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Enhancing Fault Identification, Classification and Location Accuracy in Transmission Lines: A Support Vector Machine Approach with Positive Sequence Analysis

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Abstract: This research paper presents a proposed system for fault identification, classification and location in transmission lines using a Support Vector Machine (SVM)-based technique in conjunction with a Positive Sequence Analyzer. The objective is to develop an accurate and reliable method for identifying, classifying and locating different fault types in transmission lines. The proposed system leverages the capabilities of SVMs in handling high-dimensional feature spaces and the fault signature extraction capabilities of the Positive Sequence Analyzer. Experimental evaluations are conducted to assess the performance and effectiveness of the proposed system, comparing it with existing fault identification and classification methods. The results demonstrate the superior performance and robustness of the SVM-based technique utilizing the Positive Sequence Analyzer, providing a valuable contribution to fault management and system reliability in transmission line networks.

Keywords: electrical fault detection; fault classification; fault identification; machine learning; Positive Sequence Analyzer; Support Vector Machine (SVM); transmission lines

1 INTRODUCTION

Power transmission systems must be able to accurately diagnose and classify faults to minimize interruption and restore power supply. Fault classification and location estimation are essential tasks in power transmission systems [1]. Support vector machines (SVMs) have been successfully used for fault detection and classification in transmission lines, although these techniques have limitations, including high computational burden and memory requirements for classification, that limit their real-time implementation [2, 1]. SVM combined with feature extraction techniques, including wavelet transform (WT), synchro-squeezing transform (ST), principal component analysis (PCA), empirical mode decomposition (EMD), and Hilbert-Huang transform (HHT), has been widely used for fault detection and classification on transmission lines [2]. In addition, positive sequence analyzer can be used for fault detection and classification in power systems as it extracts features related to the positive sequence component of line currents, which can be used to identify the fault zone [1, 3]. The combination of SVM-based technique and positive sequence analyzer can improve the accuracy of fault detection and classification in power systems [3]. One proposed algorithm includes the use of PCA and SVMs for fault diagnosis in power system transmission lines, with SVMs used for fault classification and positive sequence analyzer used to determine the location of faults. This approach has been tested on a 300 km, 400 kV series compensated transmission line for all eleven types of faults through digital simulation, with promising results after testing on more than 800 fault cases with varying parameters [3, 4]. These techniques and algorithms demonstrate that SVM-based technique is a popular approach for fault detection and classification in power systems and can accurately detect and classify transmission line faults.

1.1 Background and Significance of the Study

Transmission lines are critical components of electrical power systems, and their protection is of utmost importance to ensure the stability and reliability of the power grid. One of the most common causes of transmission line failure is the occurrence of faults, which can cause a cascade of failures leading to power outages and damage to the system. Fault detection and classification are crucial for the prompt and effective protection of the transmission lines. [5]

The traditional methods of fault detection and classification involve the use of time-domain and frequency-domain techniques, which are computationally expensive and often require significant computational resources. In recent years, machine learning-based techniques have gained popularity due to their ability to provide faster and more accurate fault detection and classification. In this study, we propose the use of the Support Vector Machine (SVM) method to develop a positive sequence analyzer for the protection of transmission lines. [6]

1.2 Objectives and Research Questions

The main objective of this research is to develop a positive sequence analyzer using SVM for the protection of transmission lines. The specific research questions are as follows:

- Can SVM be used to accurately detect and classify faults in transmission lines?
- What are the performance metrics of the proposed positive sequence analyzer using SVM in comparison to existing methods?
- What are the limitations of the proposed method and how can they be addressed in future work?

1.3 Methodology Overview

The proposed methodology involves the following steps is shown in Fig. 1.

The proposed methodology will be validated through simulation results, and the performance of the proposed method will be compared with existing methods.

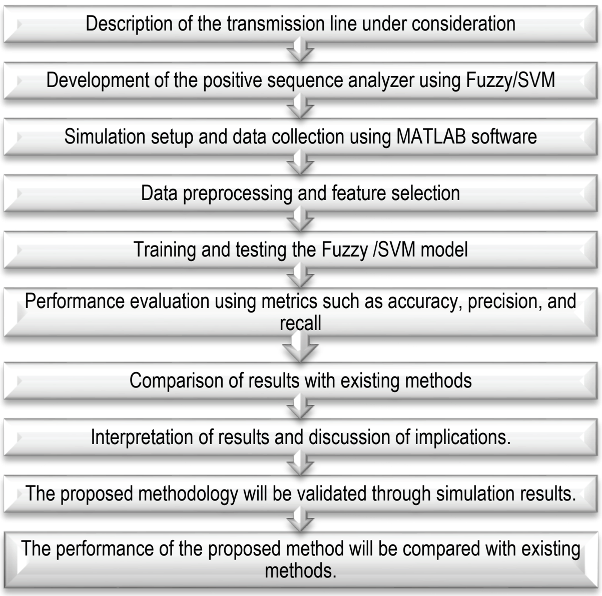

Figure 1 Methodology steps of proposed system

2 PROPOSED SYSTEM

2.1 Simulation Model

The proposed system simulation model is shown below Fig. 2.

