Journal of Electronics and Informatics (ISSN: 2582-3825)
www.irojournals.com/iroei/

Analysis and Detection of Power System Network Faults with Wavelet Transform

Reena Dangi[1], Saroj Kandel[2], Varsha Sen[3], Vision Parajuli[4], Rahul Kumar Jha[5]

[5]Department of Electrical Engineering, Western Regional Campus, Tribhuvan University, Pokhara, Nepal

E-mail: [1]reena.742418@pasc.tu.edu.np, [2]saroj.742418@pasc.tu.edu.np, [3]varsha.742418@pasc.tu.edu.np, [4]vision.742418@pasc.tu.edu.np, [5]rahul.752418@pasc.tu.edu.np

Abstract

Fault detection technique is important for enhancing protection, stability, reliability and continuity of supply. There are many fault detection techniques implemented in power system such as Fourier transform, wavelet transform, neural networks, etc. This research presents the fault identification and analysis using wavelet transform method as well as estimation of circuit breaker rating. The discrete wavelet transform is implemented for the fault identification in five bus system. Various types of line and ground faults have been considered and studied using Daubechies wavelet function. The first level decomposition is used for the fault analysis. The maximum detailed coefficients for various faults currents are analysed for the fault identification. The wavelet transform algorithm is implemented using MATLAB programming. The five-bus system is modelled in MATLAB Simulink and various faults are simulated. The switching time of fault is taken as 0.05 to 0.1 seconds. The faults have been studied at different points in the system. The fault identification method gives accurate results for different types of faults. The load flow analysis is also done for five bus system and appropriate rating of circuit breaker is estimated.

Keywords: Fourier Transform, Wavelet, Fault Detection, MATLAB, Voltage

DOI: https://doi.org/10.36548/jei.2023.3.003
Received: 04.08.2023, received in revised form: 27.08.2023, accepted: 12.09.2023, published: 25.09.2023

1. Introduction

The transmission system in the electric power system transmits power from generation sources to consumers via transmission lines. Over 80% of faults occur in transmission lines, causing voltage and current signal distortions. Common faults include open conductor and short circuit, with symmetrical and unsymmetrical categories. Fault analysis involves detection, classification, and localization, with fault categorization being a critical task. Several simulation strategies exist, with the wavelet method as it is highly preferred due to its accuracy and time response [1].

1.1 Objectives

This research aims to achieve the following objectives:

1. Identify faults using wavelet transform in five-bus systems.
2. Analyze phase current waveforms during various fault conditions.
3. Study load flow in five-bus systems and estimate circuit breaker ratings.

1.2 Scope and Limitations of the Research

In order to study the load flow and analyze faults at different point the research classifies faults in transmission lines using MATLAB Simulink. Wavelet transform provides insights into time-scale information, enabling precise analysis of waveforms during switching operations and transient faults. Filter banks can be used for wavelet transform implementation, but its dependency on threshold values requires recalibration for each new power system.

2. Literature Review

2.1 Wavelet and Wavelet Transformation

Wavelets are short-duration oscillatory waveforms used to extract information from data like audio signals and images. It is valuable in wavelet-based compression/decompression methods for minimal loss. A wavelet family is defined by a scaling filter, scaling function, and wavelet function. The scaling filter defines orthogonal wavelets, while the scaling function covers the entire spectrum[2]. Wavelet functions divide continuous-time signals into scale components, known as "daughter wavelets." Two types of wavelet transforms are discrete wavelet transforms (DWTs) and continuous wavelet transforms (CWTs), operating over different scales and translations.

2.2 Application of Wavelet Transform to Analyses Fault

Wavelet transform (WT) is a mathematical tool used to analyze transient signals, such as temporary over voltages and temporary over currents. It selects the correct wavelet function and analyzes it using translated and scaled versions[3]. WT is effective for analyzing signals at various frequencies and resolutions, with multi-resolution analysis (MRA) being a popular method. Its ability to concentrate on short time periods and long intervals enhances signal analysis[4].

