmpv*bKV;
Ploss_act=Plosspu*bKVA;
Qloss_act=Qlosspu*bKVA;
PBL_act=PBLpu*bKVA;
QBL_act=QBLpu*bKVA;

tloss=0;
tloss=sum((abs((tmpv(sn)-tmpv(rn))./complex(lrpu,lxpu)).^2).*lrpu);

end
```

ANNEX 2

A recent paper presented at the 15th IOE Graduate Conference delves into similar themes. It explores how traditional analytical and simulation methods, while effective for simple radial feeders, encounter challenges when applied to complex distribution networks due to the unknown variability of network topology during planning. In response, the study advocates for an explicit method that incorporates diverse network templates and meticulously considers the nuances of power failure scenarios.



[IOEGC15] Editor Decision

IOEGC15 Publication Committee
to me

Fri, Jun 14, 7:32 AM (5 days ago)

Rajesh Kumar Pandey:

We have reached a decision regarding your submission to 15th IOE Graduate Conference, "An Explicit Formula Based Estimation Method for Reliability of 11 kV Baneshwor Feeder".

Our decision is to: Accept Submission

[This email is auto-generated from 15th IOE Graduate Conference web portal]

IOE Graduate Conference
[Placeholder for Publication Information]

An Explicit Formula Based Estimation Method for Reliability of 11 kV Baneshwor Feeder

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Abstract

An innovative approach to reliability assessment in the planning phase of medium-voltage distribution systems is presented in this study. The method introduces a new and more accurate technique for estimating reliability indices, enabling their expression through explicit formulas while accommodating various network topologies. Initially, typical feeder structures are identified within the candidate area using a combination of tree edit distance and hierarchical clustering algorithms. Subsequently, for each typical network structure, a reliability evaluation model is established, incorporating factors such as fault isolation, load restoration, and the impact of reliability enhancement equipment, formulated through regression analysis. The feasibility and effectiveness of the proposed reliability assessment algorithm are validated through test cases, demonstrating its capability to achieve rapid and accurate reliability index calculations with minimal data requirements. This approach offers a systematic and efficient means of assessing distribution system reliability during the planning process, ensuring adaptability to diverse network configurations. Finally, this approach is implemented for Baneshwor 11 kV feeder distribution system.

Keywords

Tree edit distance, reliability estimation, Correlation agglomerative hierarchical clustering (ACH), MATLAB, Regression analysis, medium voltage distribution Feeder

1. Introduction

The distribution systems are the final link between the bulk power system and customers, and the most customer interruptions occur due to failures in the distribution systems zone. How fast and accurate estimate the reliability of distribution system core research in now days in difficult distribution topology [1]. To indicates the reliability of distribution system that is power outage in distribution networks here used system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI) . [2].

$$S_F = \sum_{k=1}^{N_E} = N_E\lambda_k(\beta_{AK}U_A + \beta_{BK}U_B + \beta_{CK}U_C) \qquad (1)$$

$$S_D = \sum_{k=1}^{N_E} = N_E\lambda_k(\beta_{AK}T_A + \beta_{BK}T_B + \beta_{CK}T_C) \qquad (2)$$

where,
S_F System Average Interruption Frequency Index (SAIFI)
S_D is System Average Interruption Duration Index (SAIDI)
The failure rate of the kth type of equipment $=\lambda_k$
N_E Represents amounts of Equipment
β is Customer identification factor (Total customer affected After failure of k_{th} type Equipment) or Normalized customer whose value is always in between 0 and 1.
T_A , T_B and T_c Represents the time which explain in table 1
U_A , U_B and U_c are 0-1 Variables which denotes the power failure status respectively

The outage time of various users, represents as T_A , T_B and T_c. The failure locating time, failure isolating time, load transfer time, and failure repairing time represents as T_dw,T_n,T_g,T_z and T_x respectively [3]. In most of paper the value of S_F and S_D is calculate analytical and simulation [4]. Network planning and optimization, specifically related to calculating β (beta) for network analysis and both methods of calculation require searching and analyzing network topology, which limits the optimization of network planning schemes. In [5] simplified algorithms to calculate the value of β however, it appears that the estimation algorithm involves significant assumptions and empirical judgment, indicating that there's still room for improvement in its accuracy and effectiveness. Improving such algorithms typically involves refining the underlying assumptions, gathering more data to make the judgments more empirical, or developing more sophisticated techniques to handle the complexities of network planning. The algorithm uses an explicit formula to calculate the reliability index. This likely means that the formula directly computes the reliability index based on input parameters without extensive

Table 1: Table 1

Type	Outage	Location
A	$T_A = T_{dw} + T_g$	Customer fall in Up-stream part of Failure point
B	$T_B = T_{dw} + T_g + T_z$	Customer fall in Down-stream part of Failure point and transferred.
