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

Rajesh Kumar Pandey [a], Nava Raj Karki [b], Basanta Kumar Gautam [c], Rupesh Kumar Sah [c]

[a] *Department of Electrical Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] Pandeyvirat312@gmail.com

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].

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

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

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

Table 1: Outage time of various users

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

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 $T_d w$,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 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.

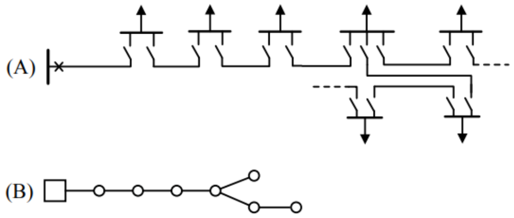

Figure 1: Topological characterization result [2]

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.

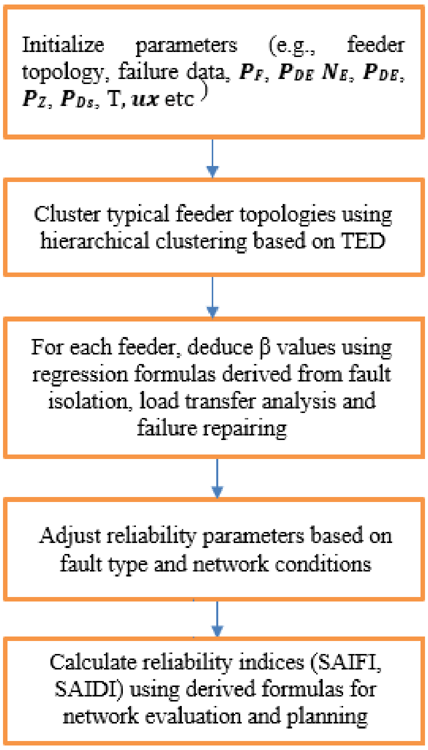

Figure 2: Flow chart of Method Implementation

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].

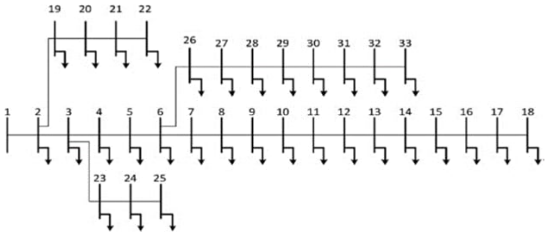

Figure 3: Single line diagram of IEEE 33 bus

Now above system can be clustered into four types.

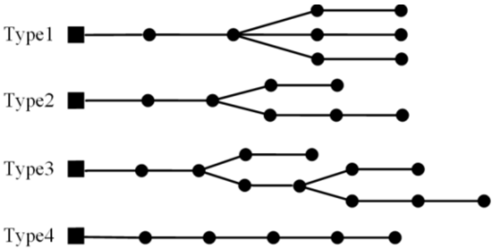

Figure 4: Typical topology of each clustered feeder structure

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.

Table 2: Value of SAIFI and SAIDI for different cluster

Topological structure type	Value of SAIFI	Value of SAIDI
Type 1	4.2086	23.8454
Type2	43423	23.117
Type 3	4.2744	20.7164
Type 4	4.6506	21.5791

Table 3: Comparison of calculation errors of SAIDI and SAIFI under different type

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%

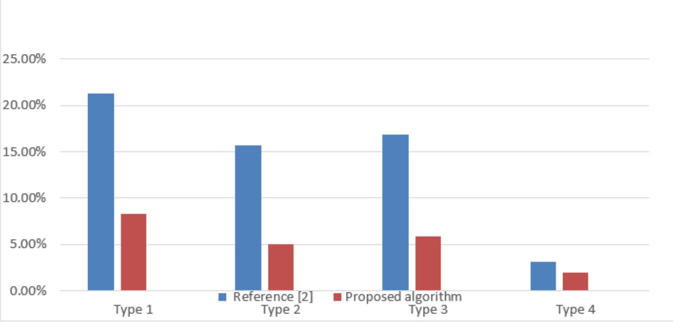

Figure 5: Comparison chart of calculation errors of SAIDI and SAIFI under different type

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.

4.2 Reliability estimation of 11 kV Baneshwor feeder

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.

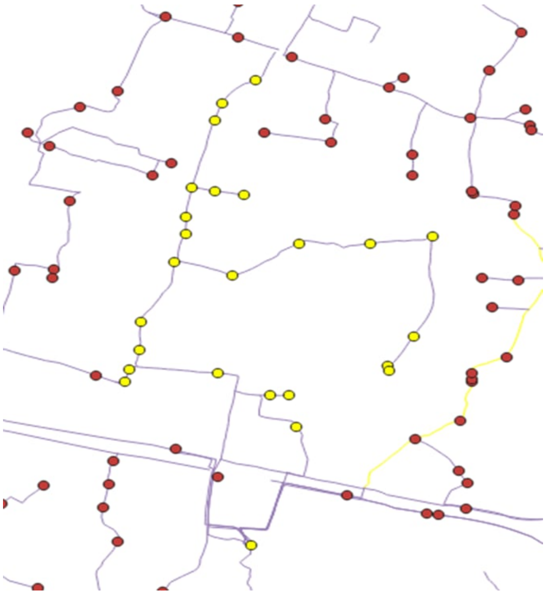

Figure 6: GIS mapping 11 kV Baneshwor feeder

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.

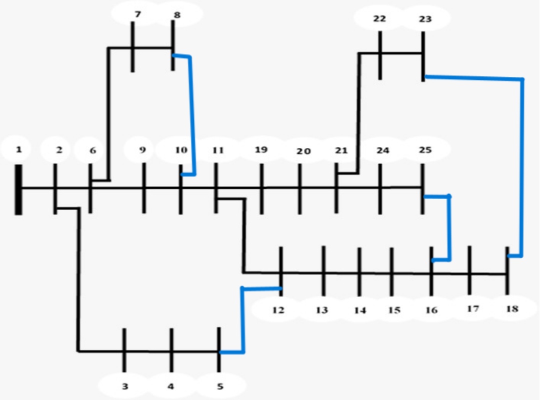

Figure 7: Single line diagram 11 kV Baneshwor feeder with tielines

Table 4: Comparison of calculation errors on reliability under different type

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%

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 corresponding β 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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