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INSTITUTE OF ENGINEERING  
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**THESIS NO: 079/MSPSE/018**

**Fault Classification and Fault Distance Estimation Scheme For Transmission Line  
Based on Discrete Wavelet Transform**

**by**

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**A THESIS  
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**DEPARTMENT OF ELECTRICAL ENGINEERING  
LALITPUR, NEPAL**

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## ABSTRACT

The prompt and precise identification and localisation of transmission line faults is essential to the stability and dependability of power systems. This thesis proposes a fault distance estimation scheme that efficiently extracts features from current signals using the Discrete Wavelet Transform (DWT). This research introduces a transmission line fault analysis framework that integrates Discrete Wavelet Transform (DWT) with machine learning techniques. Using Daubechies-4 wavelets, current signals are decomposed into multiple resolution levels, from which statistical features are extracted. A Classification Tree (CTree) is employed for fault identification and categorization, while a Decision Tree (DTree) trained on Singular Value Decomposition (SVD) features of DWT outputs is used to estimate fault distance. The proposed approach is tested on four systems: the IEEE 14-Bus benchmark, the 132 kV Kushaha–Kataiya line, the 220 kV New Bharatpur–Dana line, and the 400 kV Dhalkebar–Muzaffarpur interconnection. Simulation outcomes confirm that the framework successfully detects and distinguishes between various fault types—such as single line-to-ground, line-to-line, double line-to-ground, and three-phase faults. Fault distance predictions also exhibit very small errors across all scenarios, demonstrating the robustness and precision of the method. In summary, combining wavelet-based feature extraction with machine learning significantly enhances the speed, accuracy, and resilience of fault analysis, offering a practical solution for real-time protection of Nepal’s transmission grid and other large-scale power networks.

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## List of Abbreviations

DWT	Discrete Wavelet Transform
NEA	Nepal Electricity Authority
LG	Line-to-Ground fault
LL	Line-to-Line fault
LLG	Double Line-to-Ground fault
LLL	Three-Phase fault
DB-4	Daubechies wavelet of order 4
PMU	Phasor Measurement Unit
SVD	Singular Value Decomposition
DT	Decision Tree
Ctree	Classification Tree
RMS	Root Mean Square

# CHAPTER ONE: INTRODUCTION

## 1.1 Background

The modern world has come to depend heavily on round-the-clock and consistent supply of electricity-and a high quality of electricity, too. Computer and telecommunication networks, rail networks, banking and post office networks, continuous process industries and life support systems are a few applications which simply cannot function without an extremely dependable source of electric power. And add to this, the mind-boggling number of consumers of electricity in domestic sector whose life is interrupted, in case of the electric supply being interrupted. Thus, the importance of having continuous supply of electricity at all times cannot be over emphasized[1].

No power system can be designed so faultless that it will never break down. Hence, one must accept the breakdowns. In the vocabulary of protection engineers, such breakdowns are known faults. Of more important is, how to prevent the faults and how to mitigate the consequences of faults. The ill effects of the faults are minimized by quickly isolating the faulty element from the rest of the healthy system; thus limiting the disturbance footprint to as small area in time as space as possible[2]. Faults in the transmission lines are caused by various reasons that are generally classified into environmental, equipment, and human causes.

This thesis develops a Simulink model for Fault detection, Fault classification and Fault distance estimation for transmission line based on Discrete Wavelet Transform. This model tested on IEEE-14 Bus, 132 kV Kushaha Kataiya import, 220 kV New Bharatpur Dana Transmission line and 400 kV Muzzafarpur, Dhalkebar and Inaruwa transmission line.

## 1.2 Introduction to DWT and Its Use in Fault Distance Estimation

- The Discrete Wavelet Transform (DWT) is a mathematical technique that decomposes a signal into multiple scales, allowing analysis of both its frequency content and the specific time at which changes occur.
- Unlike traditional frequency-domain methods, DWT is highly suitable for analyzing rapidly changing signals such as fault-generated disturbances in power systems.

- During a fault on a transmission line, voltage and current signals produce sharp transients, and DWT can effectively highlight these sudden variations.
- Because of its strong time–frequency resolution, robustness against noise, and compatibility with digital measurements, DWT provides a more reliable method for fault distance estimation compared to many conventional techniques.

### 1.3 Causes of faults in Transmission line

1. Environmental Causes  
 Lightning storms: Lightning is one of the primary causes; lightning will induce overvoltages and flashovers. Windstorms: Conductors may sway and strike each other or trees due to excessive winds. Heavy snow or rain: Water loading might reduce insulation and lead to flashovers. Tree contact: Trees overgrowing or falling onto lines can lead to faults. Pollution and salt deposits: They will deposit on insulators, lowering their dielectric strength and causing leakage current or flashovers. Animals: Birds, snakes, or rodents jumping conductors or insulators will cause faults.

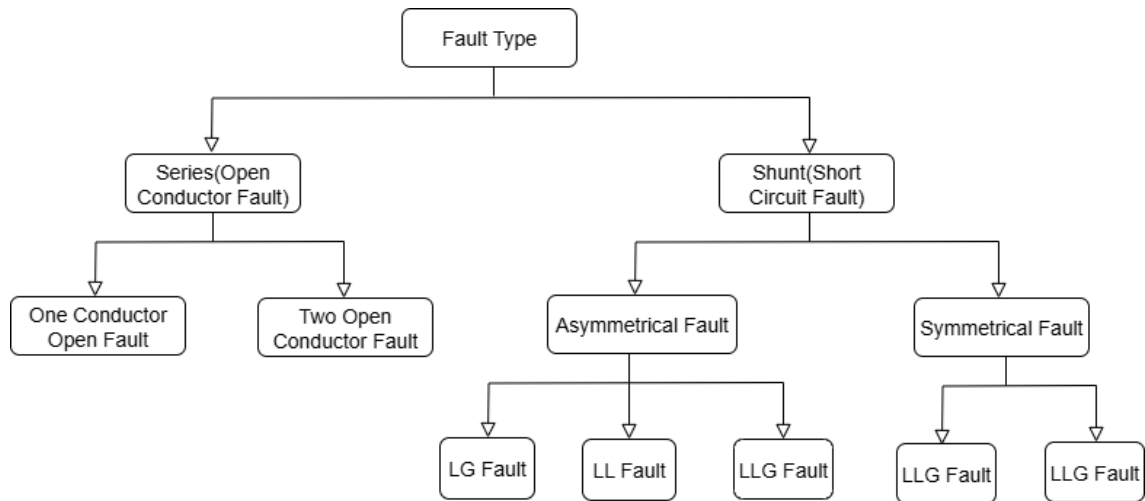
2. Equipment-Related Causes  
 Insulation failure: Due to aging, manufacturing defects, or mechanical stress. Conductor snapping: Due to mechanical fatigue, overloading, or corrosion. Poor maintenance: Wear and tear, corrosion, or loose connections can cause failures. Faulty operation of transformer or switchgear: These faults can be transferred to the transmission system.

3. Human-Caused Causes  
 Accidental connection during construction or maintenance  
 Vandalism or theft (e.g., grounding conductors)  
 Poor installation or design  
 Operational mistakes

4. Other Reasons  
 Overloading: Overheats and can lead to breakdown of insulation. Short circuits due to switching surges or ferroresonance  
 Aging infrastructure: Aging enhances the failure rate [3].

### 1.4 Classification of Faults

Power System faults are classified as shown in the figure 1.1



**Figure 1.1:** Fault Classification in Power System

## 1.5 Problem Statement

For continuous power delivery, equipment damage prevention, and system dependability, accurate and timely fault diagnosis in electrical power transmission lines is essential. Under various fault kinds, resistances, and noise circumstances, traditional protection algorithms may have trouble accurately classifying faults and estimating distances.

The goal of this project is to use Discrete Wavelet Transform (DWT) to create a clever and reliable system for fault location estimate, fault classification, and fault detection in high-voltage transmission lines. The method extracts important features from voltage and current signals captured during fault events by utilising DWT's time-frequency analysis capability. To create a fault detection, classification, and distance estimate system for high-voltage transmission lines that is precise, effective, and intelligent using Discrete Wavelet Transform (DWT) in order to increase the protection and dependability of the power system.

## 1.6 Objectives

### Main Objective

To develop an accurate, efficient, and intelligent fault detection, classification, and distance estimation scheme for high-voltage transmission lines using Discrete Wavelet Transform (DWT) for improved power system protection and reliability.

### Specific Objective

To analyse abrupt transients in current data in order to find transmission line defects.

To classify the fault type (e.g., single line-to-ground, line-to-line, double line-to-ground, or three-phase faults).

To use extracted features to obtained from DWT coefficients to estimate the fault location (distance) from the relay point or substation.

### **Scope**

- The thesis creates a system for fault detection, classification, and distance estimate based on the Discrete Wavelet Transform (DWT).
- On IEEE-14 Bus, 132 kV Kushaha–Kataiya, 220 kV New Bharatpur–Dana, and 400 kV Dhalkebar–Muzaffarpur transmission lines, the suggested scheme is implemented.
- The Nepal Electricity Authority is the source of the simulation data (NEA).
- The results demonstrate how DWT and decision tree models can be used together to provide accurate fault analysis in power systems.

### **Limitations**

- The study lacks real-time field testing and is limited to simulation-based analysis.

**Thesis Organization** The thesis is organized into five chapters. This section enlists a brief outline of each chapter and its contents.

- This chapter gives a brief introduction of the dissertation. The problem statement is described and followed by the objectives, scope and limitation of the thesis.
- Chapter 2 explores the necessary literature review done for this thesis which includes the fundamentals of Discrete Wavelet theories and research gaps.
- Chapter 3 describes the research methodology of the dissertation and overall thesis workflow.

- Chapter 4 presents the simulation results obtained fault detection, Classification and distance Estimation for IEEE-14 Bus, 132 kV Kushaha–Kataiya, 220 kV New Bharatpur–Dana, and 400 kV Dhalkebar–Muzaffarpur Transmission line.
- Chapter 5 concludes the thesis work.

Finally, this thesis will end with a list of references and the relevant appendices.

## CHAPTER TWO: LITERATURE REVIEW

This chapter presents the critical literature review done for this dissertation on condition monitoring methods, some fundamental theories of machine learning, and the fundamentals of induction machines, including how they work and what kind of problems they can have.

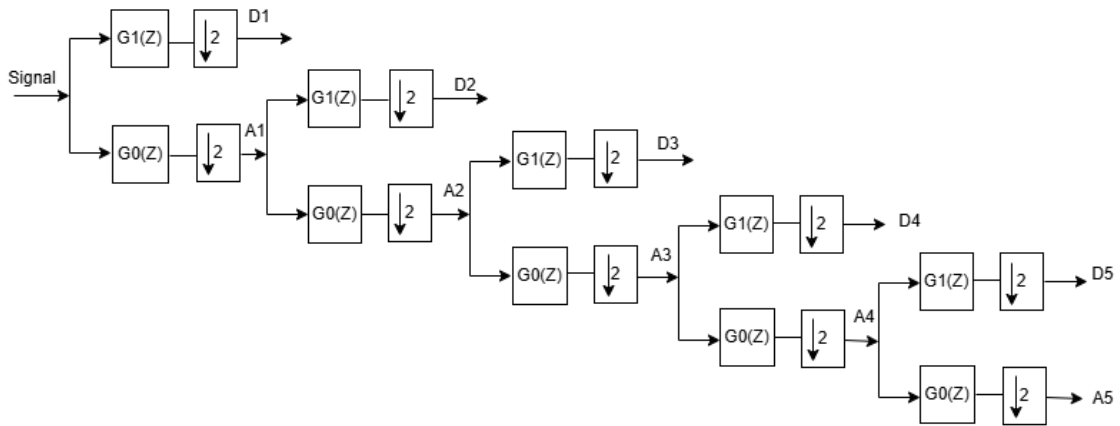
### 2.1 Discrete Wavelet Transform

#### Introduction to Wavelet Transform

The Wavelet Transform (WT) is an engineering mathematical utility for signal and analysis processing across various domains like time, frequency, and scale. Unlike conventional Fourier transforms that characterize a signal based on the frequency components, wavelet transforms provide a time-frequency analysis of a signal. This is handy when analyzing signals that have disparate frequency characteristics along time, for example, non-stationary signals such as audio signals, seismic signals, biomedical signals. Wavelet transforms find particular importance in certain fields like signal processing, image compression, and machine learning feature extraction, among others. A wavelet is a short wave with an oscillatory behavior. In contrast to sine waves, which have an infinite duration, wavelets are localized in time and frequency. They are hence appropriate for the analysis of transient and time-varying signals[4].