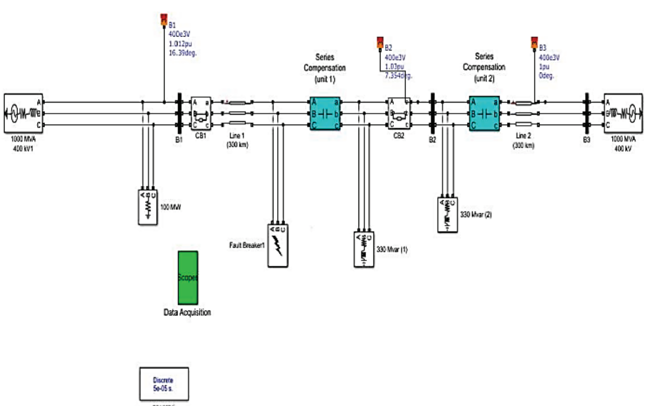

Figure 2 Simulation model for 400 kV 300 km double fed transmission line with SVM

2.2 Detection of External Fault

The prediction of external fault is illustrated in Fig. 3.

2.3 Detection Internal Fault

The proposed fault detection scheme can accurately distinguish different fault types. For the internal short-circuit fault, the proposed SVM-based detection scheme can identify the fault inception swiftly for any position along the protected line. During the internal fault, the fault breaker is located internal of long transmission line is shown in Fig. 4

2.4 Type and Configuration

The single line diagram of proposed simulation model is illustrated in Fig. 5.

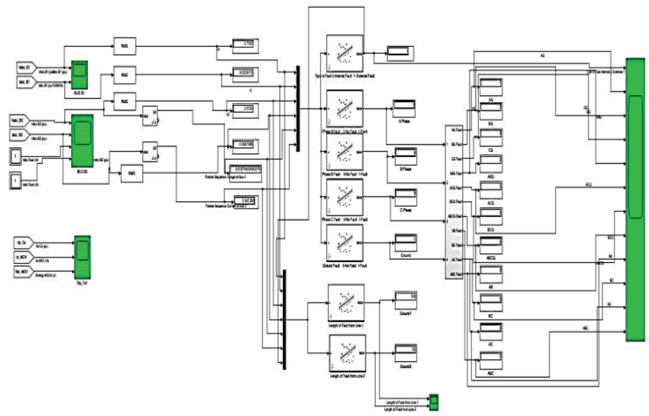

Figure 3 Simulation output of transmission line during external fault

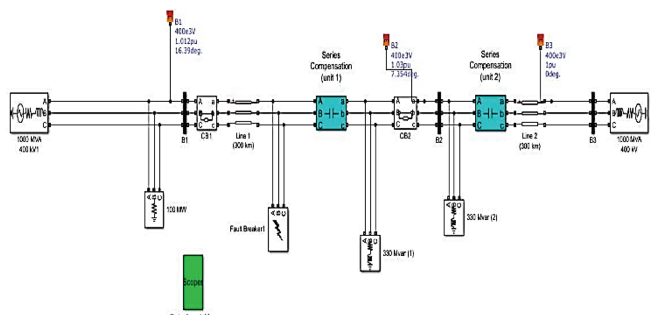

Figure 4 Simulation model for 400 kV 300 km double fed transmission line with SVM having fault internally

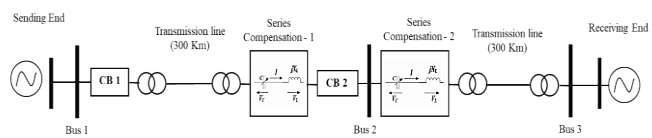

Figure 5 Single line diagram of proposed simulation model

Table 1 Specification of transmission line

Type of transmission line	Overhead transmission line
Configuration of Transmission line	Three-Phase Symmetrically Spaced Transmission line
Voltage Level and Rating	400 kV

Table 2 Transmission line-1 parameters

Number of phases	3
Line length (km):	200 and 100 km
Frequency used for RLC specification (Hz):	50 Hz
Resistance per unit length (Ohms/km) [N×N matrix] or [r1 r0 r0m]	[0.01273 0.3864]
Inductance per unit length (H/km) [N×N matrix] or [l1 l0 l0m]:	[0.9337e-3 4.1264e-3]
Capacitance per unit length (F/km) [N×N matrix] or [c1 c0 c0m]:	[12.74e-9 7.751e-9]