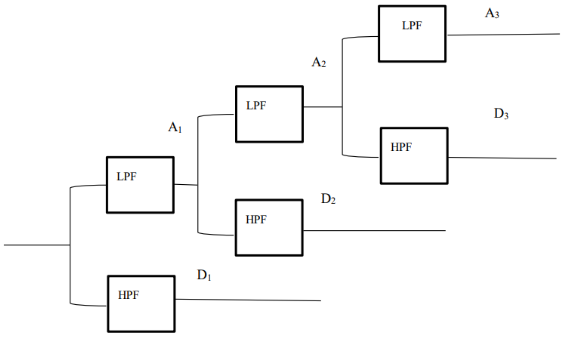

Figure 1. Filter Bank Interpretation of Discrete Wavelet Transform

(i) Daubechies Wavelet

Daubechies wavelets are orthogonal wavelets with a maximum number of vanishing moments, used to solve signal self-similarity, fractal problems, and discontinuities. It encodes polynomial behavior or information in signals, but face issues like scale leaking and shift-invariance. Alternatives have been developed, and the db4 wavelet captures transient signals during fault conditions.[5].

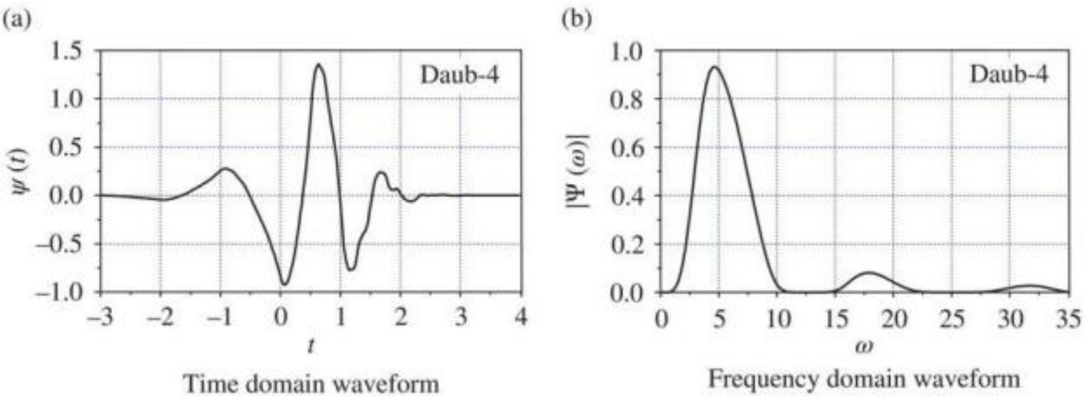

Figure 2. Daubechies Wavelet [5]

(ii) Approximation and Detail Coefficients

The wavelet transform is a method of convolution of a data function with a wavelet base, resulting in wavelet coefficients. These coefficients measure similarity between the wavelet function and the data, with high similarity indicating high frequencies. The transform helps identify these frequencies by analyzing variations in wavelet coefficients. This work uses the discrete wavelet transform (DWT) with Multi-Resolution Analysis (MRA) for fault detection and classification.[6]. The db4 wavelet splits three phase currents into approximations (A) and details (D), with details (D1) of the first decomposition level determining the abnormal state in each phase current. The norm of detail coefficients can be calculated by using the following equation;

$$\|D1\| = \sqrt{\left[\sum_{k=1}^{n_d} |D1(k)|\right]}$$

Where nd indicates number of the detail coefficients at a certain level. These coefficients are calculated for every phase A, B, C and ground. If the estimated norm value exceeds the threshold value, the phase is said to as defective.

3. Methodology

3.1 Flow Chart of Methodology to Identify Faults

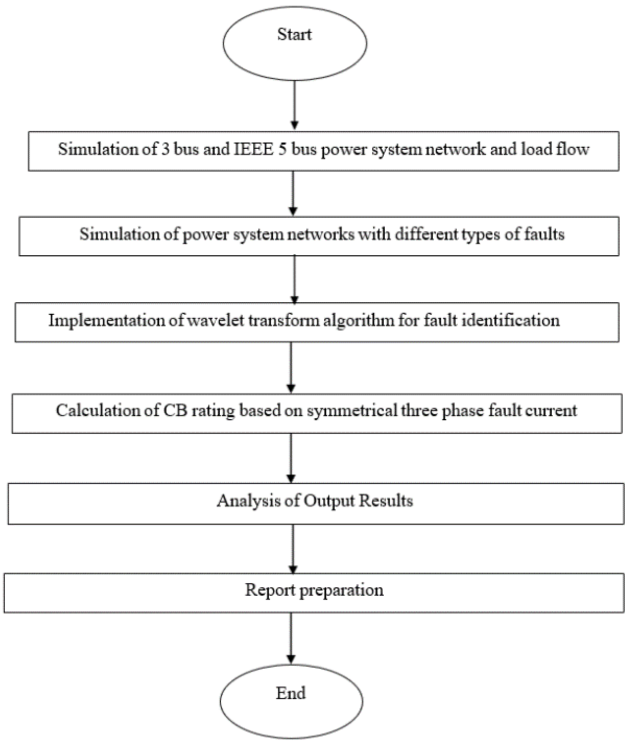

Figure 3. Flowchart Methodology

Firstly, the five bus power system networks is simulated with different types of fault and various types of faults are identified using wavelet transform. Based upon the maximum value of fault current during specific type of fault, rating of the circuit breaker is estimated.