There are two types of Wavelet Continuous Wavelet Transform(CWT) and Discrete Wavelet Transform(DWT). Continuous Wavelet Transform analyses a signal at continuous scale and shift. It produces high resolution. Discrete Wavelet Transform(DWT) analyses signal at discrete scale and position and produces Detail and approximate coefficient. CWT is excellent for signal analysis and feature detection, but too slow for real-time fault distance calculation, where DWT provides efficient, discrete, and directly usable coefficients.[5]

Figure 2.1 shows consecutively decomposition of outputs of lowpass filters, Lowpass filters maintain slow trends while eliminating high-frequency variations from the signal. An approximation of the signal is produced via lowpass filter outputs. Highpass filters maintain high-frequency variations while eliminating sluggish trends from the signal. Highpass filters' outputs offer specific details about the signal. The approximation coefficients and detail coefficients are determined by the outputs of lowpass and highpass filters, respectively. The approximation and detail information are represented by symbols A and D in the below figure[6].



**Figure 2.1:** Signal decomposition into Detail and Approximate Coefficients

The decomposition process is described by the Wavelet Analysis Tools using the subscripts 0 and 1, where 0 denotes lowpass filtering and 1 denotes highpass filtering. In the preceding picture, for instance, D2 represents the result of two cascaded filtering operations: lowpass filtering, then highpass filtering[7].

The approximation at level 2 is the summation of the approximation and detail at level 3. As the level increases, you obtain lower frequency components, or large-scale approximation and detail, of the signal. le détail and approximation, of the signal[8].

### Types of DWT

Based on Type of Wavelet Used Popular wavelet families:

Haar Wavelet: Simplest wavelet, fastest computation, less accurate for complex signals.

Daubechies (dbN): Satisfactory in most applications as they are orthogonal with narrow support.

Symlets: Symmetrically best Daubechies wavelets.

Coiflets: Nulled for signal processing in which approximation of signal and approximation of the derivative are important.

Biorthogonal: Used in image coding (for example, JPEG2000); allows symmetric filters and linear phase.

## **Level of DWT**

The DWT level refers to the number of times the signal (or image) is decomposed into approximation and detail coefficients. Each level is a further decomposition of the approximation (low-pass) part of the signal from the previous level [9].

In other words: Level 1: Divides the original signal into Approximation (A1) and Detail (D1).

Level 2: Divides A1 into A2 and D2.

Level 3: Divides A2 into A3 and D3

Level 4: Divides A3 into A4 and D4

Level 5: Divides A4 into A5 and D5

## **DB of DWT**

in the Discrete Wavelet Transform (DWT) context, db1 to db10 refer to the Daubechies wavelets, a set of orthogonal wavelets that were invented by the mathematician Ingrid Daubechies[10].

This is what db1, db2,.., db10 represent:

### **2.1.1 DWT in transmission lines for fault distance calculation**

In this study, we consider sampling frequency of 1 MHz and apply DWT up to Level 5 using Daubechies 4 (DB-4) wavelet for the calculation of approximate coefficients.

### **2.1.2 DB-4 Low Pass Filter Coefficients**

The low-pass filter coefficients  $h[k]$  for DB-4 are:

$$h[0], h[1], h[2], h[3], h[4], h[5], h[6], h[7]$$

### **2.1.3 Approximate Coefficients Calculation**

The approximate coefficients at level  $j$  are calculated from the previous level  $j - 1$  as:

$$A^j[n] = \sum_{k=0}^{L-1} h[k] A^{j-1}[2n+k] \quad (2.1)$$

Where:

- $A^j[n]$  = Approximate coefficient at level  $j$
- $L$  = Length of the filter
- $h[k]$  = Low pass filter coefficient
- $A^{j-1}[m]$  = Approximate coefficient of previous level (or input signal for  $j = 1$ )

#### 2.1.4 Multi-Level Decomposition

Let the number of input samples be  $N$ .

##### Level 1 Approximation (A1)

- Input: Original samples  $X[n]$  of length  $N$
- Downsampling: By 2
- Length of A1:  $N/2$
- Example:

$$A1[0] = h[0]X[0] + h[1]X[1] + h[2]X[2] + \dots + h[7]X[7]$$

- Frequency band: 0–250 kHz

##### Level 2 Approximation (A2)

- Input: A1 of length  $N/2$
- Downsampling: By 2
- Length:  $N/4$
- Frequency band: 0–125 kHz

### **Level 3 Approximation (A3)**

- Input:  $A_2$  of length  $N/4$
- Downsampling: By 2
- Length:  $N/8$
- Frequency band: 0–62.5 kHz

### **Level 4 Approximation (A4)**

- Input:  $A_3$  of length  $N/8$
- Downsampling: By 2
- Length:  $N/16$
- Frequency band: 0–31.25 kHz

### **Level 5 Approximation (A5)**

- Input:  $A_4$  of length  $N/16$
- Downsampling: By 2
- Length:  $N/32$
- Frequency band: 0–15.625 kHz

## **2.2 Standard Deviation Calculation**

For each fault distance, the standard deviation of  $A_5[0]$  to  $A_5[N/32 - 1]$  is calculated.

$$\sigma_{A_5} = \sqrt{\frac{1}{N/32} \sum_{i=0}^{N/32-1} (A_5[i] - \bar{A}_5)^2}$$

The standard deviation is plotted versus the fault distance.

## **Classification Tree**

A classification tree is a supervised machine learning model can predict categorical outcomes including "yes/no," "spam/not spam," or "purchaser/non-purchaser". The model is shown as a tree structure in which every leaf, terminal node, labels the data reaching each node depending on a feature[11].

### **2.3 General Fault Location Using Off-line Bus Voltages**

An method for identifying double-circuit transmission line short-circuit problems has been described in this paper [12]. This method employs voltage measurements at one or more buses to propose a new, universal fault-location technique. When a fake bus is added at the fault location, the bus impedance matrix of each sequence network can be calculated based on the location of the fault. The bus impedance matrix and voltage measurements can then be used to determine the fault site. It makes use of the distributed parameter line model. In order to generate the bus impedance matrix, it is assumed that the network data are available. For improved fault location, an ideal estimator that can recognise faulty measurement data is also suggested when numerous voltage measurements are available.

### **2.4 Time-Domain Algorithm Using Arc Voltage**

Faults that start in one phase of a distribution circuit and spread to another phase after a few cycles are known as evolving faults. A method creates a time-domain method for estimating the faults' locations has been described in this paper [13]. The single line-to-ground portion of the fault and the line-to-line-to-ground portion of the fault are the two components of the algorithm. This methodology is derived with respect for the arc voltage that occurs during failures. Regarding the one line-to-ground section of the fault, the loop or self-reactance between the monitor and the fault is used to determine the distance to the fault. Conversely, the distance is calculated using the positive-sequence reactance for the line-to-line and line-to-ground sections of the fault. Because it is independent of fault resistance, the reactance-to-fault estimate is more reliable than the resistance-to-fault estimate. Two line-to-line fault cases and two evolving fault instances are examined.

### **2.5 Traveling-Wave Based Technique**

The methodology for an online and an offline stage has been described in this paper [14]. Time-of-arrival (ToA) observations of travelling waves propagating from the fault-occurrence point to synchronised wide-area monitoring sensors located at carefully chosen substations are the only method used in the online stage. At the moment of the fault, the

recorded waveforms are analysed collectively to determine the position of the fault that is being investigated. Using Alternative Transients Program (ATP) simulations of fault transients and discrete wavelet transform postprocessing of the faulted waveform data, the overall performance of the devised technique is demonstrated.

## **2.6 PMU-Based Fault Location in Large Networks**

A general fault-location method for large transmission networks which uses phasor measurement unit (PMU) voltage measurements where the injected current at a fault point can be calculated by using the voltage change and its relevant transfer impedance on any bus has been presented in this paper[15]. A matching degree index is defined and a two-stage fault-location optimisation methodology is put forth. The first step is the fault region identification stage, which identifies the suspicious areas using the matching degree index.

## **2.7 Research Gap**

There are a number of techniques for detecting transmission line faults and estimating distance, but they are either ineffective against noise, inappropriate for non-stationary signals, or require sophisticated equipment. There isn't a complete model that can accurately identify, categorise, and locate problems in various transmission networks (132, 220, and 400 kV), particularly in Nepal. Very few studies combine machine learning and wavelet-based feature extraction for actual grid applications, and hardly none of them have been verified for use in Nepal across multiple voltage levels (132, 220, and 400 kV).

## CHAPTER THREE: METHODOLOGY

This chapter discusses the research workflow, which starts with data collection from the Nepal Electricity Authority, and ends with creating a MATLAB Simulink model for classification of faults and Fault distance estimation of Transmission line.

### 3.1 Approach

First, the literature review is done in order to understand the concept, requirements, and having knowledge regarding simulink Model for fault detection and fault distance estimation techniques. Then, data from NEA are gathered.

#### 3.1.1 Modeling

The modeling and programming for the Test System, Fault Detector, Fault Classifier, and Fault Distance Locator have been developed in the MATLAB/Simulink environment.

#### 3.1.2 Training

The training of the Fault Detector, Fault Classifier, and Fault Distance Locator has been performed within the MATLAB/Simulink environment, utilizing the generated simulation data to enhance accuracy and reliability.

**A. Training Fault Detector** The Fault Detector has been trained using maximum values of magnitude of instantaneous current flowing through of each phase generated from simulation of healthy as well as various fault scenarios, enabling the model to accurately distinguish between normal and faulty operating conditions. The Classification Tree (CTree) method has been used.

**B. Training Fault Classifier** The Fault Classifier has been trained using absolute maximum values of instantaneous current flowing through of each phase including Neutral obtained from simulation corresponding to different fault categories, enabling the model to accurately classify the type of fault occurring in the system. The Classification Tree (CTree) method has been used.

**C. Training Fault Distance Locator** The Fault Distance Locator has been trained using Singular Value Decomposition (SVD) of approximation coefficients from DWT of instantaneous current flowing through of each phase including 1 cycle Pre-Post duration of fault occurrence gathered from simulation corresponding to multiple fault cases, allowing the

model to precisely estimate the location of faults along the transmission line. The Decision Tree(DTree) method has been used.

### 3.1.3 Testing

The developed Test System, Fault Detector, Fault Classifier, and Fault Distance Locator have been systematically tested in the MATLAB/Simulink environment to evaluate their performance and reliability. For this purpose, a set of unseen fault and non-fault scenarios, different from those used in the training phase, were generated to ensure unbiased evaluation. The testing process involved assessing the accuracy of the Fault Detector in identifying fault conditions, the effectiveness of the Fault Classifier in categorizing fault types, and the precision of the Fault Distance Locator in estimating the exact fault location along the transmission line. The results obtained from the testing phase were analyzed in terms of accuracy, robustness, and computational efficiency, thereby validating the suitability of the developed models for practical power system fault analysis.

**A. Testing Fault Detector** The Fault Detector was tested in the MATLAB/Simulink environment using datasets that included both fault and non-fault conditions. The primary objective of the testing process was to evaluate the detector's ability to correctly distinguish normal operating states from abnormal faulted states. The results demonstrated that the Fault Detector achieved high accuracy in identifying fault occurrences under diverse system conditions, thereby confirming its robustness and reliability.