Table 3 Transmission line-2parameters

Number of phases	3
Line length (km):	200 and 100 km
Frequency used for RLC specification (Hz):	50 Hz
Resistance per unit length (Ohms/km) [N×N matrix] or [r1 r0 r0m]	[0.01273 0.3864]
Inductance per unit length (H/km) [N×N matrix] or [l1 l0 l0m]:	[0.9337e-3 4.1264e-3]
Capacitance per unit length (F/km) [N×N matrix] or [c1 c0 c0m]:	[12.74e-9 7.751e-9]

Table 4 Fault scenarios detail

Type of Fault	AB, AC, BC, ABG, ACG, BCG, ABC, ABCG, AG, BG, CG,
Fault Resistance	0.001Ω,10 Ω, 20 Ω, 30 Ω,40 Ω,50 Ω,60 Ω
X/R RATIO Variation	X/R ratio change to 20
Source Power Variation	SOURCE POWER change to 1500 MVA
Load Variation	LOAD VARIATION to 150 MW
Line Length Variation	Line 1 Length change to 100 km Line 2 Length change to 50 km Changing both Line1 & Line2 length at same time

2.5 Monitoring and Measurement

In this experimental setup we have considered the various conditions of fault resistance and other parameters as described in table-IV. To identify types of fault like internal or external, we have first created the different types of fault models near to bus-I and measured the 3-phase voltage and current at bus -1 and Bus -2, also we have considered positive sequence analyzer to increase the accuracy and precision of fault detection technique. By utilizing a positive sequence analyzer we have recorded the positive sequence voltage and current at Bus-2 by generating training data we are able to train the SVM for detecting internal faults. By simulating each type of fault condition model in Matlab and recording the following six values to identify both Internal and External fault.

1) Voltage at Bus1 (V1)
2) Current at Bus1 (I1)
3) Voltage at Bus 2 (V2)
4) Current at Bus 2 (I2)
5) Positive Sequence Voltage
6) Positive sequence Current.

Three phase Voltage and current at bus 1 is measured by using three phase VI Measurement model and recorded readings for all condition mentioned in above Tab. 4 this recorded readings are used to train the SVM to detect the fault and classify the type of fault, Similarly Three phase Voltage and current at bus 2 is measured by using three phase VI Measurement model and recorded readings for all condition mentioned to generate training data to train SVM

Positive sequence voltage current is measured at bus-2 using a Sequence analyzer, training the data for detecting the type of faults for the transmission line.

By simulating all conditions mentioned in above Tab. 4 we get training data with total 14 parameters shown in below Tab. 5.

Table 5 Sample Data to train SVM

Voltage at Bus-1	Current at Bus-1	Voltage at Bus-2	Current at Bus-2	+ve Seq. Voltage at bus-2	+ve Seq. Current at bus-2	Type of Fault (I/E*)	Phase-A Fault	Phase-B Fault	Phase-C Fault	Ground Fault	Line-1 Length	Line-2 Length	Fault Resistance
7.06E-01	9.30E-04	8.23E-01	1.71E-03	7.68E-01	1.27E-03	0	1	1	0	0	200	100	0.01
7.06E-01	3.02E-04	9.25E-01	1.32E-03	8.08E-01	1.27E-03	0	1	1	1	0	200	100	10
7.06E-01	5.61E-04	5.83E-01	7.62E-04	7.70E-01	1.24E-03	0	1	1	1	1	200	100	20
7.06E-01	1.22E-03	6.37E-01	1.07E-03	7.80E-01	1.22E-03	0	1	1	0	1	200	100	30
7.06E-01	1.18E-03	7.03E-01	1.38E-03	8.15E-01	1.13E-03	0	1	0	1	0	200	100	40

2.6 Control and Protection Systems

In this implementation we have used two three phase breaker near to Transmission line-1 and Bus-2 respectively. The three phase breaker parameters are shown in below Tab. 6.

Table 6 Three phase breaker parameter

Number of phases	3
Initial status:	Closed
Switching of:	Phase-A, Phase-B and Phase-C
Switching times (s):	[5/60]
Breaker resistance Ron (Ohm):	0.001
Snubber resistance Rs (Ohm):	1e5
Snubber capacitance Cs (F):	Inf

In this project we have implemented a two series compensation devices one is connected near to transmission line 1 and second is connected near to transmission line 2.

