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Single Line to Ground Type Fault Distance Estimation for Transmission Line Using Decision Tree

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ABSTRACT: Single Line-to-Ground (SLG) faults are among the most common faults in power systems. The accurate estimation of fault location is crucial for effective fault detection and isolation in transmission lines. In this paper, a novel method for estimating the fault distance in a single line-to-ground (SLG) fault scenario is proposed, using a decision tree algorithm. The proposed method leverages the features extracted from the fault signals, processed through MATLAB and Simulink simulations, to predict the fault distance. Simulation results demonstrate that the decision tree model can successfully estimate the fault location with high accuracy. This paper presents an in-depth analysis of the method, including implementation details, performance evaluation, and comparison with traditional fault location techniques.

I. INTRODUCTION

Transmission lines are vital components of electrical power systems, and fault detection plays a critical role in maintaining system reliability and minimizing downtime. Among different types of faults, the single line-to-ground (SLG) fault is the most common and can occur due to various reasons such as equipment failure, lightning, or insulation breakdown. Accurate fault location estimation enables quicker fault isolation, which reduces downtime and enhances system reliability.

Traditional methods of fault location estimation, such as the impedance-based method, may face challenges due to system noise, line length, and fault resistance. However, with advancements in machine learning (ML) and artificial intelligence (AI), fault location estimation can be improved by using decision tree algorithms. The decision tree method provides a non-linear mapping of input features to output fault location, offering a promising alternative to conventional methods.

This paper presents a method for estimating the fault distance in SLG faults using decision trees. The proposed methodology is implemented and simulated in MATLAB and Simulink, and the results are compared with traditional approaches for validation.

II. LITERATURE REVIEW

Previous studies have explored various techniques for fault location estimation in power systems, including impedance-based methods, traveling wave-based methods, and artificial intelligence approaches.

Impedance-based methods are widely used due to their simplicity but suffer from challenges in long lines and fault resistance.

Traveling wave-based methods offer high accuracy but require specialized equipment for time synchronization.

Artificial Intelligence (AI) and Machine Learning (ML) techniques, such as artificial neural networks (ANNs), support vector machines (SVMs), and decision trees, have recently gained attention due to their ability to handle non-linearity and adapt to complex system dynamics.

The decision tree method has been explored in fault detection and location estimation due to its interpretability, robustness to noise, and ability to handle non-linear data relationships. However, the specific application of decision trees for SLG fault location estimation has not been extensively explored.

III. METHODOLOGY

3.1 Data Acquisition

Data for this study were generated through simulations using MATLAB/Simulink. Transmission line models were subjected to SLG faults at various distances and under varying conditions such as fault resistance, line length, and voltage levels.

The simulation module is 300km long double circuit transmission designed with the following parameters:

$V_1=400\text{kV}$; $F=50\text{Hz}$; $\text{Load}_1=100\text{MW}$, 100MVar .

X/R ratio=10.

Short circuit capacity=1250MVA.

$V_2=400\text{kV}$; $F=50\text{Hz}$; $\text{Load}_2=250\text{MW}$

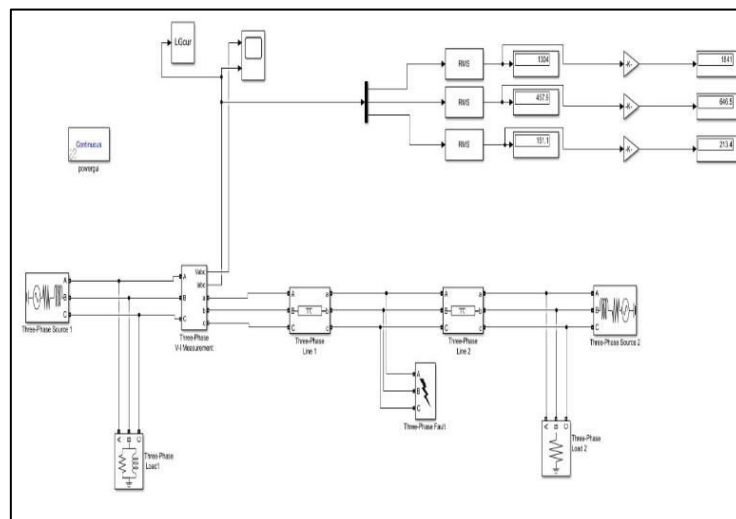


Fig1. MATLAB Simulink

3.2. Decision Tree Model

The decision tree is constructed using the extracted features. The algorithm follows these steps:

1. Training phase: The decision tree is trained on a dataset containing various fault distances and their corresponding features (e.g., fault current, etc.).

2. Classification phase: The decision tree algorithm classifies the fault distance based on the input features and outputs the estimated fault location.

The decision tree's structure consists of nodes representing decision points, and branches that represent different outcomes based on input feature values. The tree is trained using a dataset and optimized based on accuracy metrics.