**B. Testing Fault Classifier** The Fault Classifier was tested using a wide range of unseen fault scenarios representing different categories, such as single line-to-ground, double line-to-ground, line-to-line, and three-phase faults. The testing process was conducted in the MATLAB/Simulink environment with datasets not utilized during training, ensuring unbiased evaluation. The results indicated that the Fault Classifier was able to correctly identify the type of fault with a high level of accuracy, validating its effectiveness for fault categorization in power systems.

**C. Testing Fault Distance Locator** The Fault Distance Locator was tested by subjecting it to multiple fault cases with varying fault locations along the transmission line. The testing was carried out in the MATLAB/Simulink environment, and the estimated fault locations were compared with the actual fault positions. The results showed that the Fault Distance Locator provided precise estimations with minimal error, thereby confirming its suitability for accurate fault localization in transmission systems.

### 3.2 General Algorithm for Fault Location

1. Obtain the current and Voltage signal at the relay location.

The process starts with gathering from the relay position in the power system real-time voltage and current readings. Detecting and analyzing errors requires these signals.

2. Train using CTree

A Conditional Inference Tree is a form of decision tree applied in classification problems. Using labeled data—historical fault cases—the system is taught to identify several failure kinds depending on the input signals.

3. Use trained Ctree for fault classification

Arriving signals are then categorized using the trained CTree model, thereby determining the kind of fault—single line-to-ground, double line, etc.).

4. Determine the approxidental fault instant.

The system guesses the likely moment of the problem occurrence. This is absolutely essential for separating pertinent signal portions for more investigation.

5. Get one cycle pre-fault sample and one cycle post-fault samples.

Starting from the found fault instant, the system generates one cycle of current signal data before the fault (pre-fault) and one cycle following the fault (post-fault). This aids in capturing the features and change of the fault event.

6. Decompose the Extracted Signals using DB-4 Wavelet Up to Level 5

Up to level five, a Daubechies 4 (DB-4) wavelet transform breaks down the obtained current signals. For fault investigation, wavelet decomposition facilitates the isolation of signal characteristics at several frequency ranges.

7. Record the approximative coefficients acquired at level

The approximation coefficients—which reflect the low-frequency content—at the designated level are determined from the wavelet decomposition. These coefficients catch the fundamental features of the signal connected to the fault.

## 8. Training the DT-Based Fault Location Estimation Module Using These SVDs of Current Signals

To extract features, the approximation coefficients are further handled possibly using Singular Value Decomposition (SVD). A Decision Tree (DT) model trained using these characteristics approximates the fault location.

## 9. Find the fault location DWT-DTR using this trained DT (LG, LLG, LL, LLL).

The fault location for certain kinds of faults is estimated using the learned Decision Tree:

LG: Ground to Line

Double Line to Ground: LLG

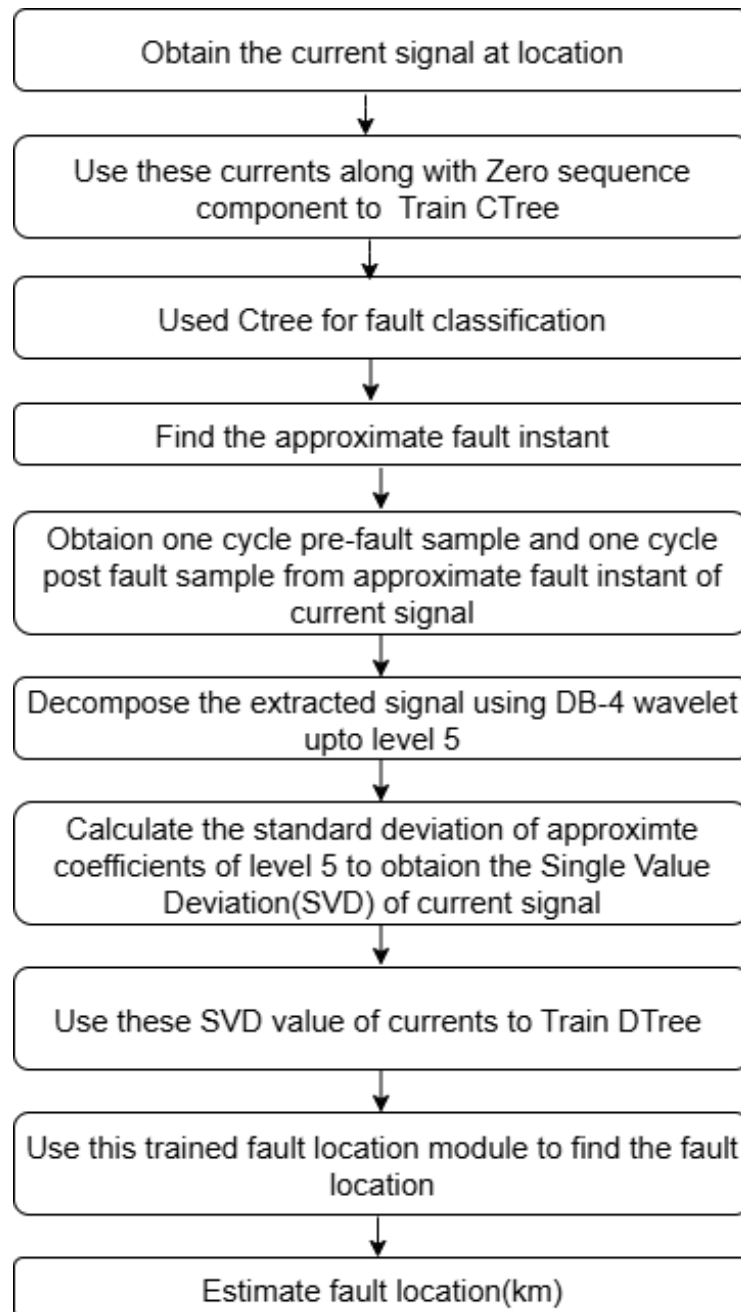
LL: Straight to-line

LLL: Three-Phase Damage

## 10. Determine the Fault Location DWT DTR (LG, LLG, LLL) Using This Trained DT

To improve the location estimation, the procedure is repeated maybe with a different arrangement or for a subset of fault types.

## 11. Projected Fault Distance (Km) Overall, the methodology that has been adopted in this dissertation is summarized in the Figure below 3.1.



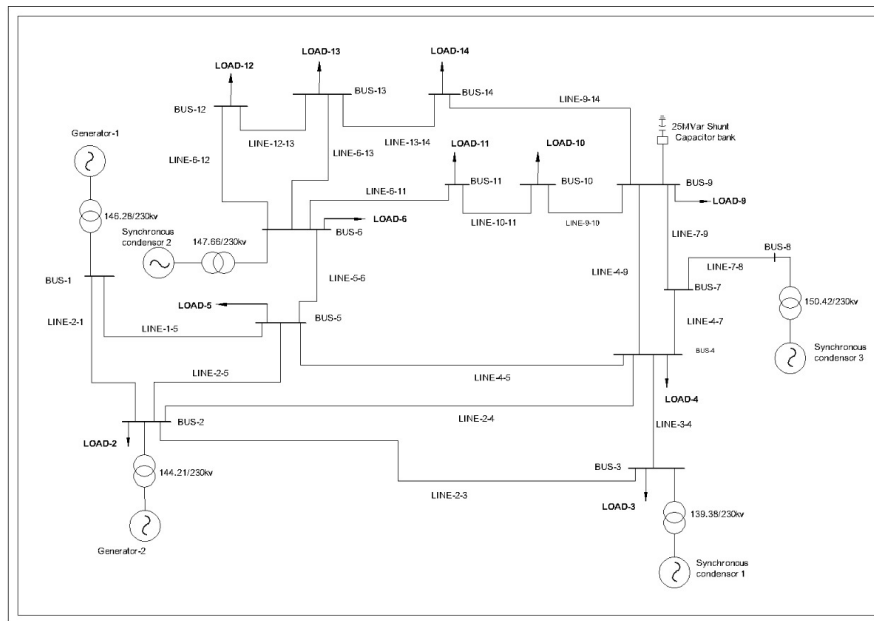
**Figure 3.1:** Summary of Overall procedure

### 3.3 Data Acquisition

This method has been tested on IEEE-14 Bus system, Kushaha Kataiya 132 kV transmission line, New Bharatput Dana 220 KV transmission line and Muzzafarpur Dhalkebar Inarauwa 400 kV transmission line. The data are collected from Nepal Electricity Authority.

### 3.3.1 IEEE 14-Bus System

Single line diagram of IEEE 14-Bus System has been shown in fig3.2



**Figure 3.2:** Single Line Diagram of IEEE 14-Bus System

### 3.3.2 Kushaha Kataiya 132 kV Transmission line

Single line diagram of Kushaha Kataiya 132 Transmission line has been shown in fig3.3

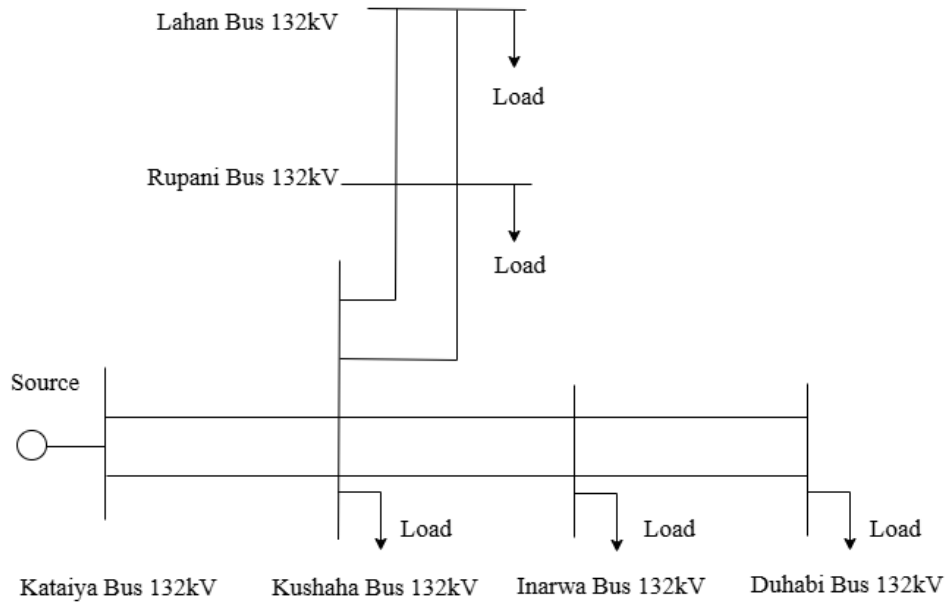
The Loading status of Kushaha, Inaruwa, Duhabi, Rupani and Lahan Bus are 5 MW, 40 MW, 150 MW, 20 MW and 35 MW respectively. The Transmission line data of Kushaha Kataiya 132 kV Transmission line has been in fig 3.1

**Table 3.1:** Transmission line data of Kushaha Kataiya 132 kV Transmission line

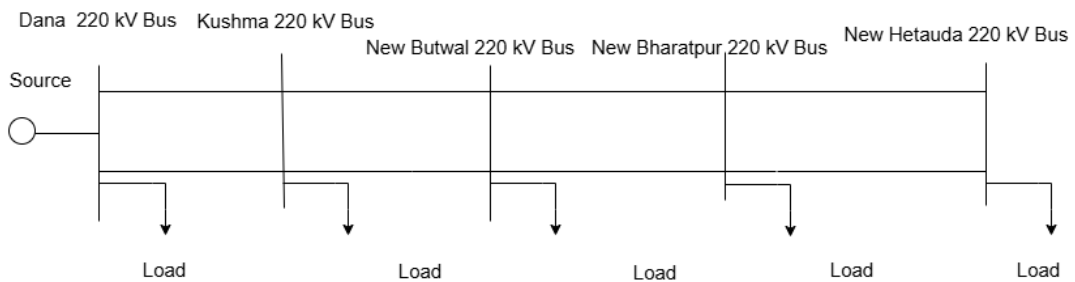
Substation	To Bus	Length(Km)	R	L	C	Ro	Lo	Co
Kataiya	Kushaha	30.00	0.1086	1.26E-03	9.36E-09	0.3259	4.68E-03	5.80E-09
Kushaha	Iraruwa	23.00	0.1086	1.26E-03	9.36E-09	0.3259	4.68E-03	5.80E-09
Inaruwa	Duhabi	15.00	0.1086	1.26E-03	9.36E-09	0.3259	4.68E-03	5.80E-09
Kushaha	Rupani	22.00	0.1086	1.26E-03	9.36E-09	0.3259	4.68E-03	5.80E-09
Rupani	Lahan	27.00	0.1086	1.26E-03	9.36E-09	0.3259	4.68E-03	5.80E-09