Series compensation devices are utilized in transmission lines to enhance the efficiency and reliability of power transmission. Here are some of the benefits of using series compensation devices:

- Increased Power Transfer Capability: Series compensation devices, such as series capacitors, can increase the power transfer capability of transmission lines by improving their voltage stability and reducing voltage drops. By injecting reactive power into the line, series compensation reduces the reactive power flow and allows for more active power transfer. [7-9]
- Voltage Profile Improvement: Series compensation helps to mitigate voltage drops and improve the voltage profile along the transmission line. It compensates for the line's inherent inductive reactance, reducing the line's overall impedance and enhancing the voltage regulation at the receiving end. [10]
- Improved System Stability: Series compensation devices contribute to system stability by damping out power oscillations and improving the transient stability of the transmission line. They help in suppressing sub-synchronous resonances and enhancing the overall dynamic response of the power system. [11]
- Increased Efficiency: By reducing the reactive power flow, series compensation devices minimize line losses,

resulting in improved overall transmission line efficiency. The reduced reactive power flow also leads to lower transmission line voltages, reducing the need for voltage support from other devices in the system. [12]

- Expanded Transmission Capacity: Series compensation allows for increased transmission capacity without the need for costly infrastructure upgrades or the construction of new transmission lines. It provides an economical solution to enhance the capacity of existing transmission infrastructure and meet growing demand for electricity. [13]
- Enhanced Voltage Control: Series compensation devices provide effective voltage control by regulating the line voltage and reducing voltage fluctuations. This is particularly beneficial in long transmission lines, where voltage drop and instability can occur due to high reactive power requirements. [14]
- Increased Grid Flexibility: Series compensation enhances the flexibility and controllability of the power grid. By manipulating the reactive power flow, system operators can adjust the power flow distribution, optimize the utilization of existing transmission lines, and effectively manage network congestion. [15]
- Reduced Environmental Impact: By improving transmission line efficiency and capacity, series compensation devices can help reduce the need for constructing new transmission infrastructure, thereby minimizing land use and environmental impact associated with new line construction.

2.7 Communication and Data Acquisition

To implement fault detection, location, and classification in a long transmission line using an SVM-based technique and positive sequence analyzer, we follow below steps:

- Data Acquisition: Collect data from the long transmission line using sensors or measurement devices placed at various points along the line. The data may include current and voltage measurements, which are crucial for fault detection and analysis.
- Pre-processing: Pre-process the acquired data to remove noise, normalize the values, and prepare it for further analysis. This step ensures that the data is suitable for training and testing the SVM classifier.
- Feature Extraction: Extract relevant features from the pre-processed data that can be used to differentiate between normal and fault conditions. Features could include the magnitudes, angles, and harmonic content of the voltage and current signals.
- Positive Sequence Analysis: Perform positive sequence analysis on the collected data to obtain the positive sequence components of the voltage and current signals. Positive sequence analysis helps in characterizing the behaviour of the transmission line during normal and fault conditions.
- Fault Labelling: Label the collected data based on the presence or absence of faults. This step is crucial for supervised learning algorithms like SVM, as they require labelled data for training.
- Training SVM Classifier: Use the labelled data to train an SVM classifier. SVM is a popular machine learning algorithm suitable for binary classification tasks. It learns to distinguish between normal and fault conditions based on the extracted features.
- Testing and Validation: Evaluate the trained SVM classifier on a separate set of test data to assess its performance. This step helps in determining the accuracy, precision, recall, and other evaluation metrics of the classifier.
- Fault Detection, Location, and Classification: Once the SVM classifier is trained and validated, we can use it to detect, locate, and classify faults in real-time data from the long transmission line. By applying the trained classifier to new data samples, we can identify the type and location of faults accurately.

3 RESULT FOR FAULT IDENTIFICATION AND CLASSIFICATION

3.1 Effect of Fault Resistance (Rf) on Positive Sequence Voltage and Current

Separating internal from external faults and classifying the fault as symmetrical or unsymmetrical fault is one of the key goals of this research project. This is done by considering the positive sequence voltage and current value at bus-2.

Using positive sequence current and voltage values is important for fault classification and detection in transmission lines because they provide valuable information about the system's behavior during a fault condition. Here are a few reasons why positive sequence quantities are preferred:

- Symmetrical Faults: Positive sequence quantities represent the symmetrical component of the fault current and voltage. During a balanced fault, where the fault impedance is purely resistive, the fault current and voltage have a positive sequence component only. By analyzing the positive sequence values, it becomes easier to identify and classify symmetrical faults such as line-to-line and line-to-ground faults.
- Simplified Analysis: Positive sequence analysis simplifies fault calculations by considering only the symmetrical component. This simplification reduces computational complexity and allows for efficient fault detection algorithms.
- Fault Discrimination: Positive sequence quantities help in distinguishing between internal and external faults. Since internal faults predominantly affect the positive sequence values, they exhibit significant changes compared to the healthy system. On the other hand, external faults may cause minor perturbations in positive sequence values but have a more pronounced impact on negative and zero sequence components. Analyzing positive sequence values aids in distinguishing between different fault types and their location within the transmission line.
- Fault Localization: Positive sequence information can be utilized to determine the location of the fault within the transmission line. By comparing the positive sequence voltage and current phasors at different locations along

the line, engineers can estimate the fault position based on the phase angle and magnitude differences.