(i) Algorithm for Fault Identification

.

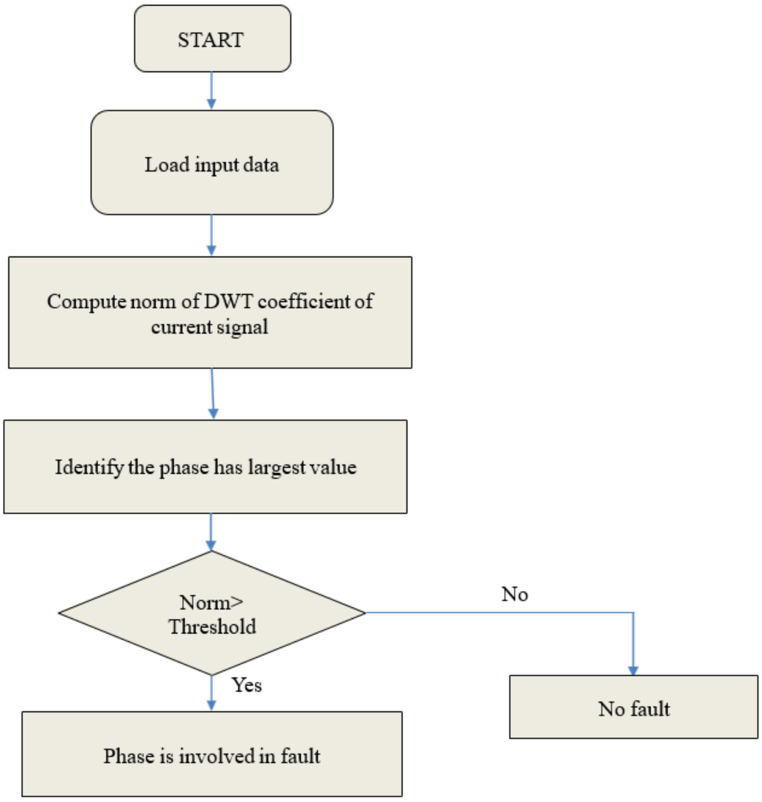

Figure 4. Algorithm for Fault Identification

The Discrete Wavelet Transform (DWT) is then applied to this signal, yielding DWT coefficients, whose magnitudes are subsequently computed. The phase with the largest norm, representing the dominant feature in the signal, is identified. This identified phase's norm is compared to a predefined threshold value, initiating the crucial thresholding step. If the norm exceeds the threshold, the algorithm concludes that no fault is present. Conversely, if the norm falls below or matches the threshold, this is taken as an indicator of a fault. The success of this fault detection approach hinges on the careful selection of the threshold value, which may require fine-tuning to suit the specific characteristics of the system and the signal in question. Moreover, its effectiveness in identifying faults depends on the particular fault types and how the current signal behaves under both normal and faulty conditions.

(ii) Simulation of IEEE 5 Bus System

A standard model of Five bus system under the MATLAB environment is used for simulation. The transmission line parameters and bus data of five bus system is shown in table below:

Table 1. Transmission Line Parameters of IEEE-5 Bus System in pu Value.

From bus	To bus	Transmission line resistance	Transmission line reactance	Transmission line susceptance
1	2	0.02	0.06	0.06
1	3	0.08	0.24	0.05
2	3	0.06	0.18	0.04
2	4	0.06	0.18	0.04
2	5	0.04	0.12	0.03
3	4	0.01	0.03	0.02
4	5	0.08	0.24	0.05

Table 2. Bus Data for IEEE 5 Bus System

Bus number	Bus code	Voltage (pu)	Generation			MVAR
			MW	MVAR	Load MW	
1	1(swing)	1.06+j0.0	0	0	0	0
2	0(PQ)	1.00+j0.0	40	30	20	10
3	0(PQ)	1.00+j0.0	0	0	45	15
4	0(PQ)	1.00+j0.0	0	0	40	5
5	0(PQ)	1.00+j0.0	0	0	60	10

The table displays the buses in a power system, each with its own number, code, voltage magnitude, and generating and load values. Bus 1, the swing bus, has a voltage magnitude of 1.06 per unit. Bus 2, 3, 4, and 5 all have a voltage magnitude of one unit. Bus 2 generates 40 MW of electricity with 30 MVARs (MegaVar) of reactive power.