### 3.3.3 New Bharatpur to Dana 220 kV Transmission line

Single line diagram of New Bharatpur Dana 220 KV Transmission line has been shown in fig3.4 The Loading status of Kusma, New Butwal, New Bharatpur and New Hetauda



**Figure 3.3:** Single Line Diagram of Kushaha Kataiya 132 kV Import



**Figure 3.4:** Single Line Diagram of New Hetauda Dana 220 kV Transmission line

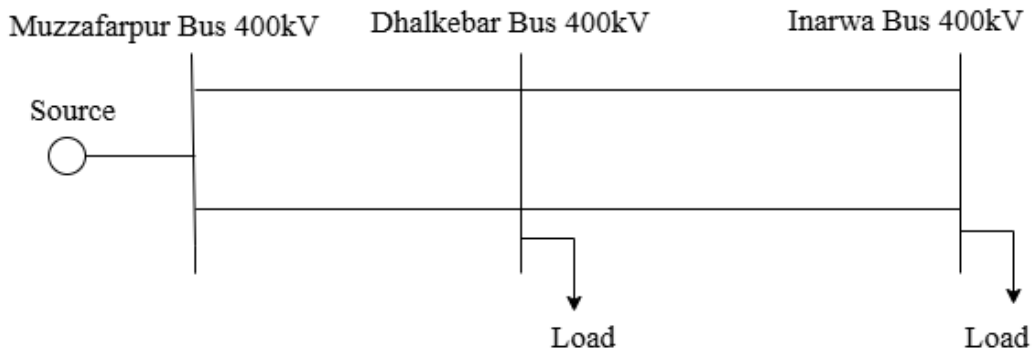
Bus are 5 MW,150 MW,100 MW and 50 MW respectively. The Line parameters of New Bharatpur Dana 220 Kv Transmission line parameters shown in fig 3.2

**Table 3.2:** New Bharatpur Dana 220 Kv Transmission Line Parameters

Substation	To Bus	Length (Km)	Conductor	R	L	C	Ro	Lo	Co
Dana	Kushma	39.80	Moose	0.0694	1.25E-03	9.58E-09	0.2011	4.49E-03	5.93E-09
Kushma	New Butwal	88.00	ACCC Drake	0.0749	1.26E-03	9.28E-09	0.2247	4.70E-03	5.75E-09
New Butwal	New Bharatpur	125.00	Bison	0.0697	1.27E-03	9.24E-09	0.2091	4.69E-03	5.73E-09
New Bharatpur	New Hetauda	71.70	Bison	0.0697	1.27E-03	9.24E-09	0.2091	4.69E-03	5.73E-09

### 3.3.4 Dhalkebar Muzzafarpur 400 kV Transmission line

The Loading status of Dhalkebar and Inaruwa Bus are 350 MW and 250 MW respectively. The Line parameters of Muzzafarpur,Dhalkebar and Inaruwa 400 Kv Transmission line parameters shown in fig 3.3



**Figure 3.5:** Single Line Diagram of Muzzafarpur Dhalkebar 400kV Transmission Line

**Table 3.3:** Transmission Line Data

Substation	To Bus	Length(Km)	Conductor	R	L	C	Ro	Lo	Co
Muzzafarpur	Dhalkebar	140.00	Moose	0.0146	7.99E-04	1.43E-08	0.1895	2.65E-03	8.26E-09
Dhalkebar	Iraruwa	153.00	Moose	0.0146	7.99E-04	1.43E-08	0.1895	2.65E-03	8.26E-09

## CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter presents the results obtained using the methodology described in Chapter 3.

### 4.1 Case A:IEEE-14 Bus System

#### 4.1.1 Simulation Results

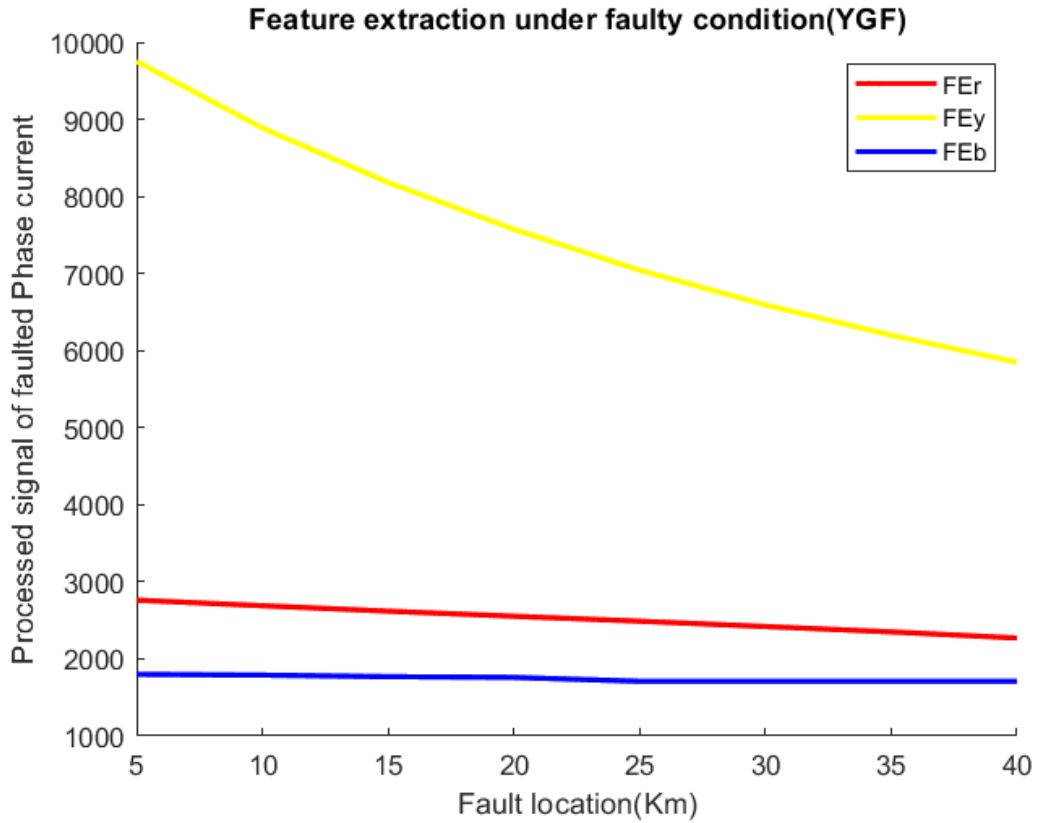
##### Feature Extraction

Table Showing Maximum of absolute value of currents at different locations obtained from IEEE-14 Bus Modelling for the fault occurring on transmission line between Bus-1 and Bus-2 as shown in Table 4.1. For all types of faults like these data set were extracted, and finally by using these all data Ctree was trained for fault detection and fault Classification.

The Standard deviation of approximate coefficient of DWT DB-4 upto level 5 were obtained for all fault type(LG,LL,LLG and LLL) and different fault locations for the fault occurring on transmission line between Bus-1 and Bus-2. The table 4.2 shows these values of standard deviation. The DWT extracted feature of current during LG fault of R, Y and B Phases are as illustrated in Figure, fig 4.1. The graphic illustrates how fault location along the transmission line affects the processed fault-current characteristics of the red (R), yellow (Y), and blue (B) phases. The feature values of all three phases progressively decline as the fault advances from the measuring end (from 5 km to 40 km). The red-phase (FEr) and blue-phase (FEb) curves stay significantly lower and almost parallel, implying their contribution to fault detection is smaller and less sensitive to distance. Overall, the figure illustrates that the fault feature energy is strongest near the fault site and lessens as the fault position goes further along the line.

**Table 4.1:** Table Showing Maximum of absolute value of currents at different locations for RG Fault of IEEE-14 Bus System

Distance (Km)	Interval		Currents (A)			
	From	Upto	R Phase	Y Phase	B Phase	Io
5	51	16667	573.15	573.15	573.15	1.33563E-07
	16668	33334	573.15	573.15	573.15	1.34941E-07
	33335	50001	573.15	573.15	573.15	1.10983E-07
	50002	66668	573.15	573.15	573.15	1.11670E-07
	66669	83335	573.15	573.15	573.15	9.84298E-08
	83336	100002	573.15	573.15	573.15	9.92732E-08
	100003	116669	2301.8	786.54	847.85	1056.060194
	116670	133336	3174.6	509.72	835.20	1513.163115
	133337	150003	2255.2	520.69	745.34	1103.525412
	150004	166670	2836.6	452.80	760.90	1432.141189
	166671	183337	2317.3	464.46	729.71	1168.838253
10	51	16667	573.14	573.14	573.14	1.06005E-07
	16668	33334	573.14	573.14	573.14	1.13588E-07
	33335	50001	573.14	573.14	573.14	8.59854E-08
	50002	66668	573.14	573.14	573.14	9.41988E-08
	66669	83335	573.14	573.14	573.14	7.48754E-08
	83336	100002	573.14	573.14	573.14	8.39389E-08
	100003	116669	2124.7	798.86	894.63	971.8213311
	116670	133336	2855.8	555.23	809.14	1383.685218
	133337	150003	2089.1	562.71	746.83	1032.890629
	150004	166670	2563.6	479.61	739.61	1300.159843
	166671	183337	2174.6	480.20	717.71	1094.92482
15	51	16667	573.14	573.14	573.14	3.96144E-08
	16668	33334	573.14	573.14	573.14	4.16359E-08
	33335	50001	573.14	573.14	573.14	3.61869E-08
	50002	66668	573.14	573.14	573.14	3.71304E-08
	66669	83335	573.14	573.14	573.14	3.32248E-08
	83336	100002	573.14	573.14	573.14	3.42167E-08
	100003	116669	1977.7	906.34	864.47	915.5696264
	116670	133336	2592.1	565.17	766.44	1275.131729
	133337	150003	1964.2	544.75	725.16	972.0084648
	150004	166670	2357.9	493.08	716.93	1189.605341
	166671	183337	2034.4	495.18	691.18	1026.71352
...						
40	51	16667	573.11	573.11	573.11	1.96011E-08
	16668	33334	573.11	573.11	573.11	1.06351E-08
	33335	50001	573.11	573.11	573.11	1.13702E-08
	50002	66668	573.11	573.11	573.11	7.58716E-09
	66669	83335	573.11	573.11	573.11	7.98160E-09
	83336	100002	573.11	573.11	573.11	7.39629E-09
	100003	116669	1512.4	969.34	769.20	701.4081599
	116670	133336	1872.0	667.81	655.70	895.0750377
	133337	150003	1488.0	598.74	645.08	731.1540712
	150004	166670	1623.1	590.03	603.90	823.4996578
	166671	183337	1550.0	565.26	597.02	766.5379829



**Figure 4.1:** Extracted Feature of fault current under Y phase to Ground Fault

**Table 4.2:** Standard deviation of DWT approximate coefficients under various fault types at different distances for IEEE 14-Bus system