- Protection System Design: The design of protective relaying systems relies on positive sequence quantities. Protective relays are responsible for detecting faults and isolating faulted sections of the transmission line. By focusing on positive sequence values, relays can make quick and accurate decisions, improving the selectivity and speed of fault detection. [15, 16]

Overall, positive sequence current and voltage values play a crucial role in fault classification and detection in transmission lines due to their simplicity, discriminative power, and ability to aid in fault localization and protection system design. Below Figs. 6 and 7 shows a graph for behavior of positive sequence current and voltage for LG, LL, LLG, LLLG faults for internal condition and Figs. 8 and 9 shows a graph for behavior of positive sequence current and voltage for LG, LL, LLG, LLLG faults for external condition respectively.

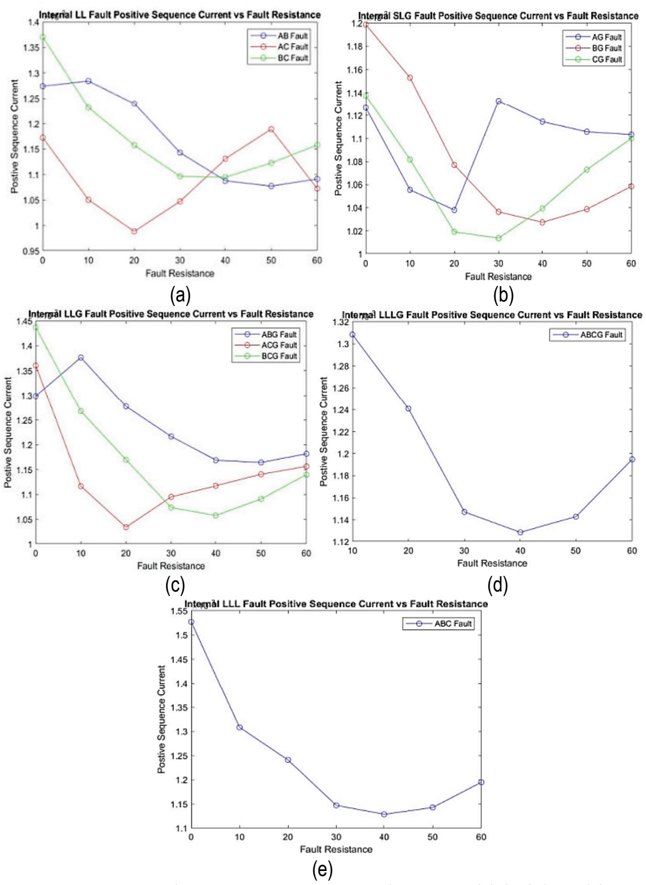

Figure 6 Variation of positive sequence current for Internal (a) SLG fault, (b) LL fault, (c) LLG fault, (d) LLLG fault and (e) LLL fault

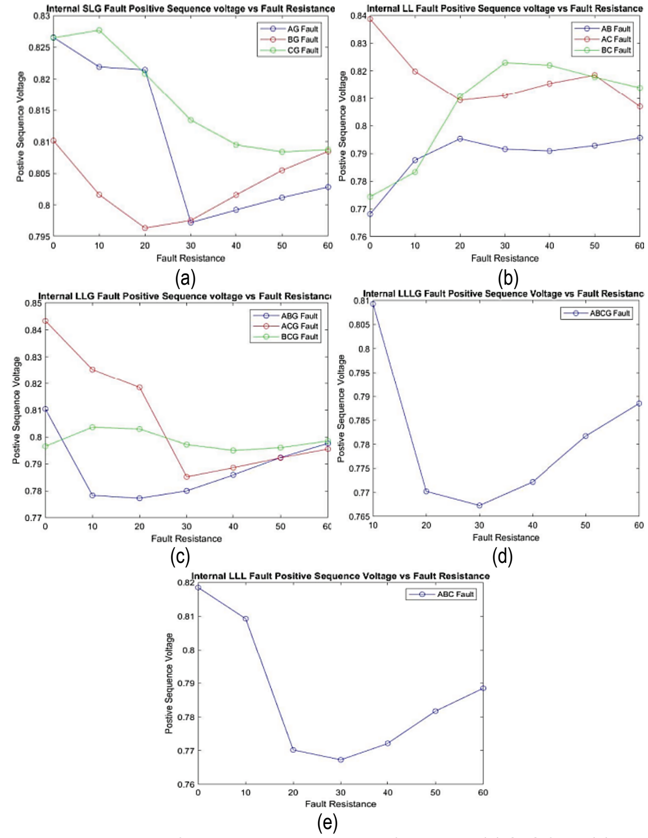

Figure 7 Variation of positive sequence voltage for Internal (a) SLG fault, (b) LL fault, (c) LLG fault, (d) LLLG fault and (e) LLL fault