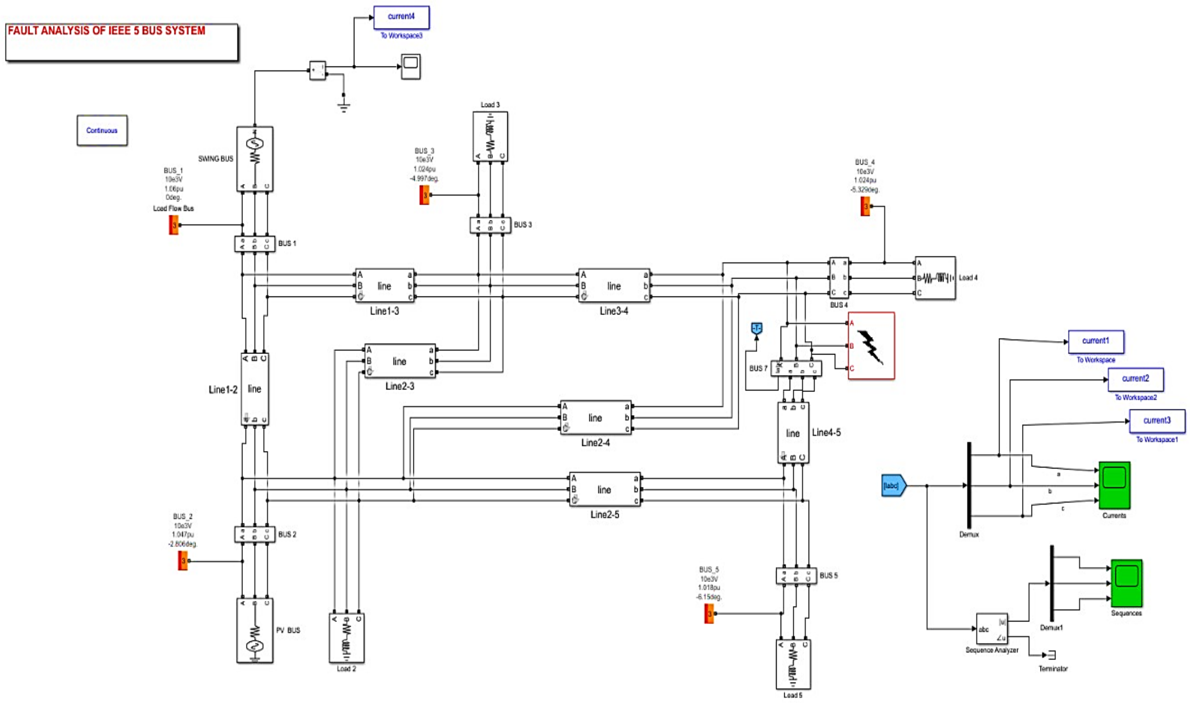

Figure 5. IEEE Five Bus System for Fault Analysis

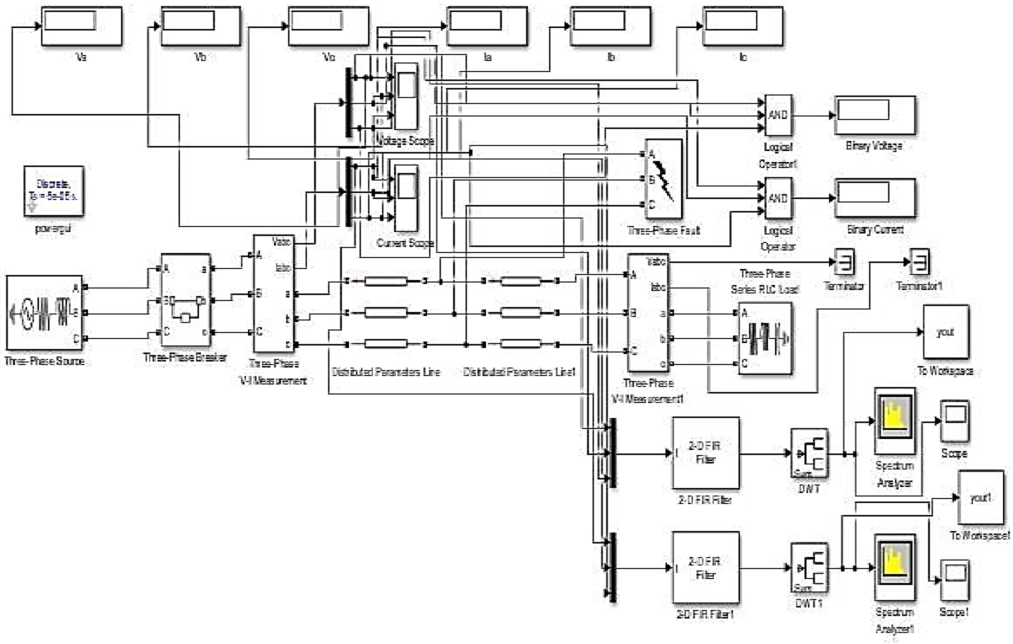

Figure 6. Wavelet Transform Model of Transmission Line for Fault Diagnosis of IEEE 5 Bus System

(iii) Implementation of Wavelet Transform [7]

Wavelet transform based on Daubechies wavelet is implemented in Matlab.m file for fault identification [7].

• Wavelet Transform Syntax to Apply on Signal [c,l] = wavedec (x,n,wname);

Where wavedec = function which decomposes the signal.

x = signal, n = wavelet layer (default = 1) wname = name of the wavelet type (such as haar, Daubechies etc).

c = Output wavelet decomposition vector

l = number of coefficients by level.

• Wavelet Transform Syntax for detailed coefficients of signal.

D = detcoef(C,L,N);

Where, detcoef = function which obtains the detailed coefficients of the signal. *c = Output wavelet decomposition vector l = number of coefficients by level.*

n = wavelet layer (default = 1)

D = Extracts the detail coefficients at the coarsest scale from the wavelet decomposition structure [C, L].

4. Results and Conclusion

4.1. Load Flow Analysis of 5 Bus System

The table 3 consists of load flow results of IEEE five bus system where the voltages are found to be 1.06, 1.0474, 1.0242, 1.0236, and 1.0179 pu in bus 1, 2, 3, 4 and 5 respectively.

Table 3. Load Flow Analysis Of 5-Bus System

Bus number	**Bus type**	**Bus voltage (pu)**	**Voltage angle(degree)**
1	swing	1.06	0
2	PV	1.0474	-2.8064

3	PQ	1.0242	-4.997
4	PQ	1.0236	-5.3291
5	PQ	1.0179	-6.1503

Explanation For using Standard Data values of IEEE 5 Bus system

Standard values are a set of guidelines that serve as a common reference point for data and results across different experiments, studies, and researches. It is crucial for assessing the validity and effectiveness of various methods, techniques, and systems. Standard values also serve as benchmarks, ensuring interoperability and ensuring reliability and accuracy. It is also essential for safety, regulatory compliance, efficiency, education, global collaboration, consumer confidence, historical data, and consistency. It is well-researched, validated, and documented, in order to make it a valuable tool for ensuring compliance with regulations and promoting efficiency in various fields. Standard values also contribute to consumer confidence, allowing for the use of historical data in decision-making and problem-solving.

The bus voltages are expressed in bar graph as below;