C	$T_C = T_{dw} + T_g + T_x$	Customer fall in Down-stream part of Failure point and not transferred, Failed user in failure point

computational iterations. The typical feeder structures are classified and clustered using a hierarchical clustering algorithm. This helps in organizing and grouping similar structures together, which can aid in analyzing their reliability characteristics. The hierarchical clustering algorithm is based on the tree edit distance (TED). TED measures the similarity between two trees by calculating the minimum number of operations (such as insertions, deletions, or substitutions) needed to transform one tree into the other. A reliability index function is derived from regression analysis. This function likely predicts the reliability index based on various factors, possibly including fault isolation, load transfer, and other relevant parameters. The algorithm considers various impacts of network topology and system faults. This indicates that it takes into account the effects of different network configurations and potential faults on the reliability of the distribution network. The algorithm offers an embedded optimization model for distribution network planning. This likely means that it includes optimization procedures to improve the planning process, possibly by optimizing the network layout or configuration to enhance reliability. Overall, the proposed algorithm seems to be comprehensive, considering various aspects of distribution network planning and reliability assessment. It integrates techniques from clustering, regression analysis, and optimization to provide a more effective approach for estimating reliability indices and optimizing distribution network planning.

2. Hierarchical clustering of network topology

2.1 Topological characterization of feeder structure

The characterization process may involve analyzing the connectivity patterns, the arrangement of sectional devices, and the redundancy or alternative pathways within the feeder network. By focusing on the connections between the main line and the branch boxes, the characterization aims to provide insights into how different topological configurations affect the network's ability to isolate faults and transfer loads in the event of disruptions.

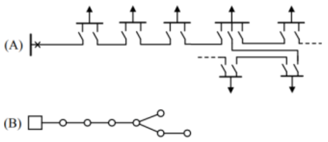


Figure 1: Topological characterization result [2]

Fig. 1 likely illustrates the differences between the original line topology fig (A) and the characterized topology fig (B), highlighting any modifications or simplifications made during the characterization process. This visualization can help researchers and practitioners understand the structural differences between the two topologies and how they may impact the feeder's reliability and resilience

2.2 Topology difference measurement

Tree Edit Distance (TED) is indeed a fascinating algorithm used to quantify the difference between two trees by calculating the minimum cost sequence of node edit operations needed to transform one tree into another.

The Tree Edit Distance (TED) algorithm [6] is a method used to compute the difference between two trees by determining the minimum cost sequence of node edit operations required to transform one tree into another. These operations typically include:

- Insertion: Adding a new node to the source tree.
- Deletion: Removing a node from the source tree.
- Substitution: Modifying a node in the source tree to match a node in the target tree.
- Relabeling: Changing the label of a node in the source tree.

2.3 Hierarchical clustering for feeder Structure

Classify feeder topologies based on their similarity, there's no single numerical value to represent the "difference" between feeder topologies. For feeder topologies clustering Agglomerative hierarchical clustering is a method used in cluster analysis to build a hierarchy of clusters.Agglomerative hierarchical clustering is often contrasted with divisive hierarchical clustering, where the process starts with all data points in one cluster and splits them recursively into smaller clusters. This algorithm starts with each feeder as a separate cluster and iteratively merges the two most similar clusters until all feeders belong to one cluster (or a stopping condition is met). TED might output some kind of "difference score" between feeders, and the average is taken to represent the overall distance between two clusters.

Process involves in Hierarchical clustering for feeder structure:

I Calculate the TED (dissimilarity score) between all N feeders in the region.

II Find the two feeders with the smallest TED (most similar).

III Merge these two feeders into a single cluster. Now it can be N-1 clusters.

IV Repeat steps I-III: Calculate distances between the remaining N-1 clusters and merge the closest ones

V Continue merging clusters based on their TED distance until there's only one cluster left or a stopping condition (e.g., a minimum similarity threshold) is reached.

This approach offers a way to group feeder topologies based on how similar their TED values are. By analyzing the resulting clusters, identify groups of feeder topologies with similar characteristics.

3. Methodology

Explicit Formula Based Estimation Method is used to calculate Reliability Distribution Network. The core aim of this thesis is to calculate the value of β (Customer identification factor). The General outline of methodology is shown in figure 2.