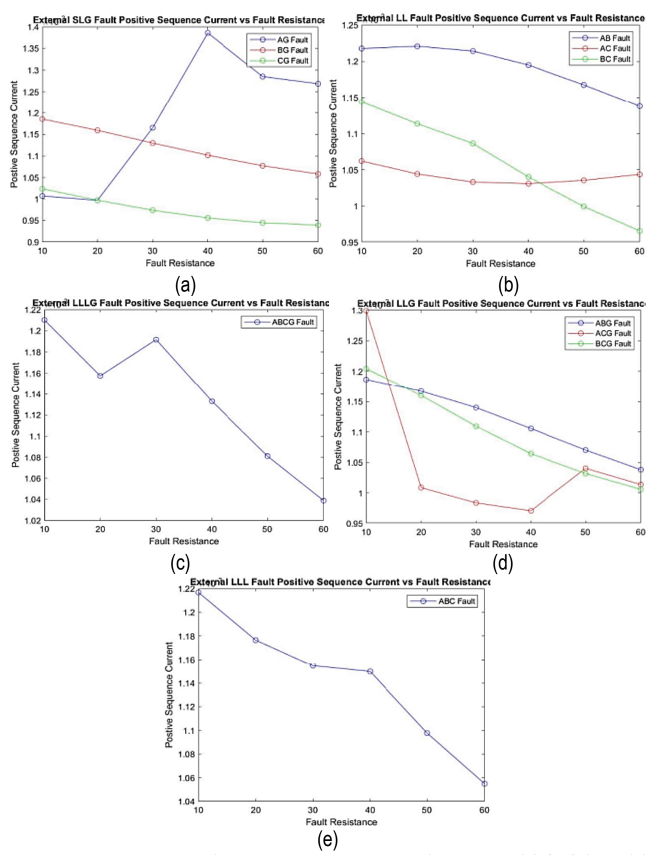

Figure 8 Variation of positive sequence current for external (a) SLG fault, (b) LL fault, (c) LLG fault, (d) LLLG fault and (e) LLL fault

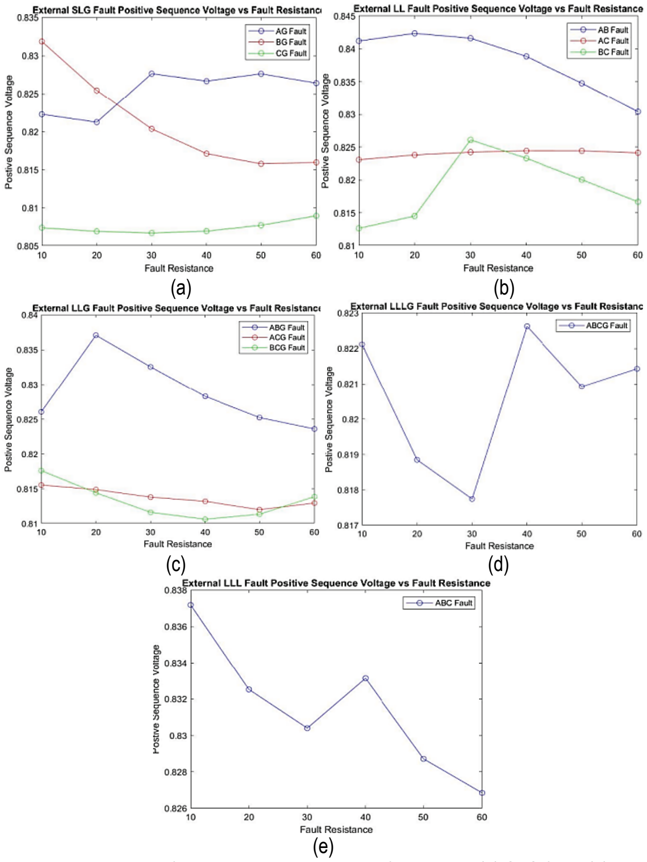

Figure 9 Variation of positive sequence voltage for external (a) SLG fault, (b) LL fault, (c) LLG fault, (d) LLLG fault and (e) LLL fault

3.2 Result for Fault Identification and Classification

The classification of fault in both Internal and external condition for LG, LL, LLG, LLLG and LLL fault is shown in Tab. 6 respectively. It shows that it will identify fault with good accuracy and precision compared with the Fuzzy system as shown in Tab. 7 below for the same Transmission line configuration.