Fault Type/Distance	Phase	5	10	15	20	25	30	35	40
RG	R	5579.317	5262.867	4983.619	4789.775	4676.948	4576.842	4451.256	4280.925
YG	Y	9752.022	8886.623	8180.227	7572.512	7041.969	6591.896	6198.813	5848.647
BG	B	10874.55	9893.562	9071.409	8380.059	7775.274	7259.370	6790.903	6380.378
RY	R	6001.717	5540.143	5158.181	4820.524	4515.165	4240.635	3983.596	3739.477
	Y	7985.659	7529.354	7143.436	6799.015	6485.456	6199.054	5928.951	5669.921
YB	Y	9514.597	8822.540	8168.601	7594.490	7075.519	6608.653	6145.507	5722.187
	B	11360.25	10664.21	10025.33	9455.851	8938.374	8466.917	8010.490	7585.322
BR	R	10642.66	9936.289	9345.966	8806.869	8308.310	7860.591	7456.488	7069.398
	B	8617.531	7869.322	7273.294	6724.917	6214.822	5765.393	5369.810	4991.055
RYG	R	8590.649	8024.742	7555.622	7144.717	6763.543	6422.756	6117.069	5846.946
	Y	9464.842	8803.186	8264.562	7799.077	7389.619	7023.178	6687.759	6381.485
YBG	Y	9722.514	8945.642	8325.338	7808.876	7315.106	6813.768	6436.356	6011.963
	B	11802.74	10988.68	10280.84	9670.095	9097.388	8511.977	8065.439	7541.845
BRG	R	8781.840	8858.864	8455.576	8119.892	7816.183	7462.690	7276.074	6967.936
	B	11348.30	10353.35	9553.196	8850.329	8222.648	7678.427	7071.161	6096.231
RYB	R	5578.897	5235.332	4979.220	4739.518	4520.943	4335.017	4152.189	3973.253
	Y	10943.01	10248.58	9636.901	9089.010	8590.589	8128.811	7697.031	7286.039
	B	10339.96	9717.255	9163.308	8656.754	8191.259	7764.469	7361.325	6977.650

## 4.2 Case B:Kushaha Kataiya 132 kV Transmission line

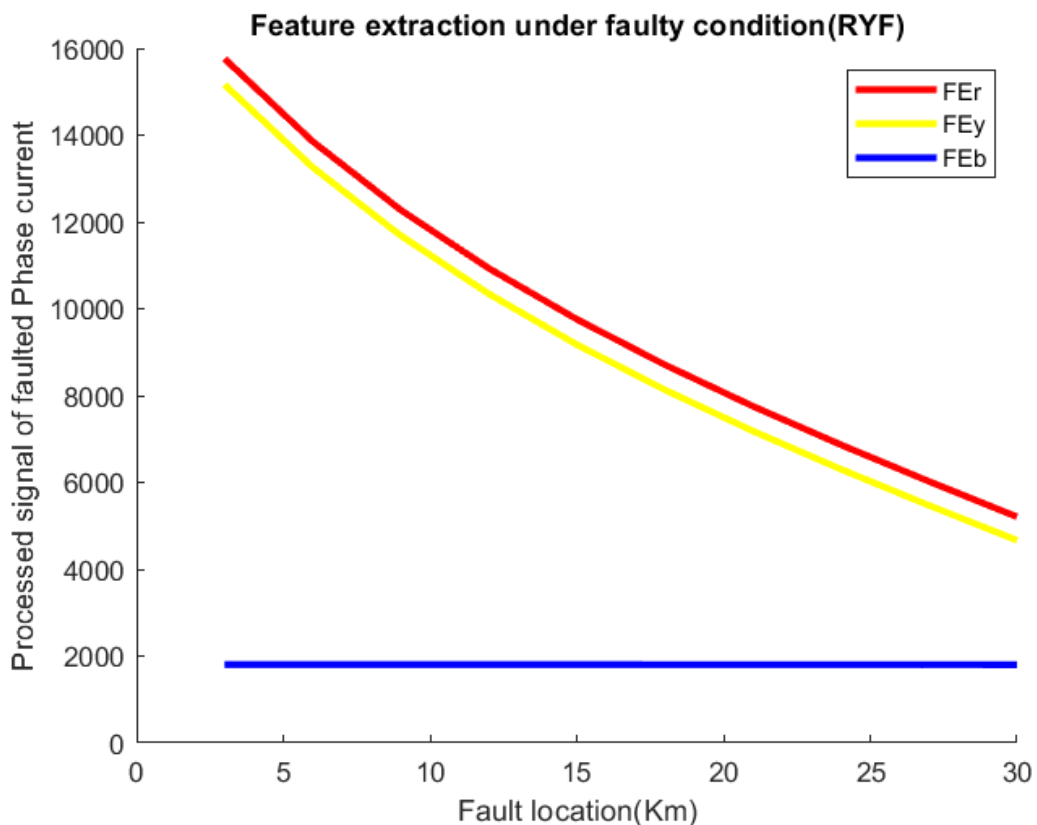
### 4.2.1 Simulation Results

#### Feature Extraction

Based on Modeling of Kushaha Kataiya 132 Transmission line maximum of absolute value of currents at different location data extracted for the fault occurring on transmission line between Kataiya Bus 132 kv and Kushaha Bus 132 kv shown in fig .4.3

The Standard deviation of approximate coefficient of DWT DB-4 upto level 5 were obtained for all fault type(LG,LL,LLG and LLL) and different fault locations for the fault occurring on transmission line between Kataiya Bus 132 kv and Kushaha Bus 132 kv.The table 4.4 shows these values of standard deviation.

The DWT extracted feature of current during LL of R,Y and B Phases are as illustrated in Figure, respectively fig 4.2.



**Figure 4.2:** Extracted Feature of fault current under R phase to Y Phase Fault

The Standard deviation of approximate coefficient of DWT DB-4 upto level 5 were obtained for all fault type(LG,LL,LLG and LLL) and different fault locations for the fault

**Table 4.3:** Table Showing Maximum of absolute value of currents at different locations for RG fault of 132 kV Transmission line

5	1	20000	449.86	449.86	449.86	5.38181E-10
	20001	40000	449.86	449.86	449.86	5.2391E-10
	40001	60000	7346.7	449.86	458.6	17095.20358
	60001	80000	7339.2	437.56	461.66	17138.10464
	80001	100000	6521.6	437.68	461.47	15157.49497
10	1	20000	449.85	449.85	449.85	3.2589E-10
	20001	40000	449.85	449.85	449.85	2.84598E-10
	40001	60000	5616.6	449.85	459.76	14435.9797
	60001	80000	5602.3	433.58	459.19	14464.26966
	80001	100000	4805.9	433.29	459.08	12210.43658
15	1	20000	449.84	449.84	449.84	5.15678E-10
	20001	40000	449.84	449.84	449.84	4.95945E-10
	40001	60000	4461.4	449.84	461.06	12948.51103
	60001	80000	4444.2	439.35	468.06	12972.14348
	80001	100000	3758.4	438.75	467.24	10688.21794
20	1	20000	449.84	449.84	449.84	4.02268E-10
	20001	40000	449.84	449.84	449.84	3.68289E-10
	40001	60000	3606.6	449.84	459.65	12196.64383
	60001	80000	3588.6	445.99	477.59	12220.70385
	80001	100000	3026.6	444.74	476.65	9954.185647
25	1	20000	449.83	449.83	449.83	5.84699E-10
	20001	40000	449.83	449.83	449.83	5.71955E-10
	40001	60000	2912	453.91	460.11	12029.87802
	60001	80000	2895.4	453.08	487.61	12056.92695
	80001	100000	2456.2	451.35	487.41	9812.997445
30	1	20000	449.82	449.82	449.82	1.06857E-09
	20001	40000	449.82	449.82	449.82	9.61622E-10
	40001	60000	2285.4	464	472.04	12479.50067
	60001	80000	2270.7	462.47	501.48	12512.14314
	80001	100000	1955.3	460.75	501.96	10311.04651

occurring on transmission line between Kataiya-Bus and Kushaha-Bus. The table 4.4 shows these values of standard deviation. The DWT extracted feature of current during LG fault of R, Y and B Phases are as illustrated in Figure, fig 4.2. The graphic illustrates how fault location along the transmission line affects the processed fault-current characteristics of the red (R), yellow (Y), and blue (B) phases. The feature values of all three phases progressively decline as the fault advances from the measuring end (from 5 km to 30 km).

**Table 4.4:** Standard deviation of DWT approximate coefficients under various fault types at different distances for 132 kV transmission line

Fault Type/Distance	Phase	3	6	9	12	15	18	21	24	27	30
RG	R	16986	14336	12346	10777	9491.2	8402.6	7451.9	6596	5800.3	5034.4
YG	Y	15092	12867	11161	9797.2	8669.6	7708	6864.3	6101.5	5390.5	4704.8
BG	B	13463	11463	9951.4	8746.1	7752.3	6908.6	6169.9	5501.4	4873.8	4284
RY	R	15758	13853	12275	10931	9757.4	8709.4	7754.2	6865.5	6022	5206.3
	Y	15162	13259	11684	10344	9174.2	8131.5	7182.9	6302.4	5469	4665
YB	Y	12588	11212	10041	9026.5	8127.3	7317	6576.5	5883.1	5226	4593.9
	B	11815	10449	9287.3	8284.3	7394.5	6593.7	5864.9	5182.9	4539.4	3923.4
BR	R	13942	12584	11111	9849.4	8743	7753.1	6849.7	6009	5211	4438.8
	B	14580	13271	11797	10532	9422.7	8429	7521	6674.6	5869.7	5088.9
RYG	R	17646	15314	13446	11893	10561	9387.4	8327.9	7348	6419.2	5515.8
	Y	15807	13800	12172	10804	9620.4	8573.5	7629.4	6758	5938.4	5151.9
YBG	Y	15424	13469	11907	10604	9479.8	8481.8	7573.1	6723.8	5909.8	5108.2
	B	14450	12567	11089	9861.2	8800.7	7855.6	6992.7	6184.6	5411.2	4654.6
BRG	R	17521	15038	13109	11532	10195	9026.4	7978	7014	6106.1	5484
	B	14856	13187	11770	10545	9465.2	8494.9	7605.6	6771.9	5971	5231.1
RYB	R	17976	15666	13778	12187	10813	9605.1	8499.6	7488	6513.2	5573.6
	Y	15987	14105	12523	11160	9959.4	8880.9	7891	6964.6	6078.1	5210.9
	B	14220	12521	11101	9886.5	8824.4	7882	7015.6	6219.1	5450.3	4711

The red-phase (FEr) and blue-phase (FEb) curves stay significantly lower and almost parallel, implying their contribution to fault detection is smaller and less sensitive to distance. Overall, the figure illustrates that the fault feature energy is strongest near the fault site and lessens as the fault position goes further along the line.

### 4.3 Case C: New Bharatpur to Dana 220 kV Transmission line

#### 4.3.1 Simulation Results

##### Feature Extraction

Based on Modeling of New Bharatpur Dana 220 KV Transmission line maximum of absolute value of currents at different location data extracted for the fault occurring on transmission line between New Butwal Bus 220 kv and New Bharatpur Bus 220 kv shown in Table .4.5 The DWT extracted feature of current during LLG of R,Y and B Phases are as illustrated in Figure, fig 4.3. The Standard deviation of approximate coefficient of DWT DB-4 upto level 5 were obtained for all fault type(LG,LL,LLG and LLL) and different fault locations for the fault occurring on transmission line between Kataiya-Bus and Kushaha-Bus. The table 4.4 shows these values of standard deviation. The graphic illustrates how fault location along the transmission line affects the processed fault-current characteristics of the red (R), yellow (Y), and blue (B) phases. The feature values of all three phases progressively decline as the fault advances from the measuring end (from 5 km to 125 km). The red-phase (FEr) and blue-phase (FEb) curves stay significantly lower

and almost parallel, implying their contribution to fault detection is smaller and less sensitive to distance. Overall, the figure illustrates that the fault feature energy is strongest near the fault site and lessens as the fault position goes further along the line.