In first Step Initialize parameters (e.g., feeder topology, failure data) means input the bus data, line data total number equipment, failure rate and reliability related data.

In Second step Extract feeder topology structures focusing on fault isolation and load transfer and Cluster typical feeder topologies using hierarchical clustering based on TED distance. Using TED method all topology made same number of nodes by insertion, deletion, substitution and relabeling.

In third step for each feeder, deduce β values using regression formulas derived from fault isolation, load transfer analysis and failure repairing.

In fourth step Adjust reliability parameters based on fault type and network conditions that means each type of topology there are 15 number of values of β because in this study 5 type of equipment is considered and for each equipment three types of customers is exist.

In fifth and final step Calculate reliability indices (SAIFI, SAIDI) using derived formulas for network evaluation and planning that is from equation 1 and 2.

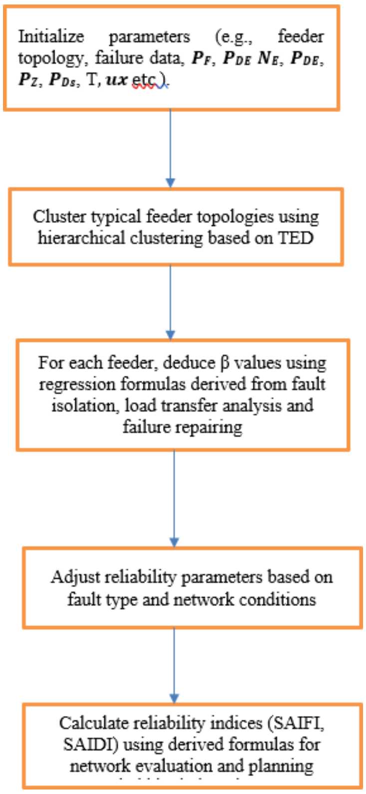


Figure 2: Flow chart of Method Implementation

4. Case Study

4.1 Reliability estimation of IEEE 33 Bus system

In first step estimate the reliability of IEEE 33 bus whose bus data, line data, tie line data and data for reliability calculation is presented in annex. The single line diagram of IEEE 33 bus is presented below and data related to reliability from [7]. Now above system can be clustered into four types. From above method it can be indicates that although the majority of the feeders belong to the ”simple radial structure” (type 4), comprising 50 % of the total, there are still significant numbers of feeders classified as ”big branch structure” (type 2) at 21%, and ”multiple branch structure” (type 1 and 3) at 13% and 16%, respectively. This distribution suggests a diversity in the topology of the distribution network. While the simple radial structure is predominant, the presence of big branch and multiple branch structures implies that there are variations in the network configuration. Furthermore, the mention that these structures are more common in overhead lines provides additional context regarding their physical characteristics and potential operational considerations. Now the value of β can be calculate different four type of cluster and for Cluster system contains five different equipment in system so there are five values of β . So each value of β (i.e normalized customer identification) should consider three different Scenario. Since there are 15 values of β for each cluster The value of SAIFI and SAIDI calculated from equation 1 and 2. From above result clearly seen that the error present in type 1 for proposed method is reduce in large amounts in compare approximate evaluation method but in type 4 that is in simple radial structure errors in both methods seen to be closer due to simplicity in topology.