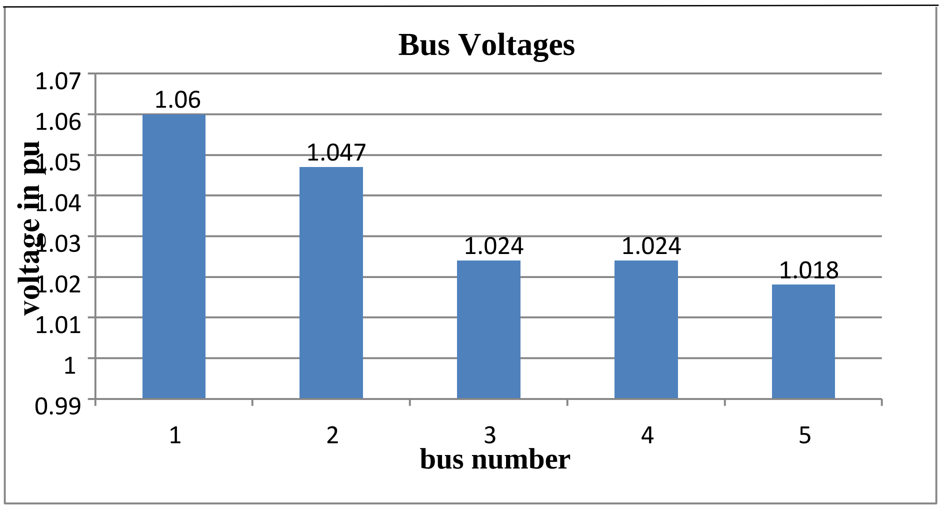

Figure.7 Bus Voltages

4.2 Fault Analysis in Five Bus System at Line 4-5

The results for fault study at line 4-5 are presented below:

a) A-G Fault

The waveform shows that the fault current in phase A rises to maximum value during AG fault whereas the fault currents in other phases remain zero.

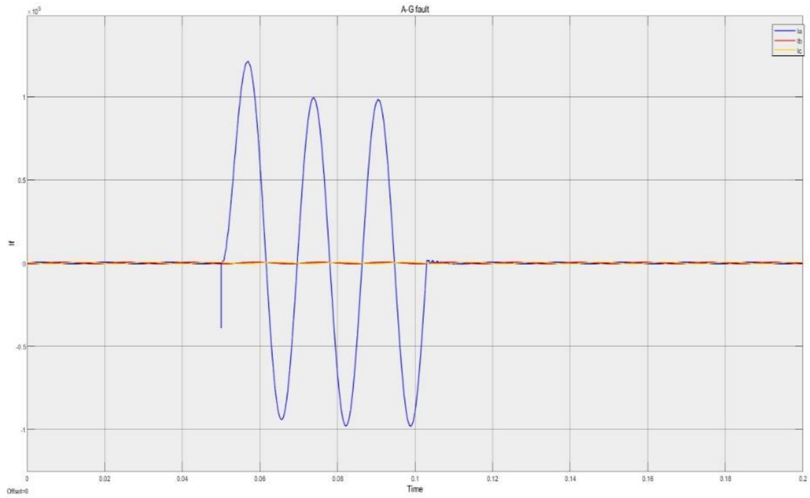

Figure 8. Waveform of Fault Current During A-G Fault

The figure 8 and 9 shows that all the sequence components (positive, negative and zero) of the fault current are equal during AG fault.

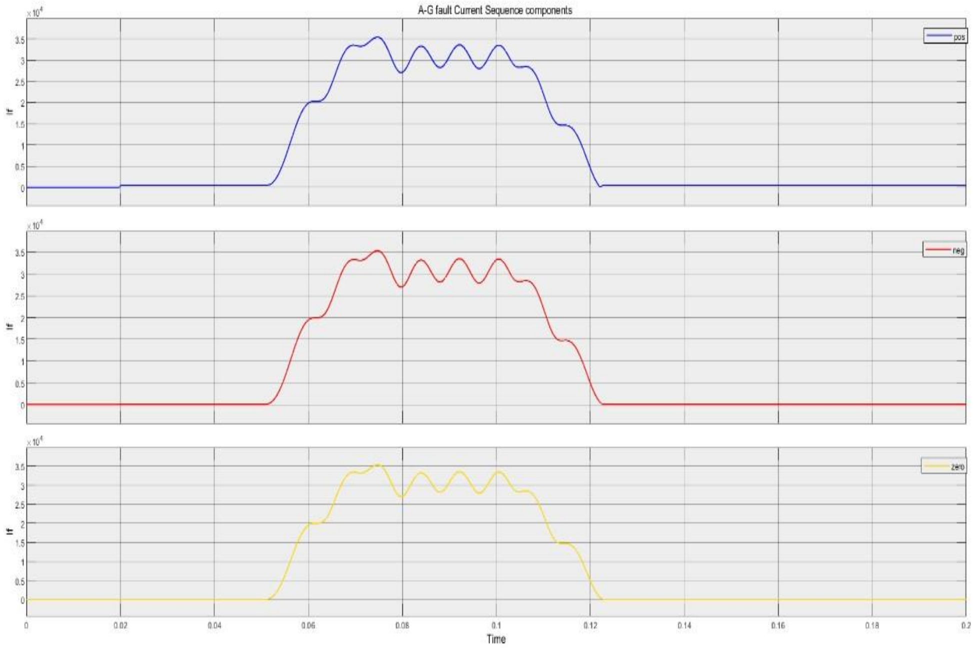

Figure 9. Sequence Component of Fault Current (A-G fault)