Table 7 Fault classification result

Fault type	Fault location (Distance from the relay in km)	Fault resistance (in Ohms)	Output of the SVM classifier			
			Phase A	Phase B	Phase C	Ground G
No fault	-	-	0	0	0	0
AG	100	10	1	0	0	1
AB	80	20	1	1	0	0
AC	50	30	1	0	1	0
BC	70	40	0	1	1	0
BG	90	50	0	1	0	1
CG	150	60	0	0	1	1
ABG	200	0.001	1	1	0	1
ACG	270	20	1	0	1	1
BCG	300	60	0	1	1	1
ABC	180	50	1	1	1	0
ABCG	210	40	1	1	1	1

3.3 Result for Fault Location

The second aim of this research is to identify the location of fault from line-1 and line2 to resolve the fault within a short time for maintaining the continuity of supply. Fig. 10 show the result for fault location which is near about 99% accurate.

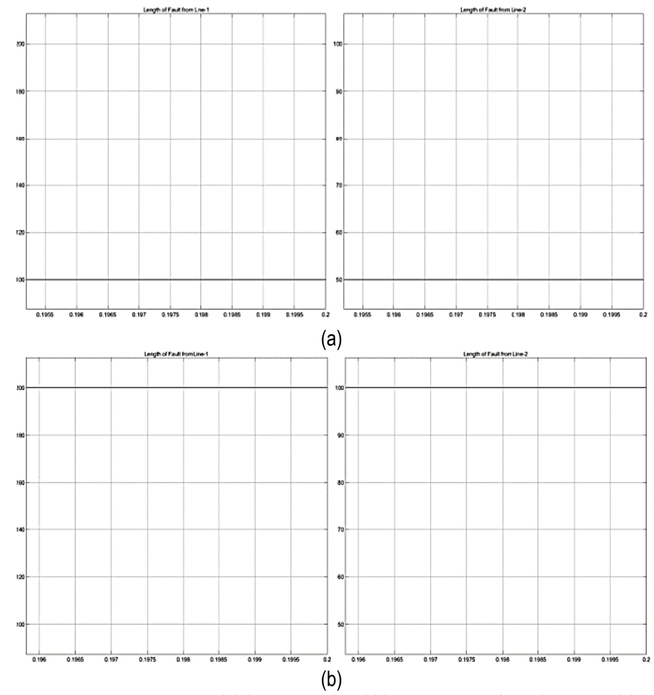

Figure 10 Fault location (a) from Line -1 is 100 km and Line-2 is 50 km and (b) from Line-1 is 200 km and Line-2 is 100 km

3.4 Effect of Line Length Variation

The line length has been altered to 50% of its nominal value, which is 200 km, to test the validity of the proposed design under various line length conditions. All type of fault has been simulated in line connected between Bus-1 and 3 with different ranges of fault resistance i.e. $Rf = 0.01$, 10, 20, 30, 40, 50, 60 Ω. Fig. 11 shows accuracy of the proposed system for detecting, classifying and locating the SLG, LL, LLG, LLLG and LLL faults. The average accuracy of proposed system is shown in below Fig. 13 it proves that proposed system is having near about 84% accuracy during line length variation.

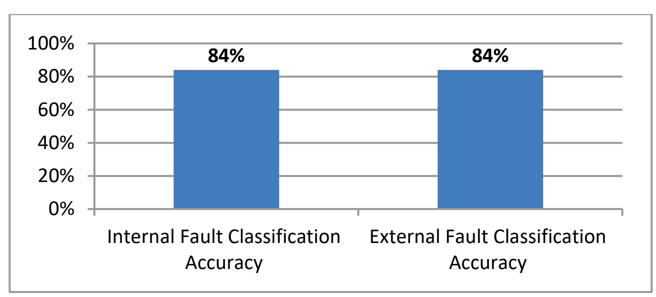

Figure 11 Average Accuracy of SVM system during Line Length Variation

3.5 Effect of Source Impedance(X/R Ratio) Variation

In some conditions the source impedance get varied, in this proposed system the X/R ratio get increased by double of given value i.e. to 20 ohm. Below Fig. 12 result shows accuracy of proposed system during Source impedance variation from that we can say that proposed system has 96% accuracy in internal fault and 87% in external fault.