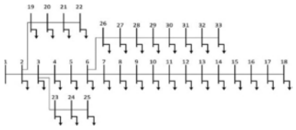


Figure 3: Single line diagram of IEEE 33 bus

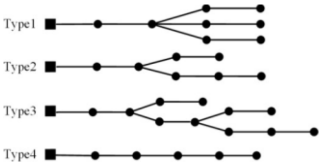
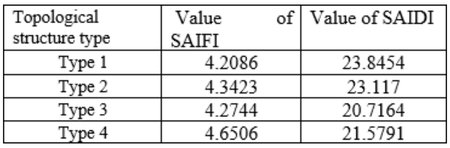
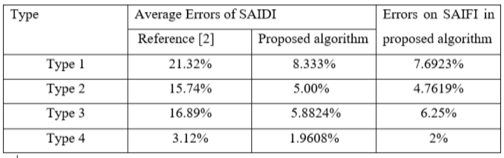


Figure 4: Typical topology of each clustered feeder structure



Topological structure type	Value of SAIFI	Value of SAIDI
Type 1	4.2086	23.8454
Type 2	4.3423	23.117
Type 3	4.2744	20.7164
Type 4	4.6506	21.5791

Figure 5: Value of SAIFI and SAIDI for different cluster



Type	Average Errors of SAIDI		Errors on SAIFI in proposed algorithm
	Reference [2]	Proposed algorithm	
Type 1	21.32%	8.333%	7.6923%
Type 2	15.74%	5.00%	4.7619%
Type 3	16.89%	5.8824%	6.25%
Type 4	3.12%	1.9608%	2%

Figure 6: Comparison of calculation errors of SAIDI and SAIFI under different type

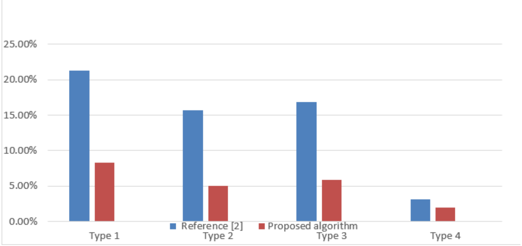


Figure 7: Comparison chart of calculation errors of SAIDI and SAIFI under different type

4.1 Reliability estimation of 11 kV Baneshwor feeder

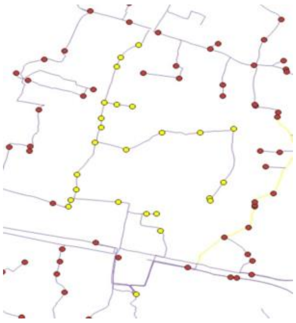


Figure 8: GIS mapping 11 kV Baneshwor feeder

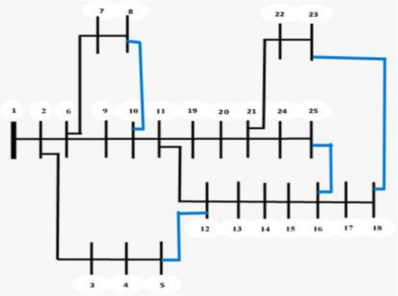
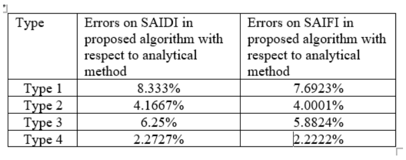


Figure 9: Single line diagram 11 kV Baneshwor feeder with tielines

The real system data of Nepal Electricity Authority (NEA) 11 kV baneshwor feeder is considered for the analysis. It includes 24 distribution transformers. The scheduled and unscheduled outages of this section for the past 1 year (September 2022-September 2023) is taken to estimate the reliability. From above method it can be indicates that although the majority of the feeders belong to the ”simple radial structure” (type 4), comprising 45 % of the total, there are still significant numbers of feeders classified as ”big branch structure” (type 2) at 25%, and ”multiple branch structure” (type 1 and 3) at 13% and 17%, respectively. This distribution suggests a diversity in the topology of the distribution network. While the simple radial structure is predominant, the presence of big branch and multiple branch structures implies that there are variations in the network configuration. Furthermore, the mention that these structures are more common in overhead lines provides additional context regarding their physical characteristics and potential operational considerations. Now the value of β can be calculate different four type of cluster and for Cluster system contains five different equipment in system so there are four values of β . So each value of β (i.e normalized customer identification) should consider three different Scenario. Since there are 15 values of β for each cluster The value of SAIFI and SAIDI calculated from equation 1 and 2.



Type	Errors on SAIDI in proposed algorithm with respect to analytical method	Errors on SAIFI in proposed algorithm with respect to analytical method
Type 1	8.333%	7.6923%
Type 2	4.1667%	4.0001%
Type 3	6.25%	5.8824%
Type 4	2.2727%	2.2222%

Figure 10: Comparison of calculation errors on reliability under different type

5. Results and Conclusion

This paper introduces an enhanced approach for estimating distribution network reliability, leveraging a TED-based hierarchical clustering method. This method identifies typical feeder topology structures within the evaluated area and clusters similar feeders for network reliability assessment. Additionally, the proposed method deduces the reliability index formula and its correspondingβ through regression analysis. Through a case study, the paper demonstrates the effectiveness and advantages of this method in evaluating and planning network reliability, showcasing its potential for enhancing the resilience of distribution networks

6. Recommendation

The above Result and conclusion show that the Estimation of reliability through An Explicit Formula Based Estimation requires less input data and it minimizes an error in compare to other analytical and simulation-based method for feeder having complex topological structure. So in above method all three type of Customers considered during calculation of β . since after calculating the value of SAIFI and SAIDI for Baneshwor Feeder NEA will be plan for reliability enhancement. Since using this method estimate the reliability of Complex topology feeder which help in planning and reliability enhancement of distribution system of NEA.

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