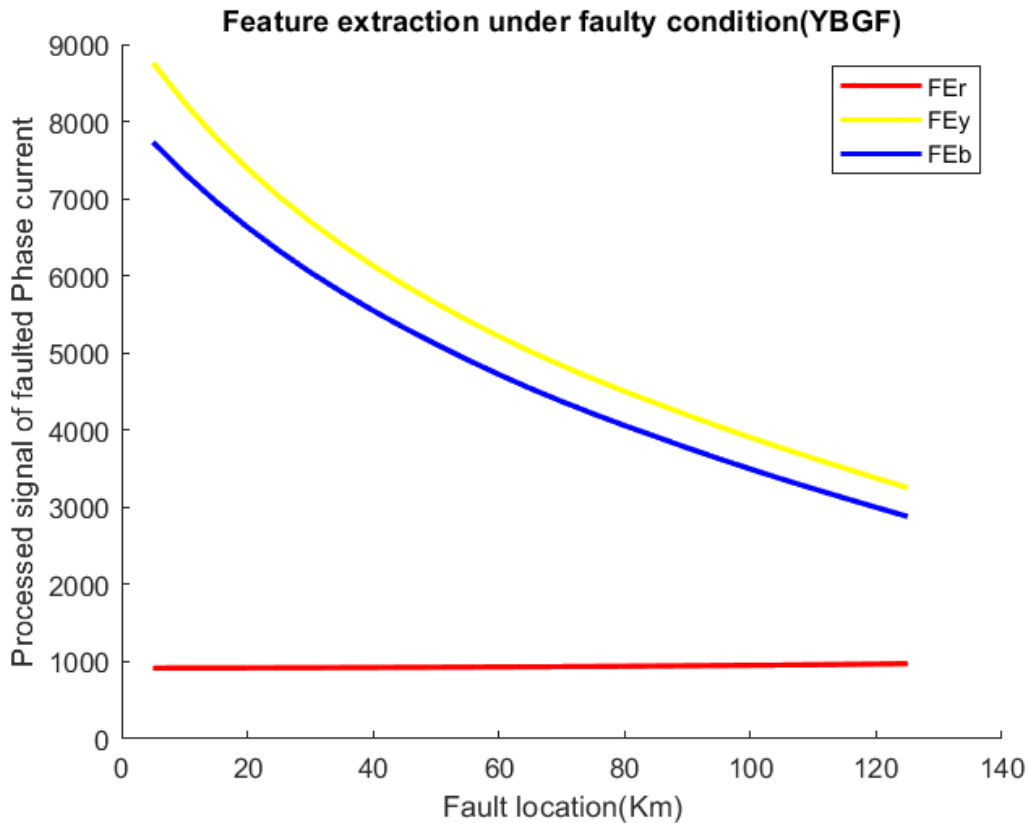
**Table 4.5:** Table Showing Maximum of absolute value of currents at different locations for YG fault of 220 kV Transmission line

Distance (Km)	Interval		Currents (A)			
	From	Upto	R Phase	Y Phase	B Phase	Io
5	51	20000	218.949	218.949	218.949	1.93716E-10
	20001	40000	218.949	218.949	218.949	1.74963E-10
	40001	60000	292.965	3558.3	311.669	8567.787812
	60001	80000	269.228	3069.67	226.16	7051.769055
	80001	100000	260.772	2835.49	212.521	6259.544739
10	51	20000	218.947	218.947	218.947	5.94064E-10
	20001	40000	218.947	218.947	218.947	5.46187E-10
	40001	60000	291.167	3263.68	311.755	8081.059908
	60001	80000	268.436	2829.89	226.207	6567.820517
	80001	100000	260.317	2613	215.345	5832.289946
15	51	20000	218.946	218.946	218.946	2.10489E-10
	20001	40000	218.946	218.946	218.946	2.38492E-10
	40001	60000	290.894	3044.2	311.823	7614.706694
	60001	80000	264.023	2627.38	222.939	6181.938712
	80001	100000	259.551	2420.65	213.961	5469.613428
...						
120	51	20000	218.912	218.912	218.912	5.26032E-10
	20001	40000	218.912	218.912	218.912	5.12716E-10
	40001	60000	310.586	1183.67	303.764	4663.993561
	60001	80000	291.684	993.424	248.422	3931.416075
	80001	100000	286.368	911.733	242.651	3163.356511
125	51	20000	218.91	218.91	218.91	2.30539E-09
	20001	40000	218.91	218.91	218.91	2.12328E-09
	40001	60000	310.203	1140.14	302.092	4633.410502
	60001	80000	295.107	956.372	251.869	3947.595226
	80001	100000	290.827	879.505	245.766	3166.130025

The Standard deviation of approximate coefficient of DWT DB-4 upto level 5 were obtained for all fault type(LG,LL,LLG and LLL) and different fault locations for the fault occurring on transmission line between New Butwal Bus 220 kv and New Bharatpur Bus 220 kv. Standard deviation of DWT under these fault at various distances are shown in table 4.6

**Table 4.6:** Standard deviation of DWT approximate coefficients under various fault types at different distances for 220 kV Transmission line

Distance	Fault_Type/Phase																	
	RG	YG	BG	RY		YB		BR		RYG		YBG		BRG		RYB		
	R	Y	B	R	Y	Y	B	R	B	R	Y	Y	B	R	B	R	Y	B
5	8153	7533	6584	8957	8620	7333	6908	7531	7883	9724	8713	8758	7731	8957	8620	9909	9311	7968
10	7589	7027	6147	8464	8124	6939	6511	7082	7436	9135	8235	8244	7328	8464	8124	9332	8792	7510
15	7096	6584	5764	8018	7676	6589	6160	6680	7035	8611	7801	7791	6962	8018	7676	8811	8328	7101
20	6662	6193	5426	7614	7270	6275	5845	6321	6676	8143	7406	7390	6630	7614	7270	8341	7907	6738
25	6276	5845	5126	7245	6899	5988	5557	5994	6350	7720	7043	7029	6326	7245	6899	7913	7523	6407
30	5930	5532	4858	6906	6559	5724	5293	5696	6053	7335	6709	6702	6047	6906	6559	7522	7170	6105
35	5619	5250	4617	6593	6245	5481	5050	5422	5780	6983	6400	6405	5789	6593	6245	7162	6844	5826
40	5336	4994	4398	6304	5954	5254	4823	5169	5528	6659	6114	6131	5549	6304	5954	6830	6541	5568
45	5079	4760	4198	6035	5685	5044	4612	4936	5295	6360	5848	5878	5323	6035	5685	6522	6260	5328
50	4843	4546	4015	5784	5433	4848	4417	4719	5079	6083	5599	5644	5113	5784	5433	6235	5998	5106
55	4626	4349	3847	5549	5197	4662	4231	4516	4876	5825	5365	5423	4911	5549	5197	5968	5750	4896
60	4426	4166	3691	5328	4976	4488	4056	4325	4686	5584	5146	5215	4721	5328	4976	5717	5519	4699
65	4241	3997	3545	5121	4768	4323	3892	4462	4886	5357	4939	5019	4541	5121	4768	5481	5300	4514
70	4068	3839	3410	4924	4571	4169	3739	4278	4703	5145	4742	4837	4372	4924	4571	5259	5094	4341
75	3906	3692	3281	4739	4385	4023	3593	4105	4530	4943	4559	4665	4211	4739	4385	5049	4899	4177
80	3755	3553	3160	4562	4209	3885	3457	3940	4367	4753	4382	4501	4059	4562	4209	4850	4714	4022
85	3612	3423	3047	4394	4040	3753	3325	3784	4209	4572	4215	4348	3915	4394	4040	4661	4536	3875
90	3477	3299	2940	4233	3880	3622	3194	3632	4057	4399	4056	4194	3769	4233	3880	4480	4365	3729
95	3350	3182	2838	4079	3726	3502	3079	3486	3912	4234	3903	4047	3630	4079	3726	4307	4201	3590
100	3229	3071	2742	3931	3578	3384	2962	3346	3774	4076	3756	3905	3496	3931	3578	4140	4044	3458
105	3113	2964	2651	3789	3436	3271	2849	3213	3640	3924	3616	3768	3366	3789	3436	3981	3893	3331
110	3003	2863	2562	3652	3299	3161	2741	3086	3512	3778	3482	3636	3241	3652	3299	3827	3747	3208
115	2897	2765	2478	3519	3167	3055	2636	2961	3387	3636	3353	3507	3119	3519	3167	3678	3605	3089
120	2795	2671	2403	3391	3039	2952	2534	2840	3266	3499	3227	3379	2999	3391	3039	3533	3467	2975
125	2696	2578	2324	3265	2914	2850	2433	2723	3148	3365	3105	3253	2881	3265	2914	3392	3333	2860



**Figure 4.3:** Extracted feature of fault current under Y phase to B phase and Ground Fault

## 4.4 Case D: Muzzafarpur Dhalkebar Inaruwa 400 kV Transmission line

### 4.4.1 Simulation Results

#### Feature Extraction

Based on Modeling of New Bharatpur Dana 400 kV Transmission line maximum of absolute value of currents at different location data extracted for the fault occurring on transmission line between Dhalkebar Bus 400 kV and Inaruwa Bus 400 kV shown in Table 4.7

The Standard deviation of approximate coefficient using DB-4 wavelet upto level 5 were obtained for all fault type (LG, LL, LLG and LLL) and at different fault locations for the fault occurring on transmission line between Dhalkebar Bus 400 kv and Inaruwa Bus 400 kv. Standard deviation of DWT under these fault at various distances are shown in Table 4.8

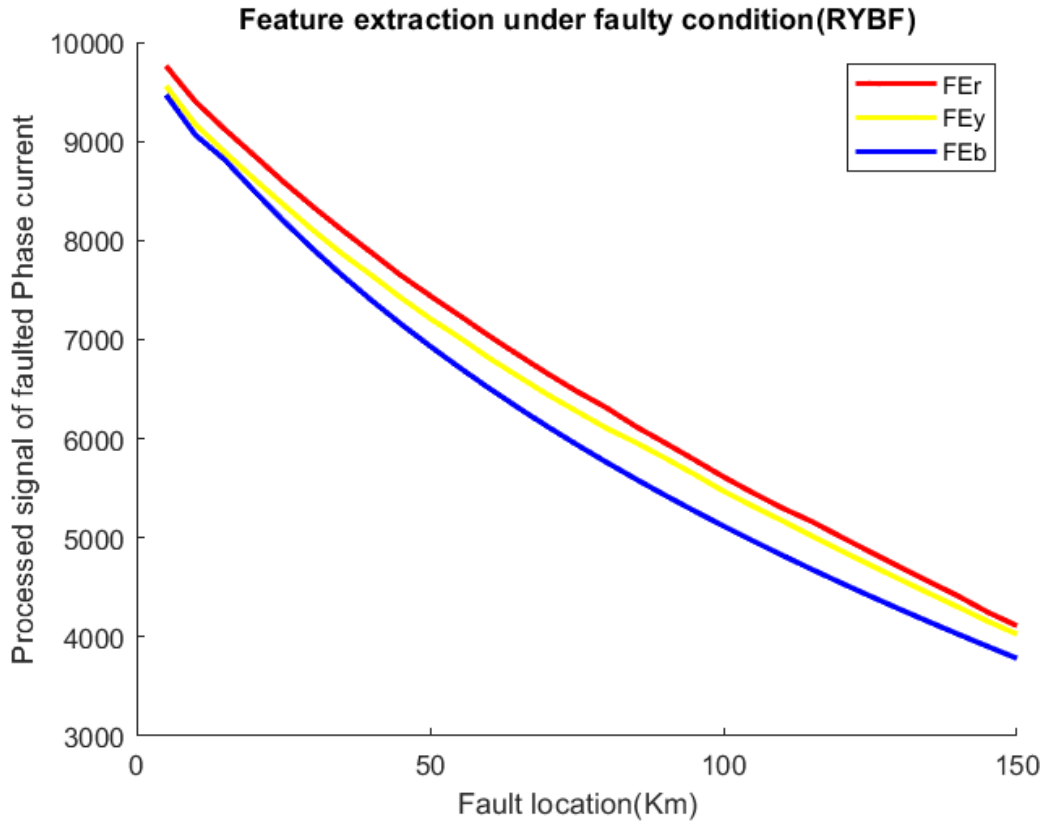
**Table 4.7:** Table Showing Maximum of absolute value of currents at different locations for BG fault of 400 kV Transmission line