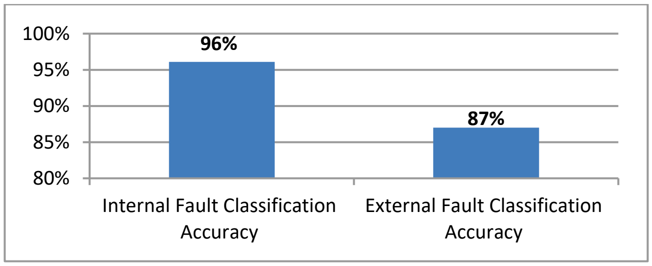

Figure 12 Average Accuracy of SVM system during X/R Ratio Variation

3.5 Effect of Source Power Variation

Below Fig. 13 shows the accuracy of the proposed system when source power varied from 1000 MW to 1500 MW. Result shows that the proposed system has overall 97% internal and 81% external fault accuracy.

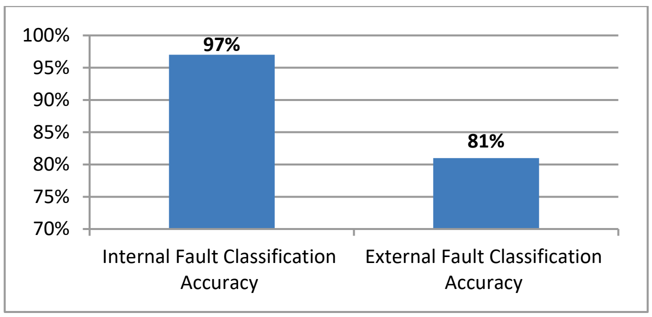

Figure 13 Average accuracy of SVM system during source power variation

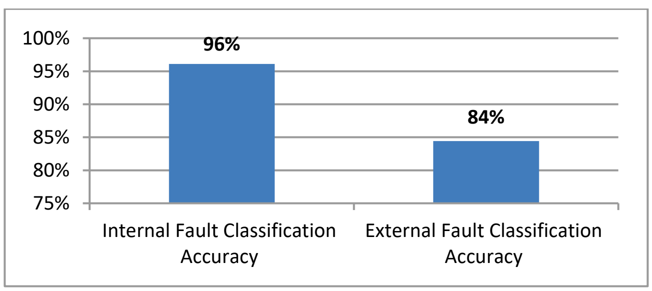

Figure 14 Average accuracy of SVM system during load variation

3.6 Effect of Load Variation

Practically when the load on the system gets varied, the proposed system should have greater accuracy for fault identification and classification. Accuracy of proposed system during load variation is shown below Fig. 14; it shows that proposed system has greater accuracy during load variation.

4 COMPARISONS OF RESULTS WITH EXISTING METHODS

Support Vector Machines (SVM) is known for their excellent classification accuracy, especially when dealing with high-dimensional datasets and complex decision boundaries. SVM can handle both linear and non-linear classification problems effectively.

ANN systems are capable of handling imprecise and uncertain data.

In some cases, the accuracy of ANN systems may be slightly lower compared to SVM.

Below Tab. 8 shows the overall accuracy of both SVM and ANN system for proposed system. It is clear that SVM has greater accuracy than ANN system.

Table 8 Accuracy of SVM and ANN technique for proposed system

Name of fault	Internal fault classification accuracy		External fault classification accuracy	
	ANN technique	SVM technique	ANN technique	SVM technique
AG	100%	100%	100%	100%
BG	71%	100%	86%	100%
CG	100%	100%	86%	100%
AB	100%	100%	0%	100%
AC	57%	100%	57%	71%
BC	43%	86%	43%	71%
ABG	71%	100%	71%	100%
ACG	14%	100%	29%	100%
BCG	57%	100%	100%	71%
ABC	71%	100%	71%	100%
ABCG	0%	86%	100%	43%
Average	**62%**	**97%**	**68%**	**87%**

5 CONCLUSIONS

In this study, a novel technique for fault classification and defective phase identification is introduced, utilizing a single-ended mixed Support Vector Machine (SVM). The technique focuses on analyzing the approximation coefficients of current signals, which are exclusively measured at one end of the line. The proposed SVM-based approach offers several advantages, including the ability to identify faults in both primary and backup protection systems, covering up to 92% of the entire line length. Furthermore, the suggested SVM-based relay demonstrates remarkable performance with minimal training patterns.

The proposed method exhibits a high level of accuracy in locating various types of shunt faults, achieving a success rate of 92% across different fault locations. Extensive testing confirms the reliability and selectivity of the approach, providing satisfactory performance for three-phase transmission lines. Although the training process is performed offline, it should be noted that the training time for constructing the SVM network increases with larger training data sizes resulting from system configuration changes.

The effectiveness of the proposed scheme is demonstrated through successful detection and classification of different types of faults, including symmetrical and unsymmetrical faults, as well as unique cases involving High Impedance Faults (HIF), evolving faults, current transformer (CT) saturation, capacitive voltage transformer (CVT) transients, close-in faults, swing conditions, and source strength variations. A comparative analysis conducted against recently proposed techniques highlights the scheme's potential and robustness.

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