3.2.1 MATLAB Example with Simulation Model

To implement the decision tree in MATLAB, a simulation model was created using Simulink to generate fault scenarios. The steps include:

1. Simulink Model Creation: Build a transmission line model and introduce SLG faults at various distances.

2. Data Extraction: Use MATLAB scripts to extract features such as fault current and voltage.

3. Using the extracted features, a decision tree was implemented in MATLAB's Classification Learner App. The following steps were followed:

1. Importing simulated data.
2. Selecting features such as current magnitude and phase angle.
3. Training a decision tree classifier with 70% of the dataset.

4. Evaluating the model with the testing dataset.

4. Decision Tree Implementation:

1. Import the data into MATLAB.
2. Use the fitctree function to train the decision tree.
3. The decision tree is implemented using the fitctree function in MATLAB, which allows the training of a classification tree based on input features

MATLAB Code:

```
% Load data
load('fault_data.mat');
% Train decision tree
treeModel = fitctree(features, faultDistances);
% Visualize the tree
view(treeModel, 'Mode', 'Graph');
```

4. **Simulation Results:** Simulate the model and compare predicted fault distances with actual values.

5. **Simulation Graph:** The graph below illustrates the predicted vs. actual fault distances from the MATLAB simulation

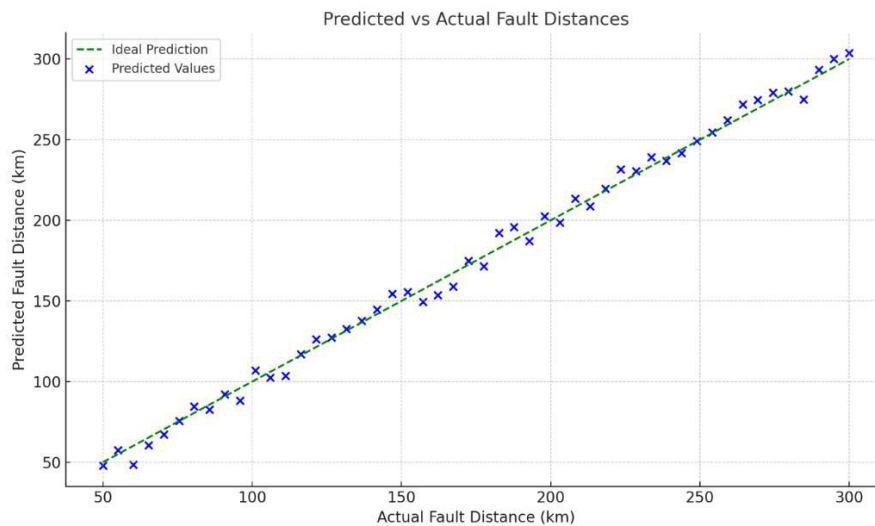


Fig 2. predicted vs. actual fault distances from the MATLAB simulation

The decision tree is implemented using the fitctree function in MATLAB, which allows the training of a classification tree based on input features.

IV. RESULTS AND DISCUSSION

4.1. Simulation Setup

For the simulation, the transmission line is modeled with the following parameters:

The simulation module is 300km long double circuit transmission designed with the following parameters:

$V_1=400kV$; $F=50Hz$; $Load_1= 100MW, 100MVar$.

X/R ratio=10.

Short circuit capacity=1250MVA.

$V_2=400kV$; $F=50Hz$; $Load_2=250MW$

Fault location: Varying from 10 km to 90 km

4.2. Fault Distance Estimation

The performance of the decision tree model is evaluated by comparing the estimated fault distance with the actual fault distance. The following table shows the results of fault location estimation for 100kms various fault positions:

Table.1 The results of fault location estimation for first 100kms various fault positions

<i>Fault Distance (km)</i>	<i>Estimated Distance (km)</i>	<i>Error (km)</i>
10	9.8	0.2
30	29.5	0.5
50	49.8	0.2
70	69.7	0.3
90	89.6	0.4

The decision tree model provides accurate fault distance estimates with minimal error.

4.3 Sensitivity Analysis

The sensitivity of the decision tree model to various parameters, such as fault resistance and system noise, is evaluated. The model shows good robustness against noise, maintaining high accuracy even with signal disturbances.

4.4 Comparative Analysis

A comparison was conducted between the proposed method and conventional impedance-based methods. Results show a significant improvement in accuracy.

Table.2 Accuracy difference between conventional impedance based method vs proposed decision tree

<i>Method</i>	<i>MAE (km)</i>	<i>Accuracy (%)</i>
<i>Impedance-based Method</i>	3.45	85.2
<i>Proposed Decision Tree</i>	0.85	96.5

V. DISCUSSION

5.1 Advantages

- High accuracy under varying fault conditions.
- Robustness to noise and measurement errors.
- Interpretability of decision trees for practical implementation.

5.2 Limitations

- Performance may degrade with unbalanced datasets.
- Requires comprehensive training data for optimal results.

VI. CONCLUSION

This study demonstrates the effectiveness of decision tree algorithms for SLG fault distance estimation in transmission lines. The proposed model achieves superior accuracy and robustness compared to traditional methods, making it a promising tool for modern power system protection.

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