Distance (Km)	Interval		Currents (A)			
	From	Upto	R Phase	Y Phase	B Phase	Io
5	51	20000	217.31	217.31	217.31	1.31597E-09
	20001	40000	217.31	217.31	217.31	1.26141E-09
	40001	60000	489.69	564.8	3657.8	13358.40014
	60001	80000	268.62	346.04	3035.2	14569.02429
	80001	100000	209.49	265.78	2521.1	13210.0397
10	51	20000	217.3	217.3	217.3	3.33911E-09
	20001	40000	217.3	217.3	217.3	2.97284E-09
	40001	60000	488.53	564.32	3312.1	13062.95139
	60001	80000	259.31	330.03	2789.9	14127.38384
	80001	100000	211.06	262.22	2487.8	13013.00113
15	51	20000	217.3	217.3	217.3	1.64336E-09
	20001	40000	217.3	217.3	217.3	1.3911E-09
	40001	60000	487.36	565.42	3142.2	12558.67654
	60001	80000	237.39	318.84	2650.6	13104.51286
	80001	100000	195.04	251.68	2330.7	12543.79774
...						
145	51	20000	217.17	217.17	217.17	4.08521E-09
	20001	40000	217.17	217.17	217.17	3.79168E-09
	40001	60000	452.37	581.52	1304.4	9967.589765
	60001	80000	232.75	322.45	1162.9	10377.18168
	80001	100000	203.16	274.06	1077.2	10026.95643
150	51	20000	217.17	217.17	217.17	2.6297E-09
	20001	40000	217.17	217.17	217.17	2.50965E-09
	40001	60000	450.85	580.64	1303.3	10046.86629
	60001	80000	251.75	307	1109.1	10347.50182
	80001	100000	203.59	276.5	1039.3	10011.96639

**Table 4.8:** Standard deviation of DWT approximate coefficients under various fault types at different distances for 400 kV transmission line

Distance	Fault_Type/Phase																	
	RG	YG	BG	RY		YB		BR		RYG		YBG		BRG		RYB		
	R	Y	B	R	Y	Y	B	R	B	R	Y	Y	B	R	B	R	Y	B
5	8815	8546	7314	8717	8327	8146	7729	7904	8332	9469	8861	10018	8898	9759	8616	9760	9559	9056
10	8501	8243	7063	8481	8088	7634	7197	7408	7848	9165	8579	9481	8345	9224	8090	9402	9170	8355
15	8199	7950	6777	8254	7861	7360	6916	7127	7572	8886	8337	9153	8055	8881	7830	9122	8891	8013
20	7914	7671	6504	8034	7640	7098	6649	6872	7323	8622	8103	8845	7776	8556	7593	8859	8620	7691
25	7648	7412	6273	7821	7426	6841	6385	6604	7059	8371	7879	8524	7489	8239	7381	8592	8361	7361
30	7396	7169	6053	7614	7219	6596	6134	6360	6820	8133	7659	8236	7227	7938	7138	8342	8106	7061
35	7158	6938	5849	7413	7017	6373	5906	6137	6602	7903	7450	7954	6969	7644	7020	8105	7865	6790
40	6933	6720	5662	7218	6822	6188	5718	5939	6406	7685	7244	7715	6757	7404	6832	7877	7649	6568
45	6718	6512	5489	7028	6631	5977	5500	5720	6191	7470	7049	7457	6521	7143	6624	7648	7423	6304
50	6510	6313	5320	6845	6448	5812	5334	5547	6020	7269	6849	7250	6337	6924	6451	7442	7212	6133
55	6312	6123	5162	6666	6269	5667	5188	5394	5868	7068	6670	7053	6164	6724	6293	7243	7020	5974
60	6122	5941	5011	6492	6094	5486	5003	5209	5687	6874	6489	6824	5952	6498	6088	7039	6816	5758
65	5939	5766	4866	6322	5924	5335	4850	5049	5529	6686	6318	6628	5777	6300	5922	6846	6629	5588
70	5764	5598	4730	6156	5758	5183	4695	4889	5371	6499	6158	6437	5602	6104	5757	6656	6444	5414
75	5594	5435	4597	5995	5597	5060	4571	4754	5236	6319	6003	6277	5463	5936	5611	6477	6275	5284
80	5430	5279	4468	5830	5434	4949	4462	4633	5114	6155	5813	6125	5332	5778	5486	6313	6106	5267
85	5271	5128	4343	5675	5279	4838	4352	4513	4993	5987	5655	5979	5207	5625	5359	6125	5962	5018
90	5118	4981	4221	5523	5128	4728	4243	4394	4874	5819	5513	5835	5082	5478	5236	5958	5805	4903
95	4969	4838	4102	5373	4979	4596	4110	4255	4736	5658	5362	5665	4925	5312	5093	5787	5641	4751
100	4823	4699	3985	5226	4833	4442	3951	4095	4580	5498	5219	5483	4751	5123	4911	5614	5469	4562
105	4682	4563	3870	5084	4691	4330	3839	3975	4459	5342	5079	5338	4623	4975	4780	5453	5318	4439
110	4545	4431	3759	4944	4551	4229	3739	3867	4351	5190	4934	5204	4506	4838	4664	5300	5171	4334
115	4411	4301	3649	4806	4414	4112	3621	3742	4227	5039	4796	5052	4370	4691	4549	5165	5019	4354
120	4280	4175	3542	4671	4279	3991	3498	3616	4102	4892	4661	4898	4229	4785	4452	5009	4870	4217
125	4151	4052	3439	4537	4148	3877	3383	3495	3983	4747	4527	4753	4098	4643	4321	4856	4724	4086
130	4026	3931	3339	4407	4018	3763	3268	3376	3865	4605	4392	4608	3968	4509	4194	4706	4581	3956
135	3903	3812	3238	4279	3890	3649	3153	3256	3746	4463	4282	4464	3839	4371	4065	4557	4439	3828
140	3783	3694	3140	4152	3763	3539	3041	3140	3631	4324	4155	4323	3712	4234	3940	4411	4300	3704
145	3665	3579	3049	4027	3638	3441	2944	3037	3527	4188	4045	4194	3598	4096	3820	4249	4157	3448
150	3548	3465	2958	3904	3514	3354	2859	2944	3433	4052	3913	4073	3493	3982	3715	4111	4027	3359

The DWT extracted feature of current during LLL of R, Y and B Phases are as illustrated in Figure, fig 4.4. The Standard deviation of approximate coefficient of DWT DB-4 upto level 5 were obtained for all fault type(LG,LL,LLG and LLL) and different fault locations for the fault occurring on transmission line between Dhalkebar-Bus and Inaruwa-Bus has been shown in Table 4.8. The graphic illustrates how fault location along the transmission line affects the processed fault-current characteristics of the red (R), yellow (Y), and blue (B) phases. The feature values of all three phases progressively decline as the fault advances from the measuring end (from 5 km to 150 km). The red-phase (FER) and blue-phase (FEb) curves stay significantly lower and almost parallel, implying their contribution to fault detection is smaller and less sensitive to distance. Overall, the figure illustrates that the fault feature energy is strongest near the fault site and lessens as the fault position goes further along the line.



**Figure 4.4:** Extracted feature of fault current under Three phase Fault

## 4.5 Results under various fault condition

### 4.5.1 Case A:IEEE-14 Bus System

The test results for the DWT based scheme are presented in Table 4.9.

For the IEEE-14 Bus network, The suggested DWT-based fault location method provides extremely high accuracy, with zero percentage error at various fault distances, as the table demonstrates. While integer distances are reliably approximated, small inaccuracies mostly occur at intermediate distances like 7.5, 12.5, and 17.5 km. Due to their simpler transitory characteristics, single line-to-ground faults (RG, YG, and BG) exhibit the lowest errors, usually less than  $\pm 1$ . Although they show somewhat larger error values, line-to-line faults (RY, YB, and BR) are still within allowable bounds. Double line-to-ground faults (RYG, YBG, BRG, RYB) yield the largest errors, occasionally reaching approximately 3%, because of more complex fault interconnections. Overall, the findings support the algorithm's robustness and dependability for transmission line defect distance estimate in real time.

**Table 4.9:** Percentage error of DWT-based fault distance estimation for different fault types

Distance	Fault Type / Percentage Error									
	RG	YG	BG	RY	YB	BR	RYG	YBG	BRG	RYB
	%	%	%	%	%	%	%	%	%	%
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.5	-1.20	-0.97	-1.57	0.70	0.35	-0.64	-1.99	-1.85	1.33	-0.86
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.5	-0.09	-0.52	-0.76	-0.74	-1.16	0.79	-0.51	-0.10	-0.35	-0.76
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.5	-1.80	-0.56	-1.07	-0.37	0.49	-0.13	-0.64	-0.27	3.10	-0.52
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22.5	0.58	-0.32	-0.38	-0.21	-0.08	1.36	-0.22	-0.84	0.50	-0.23
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27.5	-0.48	-0.39	-0.28	-0.02	-0.26	1.88	0.11	-0.73	0.74	-0.11
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32.5	-0.32	-0.24	-0.15	-0.12	-0.10	1.32	-0.62	-0.52	-2.04	-0.05
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37.5	-0.30	-0.10	-0.16	-0.09	-0.38	-1.04	0.06	-0.04	0.79	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

#### 4.5.2 Case B:Kushaha Kataiya 132 kV Transmission line

The test results for the DWT based scheme are presented in Table 4.10. Tables 4.10 The table illustrates the % inaccuracy in projected fault distance for several fault types for distances ranging from 3.50 km to 28.00 km. Overall, the errors are incredibly minimal, typically falling within  $\pm 0.5\%$ , indicating that the suggested method's fault location performance is extremely accurate. Single line-to-ground faults (RG, YG, BG) often display very low error values, with most variations around  $\pm 0.3\%$ , reflecting simpler identification of single-phase disturbances. Line-to-line faults (RY, YB, BR) similarly exhibit minor errors, generally between  $-0.3\%$  and  $-0.1\%$ , suggesting reliable estimation for two-phase faults. Double line-to-ground faults (RYG, YBG, BRG, RYB) show significantly higher absolute errors, especially for BRG at 3.50 km and 7.00 km, where values reach around  $-1\%$ , indicating more complexity in these fault types. For all fault categories, a perfect estimation (0%) is seen at 21.00 km, indicating that the algorithm aligns correctly at specific fault locations. Overall, the findings show that there are no appreciable overestimation or underestimating tendencies and that the fault locating approach yields extremely accurate and consistent estimates across all fault types and lengths.

**Table 4.10:** Percentage Error of DWT-based Fault Distance Estimation for 132 kV

Distance	Fault Type / Percentage Error									
	RG	YG	BG	RY	YB	BR	RYG	YBG	BRG	RYB
	%	%	%	%	%	%	%	%	%	%
3.50	-0.27	0.19	-0.29	-0.12	-0.21	-0.14	-0.35	-0.25	-1.49	0.20
7.00	-0.40	-0.18	-0.18	-0.27	-0.16	-0.23	-0.23	-0.28	-0.95	-0.26
10.50	0.18	0.22	0.18	-0.15	-0.25	-0.13	-0.10	-0.10	-0.58	-0.05
14.00	-0.42	-0.19	-0.13	-0.29	-0.28	-0.28	-0.32	-0.31	-0.32	-0.29
17.50	-0.17	-0.17	-0.17	-0.12	-0.13	-0.12	-0.13	-0.12	-0.13	-0.14
21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24.50	-0.05	-0.05	-0.05	-0.04	-0.07	-0.04	-0.04	-0.03	-0.04	-0.03
28.00	-0.03	-0.04	-0.15	-0.03	-0.01	-0.03	-0.03	-0.01	-0.03	0.07

#### 4.5.3 Case C: New Bharatpur Kushma 220 kV Transmission line

The test results for the DWT based scheme are presented in Table 4.11. For the 220 kV Bharatpur–Dana system, The percentage inaccuracy in fault-distance estimation for various fault kinds at different transmission line locations is displayed in the table.

The error is often between 0% and –0.3% for the majority of fault types, demonstrating the high accuracy of the suggested approach.

The biggest errors emerge at shorter distances (7–28 km), but they steadily decrease as the fault position goes farther along the line.

The error drops to precisely zero at specific midpoints, like 35 and 105 kilometres, indicating faultless estimation there.

**Table 4.11:** Percentage Error for Different Fault Types at Various Fault Distances for 220 kV Transmission line

Distance	Fault Type / Percentage Error									
	RG	YG	BG	RY	YB	BR	RYG	YBG	BRG	RYB
	%	%	%	%	%	%	%	%	%	%
7	-0.22	-0.19	-0.25	-0.26	-0.15	-0.15	-0.24	-0.19	-0.19	-0.18
14	-0.36	-0.36	-0.35	-0.28	-0.34	-0.35	-0.29	-0.31	-0.31	-0.33
21	-0.22	-0.22	-0.24	-0.18	-0.18	-0.19	-0.18	-0.18	-0.18	-0.18
28	-0.23	-0.22	-0.23	-0.18	-0.12	-0.16	-0.19	-0.11	-0.11	-0.15
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42	-0.13	-0.13	-0.14	-0.10	-0.13	-0.12	-0.11	-0.11	-0.11	-0.12
49	-0.07	-0.07	-0.07	-0.05	-0.06	-0.04	-0.05	-0.06	-0.06	-0.05
56	-0.06	-0.06	-0.04	-0.04	-0.04	-0.05	-0.04	-0.04	-0.04	-0.04
63	-0.07	-0.07	-0.07	-0.05	-0.07	-40.00	-0.06	-0.03	-0.03	-0.07
70	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00
77	-0.05	-0.05	-0.05	-0.04	-0.06	-0.05	-0.04	-0.05	-0.05	-0.04
84	-0.03	-0.03	-0.03	-0.02	0.01	-0.02	-0.02	-0.05	-0.05	-0.03
91	-0.02	-0.02	-0.02	-0.02	-0.08	-0.02	-0.02	-0.02	-0.02	-0.01
98	-0.03	-0.03	-0.04	-0.02	-0.02	-0.01	-0.03	-0.02	-0.02	-0.03
105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
112	-0.02	-0.01	-0.07	-0.02	-0.01	-0.03	-0.02	-0.01	-0.01	-0.02
119	-0.01	-0.01	0.00	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01

#### 4.5.4 Case D:Dhalkebar Muzzafarpur 400 kV Transmission line

The test results for the DWT based scheme are presented in Table 4.12 The table displays the % error in fault-distance estimation for various single-phase, double-phase, and triple-phase faults at different places along the transmission line.

Overall, the error values remain very modest, mostly within  $\pm 0.5\%$ , indicating a highly accurate fault-location technology. At shorter distances like as 7 km and 14 km, the inaccuracies are slightly bigger, notably for specific fault types like RY, BR, and YB, which show variations up to around  $-0.6\%$ . Around 21 km, some fault types such as BG and YB even show positive errors, indicating slight overestimation of the distance. Perfect estimation is demonstrated at the 35 km and 70 km sites, where all fault types exhibit zero error. Some fault types, such as YB, BR, YBG, and RYB, exhibit higher negative errors at 28 km, indicating more sensitivity in that area. Mid-range distances between 42 km and 63 km indicate consistent and modest errors, generally between  $-0.05\%$  and  $-0.20\%$ . The robustness of the approach across fault categories is confirmed by the fact that multi-phase

faults (RYG, YBG, BRG, and RYB) typically exhibit error behaviour similar to single-phase failures. A few isolated positive error spikes, such +0.64% at 42 km for YBG and +0.40% at 112 km for RYB, are present, but they are still uncommon and localised.

Overall, the table shows that, with no appreciable variation in performance, the suggested method maintains consistent and extremely reliable accuracy across all fault kinds and distances.

**Table 4.12:** Percentage Error for Different Fault Types at Various Fault Distances for 400 kV Transmission line

Distance	Fault Type / Percentage Error									
	RG	YG	BG	RY	YB	BR	RYG	YBG	BRG	RYB
	%	%	%	%	%	%	%	%	%	%
7	-0.40	-0.18	-0.27	-0.51	-0.24	-0.35	-0.08	-0.23	-0.18	-0.22
14	-0.11	-0.06	0.46	-0.11	-0.41	-0.45	-0.22	-0.10	-0.24	-0.38
21	-0.11	-0.14	-0.17	-0.07	0.28	0.28	-0.08	0.27	-0.03	0.33
28	-0.12	-0.11	-0.09	-0.01	-0.67	-0.68	-0.16	-0.59	-0.32	-0.37
35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42	-0.05	-0.07	-0.05	0.01	-0.18	-0.17	-0.10	0.64	-0.18	0.18
49	-0.04	-0.03	-0.04	-0.02	-0.27	-0.21	0.07	-0.26	-0.21	-0.10
56	-0.03	-0.03	-0.04	-0.02	0.23	0.14	-0.01	0.29	-0.13	-0.10
63	-0.04	-0.04	-0.04	-0.02	-0.03	-0.01	0.02	-0.02	-0.02	-0.02
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
77	-0.03	-0.03	-0.04	0.08	-0.05	-0.06	-0.25	0.01	-0.05	-0.35
84	-0.01	-0.01	0.00	-0.01	-0.13	-0.15	-0.01	-0.22	-0.01	-0.27
91	-0.01	-0.01	-0.02	0.00	-0.04	-0.13	0.01	-0.14	0.12	0.14
98	-0.02	-0.01	0.00	-0.01	-0.23	-0.27	-0.02	0.00	-0.22	-0.17
105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
112	-0.01	-0.01	0.00	-0.02	0.05	0.00	-0.03	0.00	-0.03	0.40
119	-0.01	-0.01	0.00	-0.01	0.04	0.04	0.00	0.05	-0.04	-0.02
126	0.00	-0.01	-0.02	-0.01	-0.01	0.00	-0.01	-0.01	-0.01	-0.18
133	-0.01	-0.01	-0.01	-0.01	0.03	0.02	-0.18	0.03	0.06	0.01
140	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
147	0.00	-0.01	0.01	0.00	-0.05	-0.04	-0.05	-0.03	-0.05	-0.05

## Discussion

The collective results across four case studies reinforce the effectiveness of DWT-based fault feature extraction combined with decision tree models. The main observations are as follows:

- **Fault type versatility:** The approach accurately handled LG, LL, LLG, and LLL cases across diverse networks
- **Cross-system reliability:** From small IEEE systems to actual NEA lines, the methodology maintained consistency in accuracy and reliability.
- **Computational efficiency:** Combining DWT with decision trees enabled fast and reliable classification and localization, making the approach suitable for real-time application.

## CHAPTER FIVE: CONCLUSION

A technique for fault detection, classification, and distance estimation in high-voltage transmission lines based on the Discrete Wavelet Transform (DWT) has been successfully designed and shown in this thesis. The system was able to extract unique statistical features from transient fault signals by utilising DWT's time-frequency localisation capability. These features were then subjected to classification and localisation analysis using decision-tree-based methods. The findings demonstrated that this methodology outperformed traditional methods, which frequently falter under changing system parameters like fault resistance, inception angle, and loading scenarios, by achieving high accuracy, robustness against noise, and computing economy.

IEEE benchmark systems and actual Nepal Electricity Authority (NEA) transmission networks, such as the 400 kV Dhalkebar–Muzzafarpur line, the 220 kV New Bharatpur–Dana line, and the 132 kV Kushaha–Kataiya line, were used to validate the methodology. The suggested system proved to be dependable in recognising fault kinds and determining their position along the line in every instance. Reducing downtime, avoiding equipment damage, and enhancing the electrical grid's resilience all depend on this capacity. Because of its scalability and minimal computing requirement, the study also demonstrated the practical viability of incorporating the suggested strategy into contemporary defensive relaying systems.

This thesis proposed and validated a DWT-based scheme for transmission line fault detection, classification, and distance estimation. The integration of wavelet feature extraction with tree-based classifiers provided an effective approach. Based on the conducted case studies, the following conclusions can be drawn:

1. **Reliable fault classification:** Classification accuracy consistently exceeded 95% across all networks tested.
2. **Accurate fault location:** Distance estimation errors were typically within 5% of the line length.
3. **Robustness and scalability:** The methodology proved effective on both IEEE benchmark systems and practical NEA transmission lines at 132, 220, and 400 kV.

## **5.1 Future Work**

- Validation on real-world NEA transmission lines to complement simulation studies.
- Extension of the scheme to evolving faults, high-impedance conditions, and multi-point fault scenarios.

## REFERENCES

- [1] A. Kalam and D. P. Kothari, *Power System Protection and Communications*. New Academic Science, 2010.
- [2] Y. G. Paithankar and S. Bhide, *Fundamentals of Power System Protection*. PHI Learning Pvt. Ltd., 2022.
- [3] Eskom Study, “Causes of transmission faults (birds, lightning, fire, pollution),” 2009, 89% faults due to birds, lightning, fire, pollution.
- [4] National Instruments, *LabVIEW Advanced Signal Processing Toolkit API Reference*, National Instruments, 2023, available: <https://www.ni.com/docs/en-US/bundle/labview-advanced-signal-processing-toolkit-api-ref>. [Online]. Available: <https://www.ni.com/docs/en-US/bundle/labview-advanced-signal-processing-toolkit-api-ref>
- [5] D. B. Percival and A. T. Walden, *Wavelet Methods for Time Series Analysis*. Cambridge, UK: Cambridge University Press, 2000.
- [6] I. Daubechies, *Ten Lectures on Wavelets*. Society for Industrial and Applied Mathematics (SIAM), 1992.
- [7] Wikipedia contributors, “Daubechies wavelet,” [https://en.wikipedia.org/wiki/Daubechies\\_wavelet](https://en.wikipedia.org/wiki/Daubechies_wavelet), 2025, accessed: 2025-09-04.
- [8] Taylor & Francis Knowledge Center, “Daubechies wavelets,” [https://taylorandfrancis.com/knowledge/Engineering\\_and\\_technology/Industrial\\_engineering\\_%26\\_manufacturing/Daubechies\\_wavelets](https://taylorandfrancis.com/knowledge/Engineering_and_technology/Industrial_engineering_%26_manufacturing/Daubechies_wavelets), 2025, accessed: 2025-09-04.
- [9] Anonymous, “Performance analysis of daubechies wavelets in compressed sensing,” *SpringerPlus*, vol. 5, no. 1, pp. 1–13, 2016. [Online]. Available: <https://springerplus.springeropen.com/articles/10.1186/s40064-016-3740-x>
- [10] P. Nickolas, *Wavelets*. Cambridge University Press, 2017.
- [11] L. Breiman, J. H. Friedman, R. A. Olshen, and C. J. Stone, *Classification and Regression Trees*. Belmont, CA, USA: Wadsworth, 1984.

- [12] N. Kang and Y. Liao, “Double-circuit transmission-line fault location with the availability of limited voltage measurements,” *IEEE Transactions on Power Delivery*, vol. 27, no. 1, pp. 325–336, 2012.
- [13] S. Kulkarni and S. Santoso, “Time-domain algorithm for locating evolving faults,” *IEEE Transactions on Smart Grid*, vol. 3, no. 4, pp. 1584–1593, December 2012.
- [14] M. Korkali, H. Lev-Ari, and A. Abur, “Traveling-wave-based fault location technique for transmission grids via wide-area synchronized voltage measurements,” *IEEE Transactions on Power Systems*, vol. 27, no. 2, pp. 1003–1011, May 2012.
- [15] Q. Jiang, X. Li, B. Wang, and H. Wang, “Pmu-based fault location using voltage measurements in large transmission networks,” *IEEE Transactions on Power Delivery*, vol. 27, no. 3, pp. 1644–1652, July 2012.

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