The maximum and rms value of fault current is observed to be 1.214e+05 and 4.022e+04 respectively and the result displayed during AG fault is shown in figure below;

```
q =

   1.2090e+03

Single Line to Ground Fault in Phase A is Detected
```

Figure 10. MATLAB Results for A-G Fault

b) AB-G Fault

The waveform shows that the fault current in phase A and phase B rise to maximum value during AB-G fault whereas the fault current in phase C remain zero.

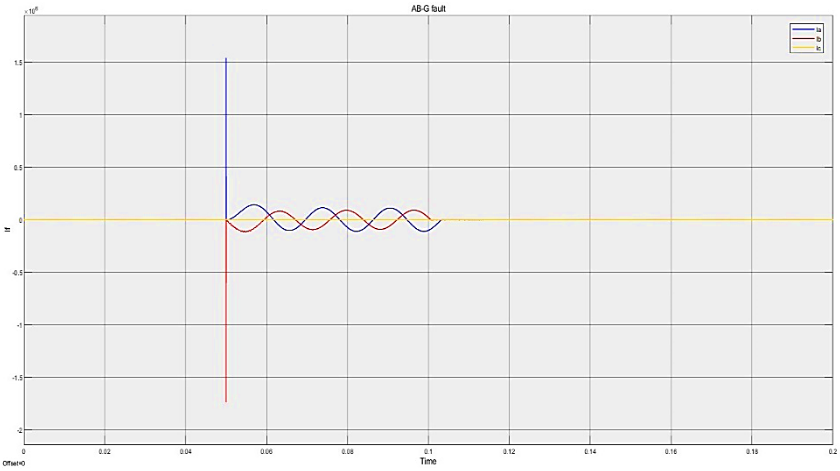

Figure 11. Waveform of Fault Current for AB-G Fault

The maximum and rms value of fault current is observed to be 1.539e+06 and 7.58e+04 respectively and the result displayed during AB-G fault is shown in figure below;

```
q =

  225.5038

Double Line to Gournd Fault (AB-G) is Detected
```

Figure 12. MATLAB Results For AB-G Fault

c) ABC Fault

The waveform shows that the fault current in phase A , phase B and phase C rise to maximum value during ABC fault.

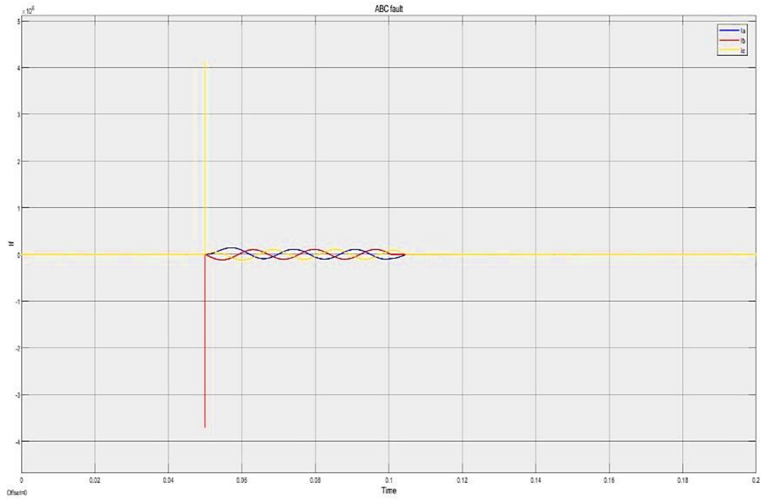

Figure 13. Waveform of Fault Current for ABC Fault

The maximum and rms value of fault current is observed to be 1.418e+05 and 5.815e+04 respectively and the result displayed during AB-G fault is shown in figure below;

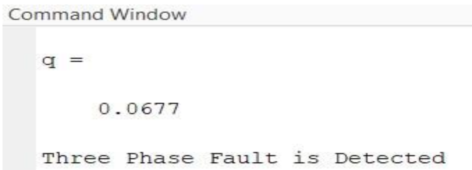

Figure 14. MATLAB Results for ABC fault

d) No Fault Condition

The waveform shows that the currents in phase A, phase B and phase C remain normal during normal condition.

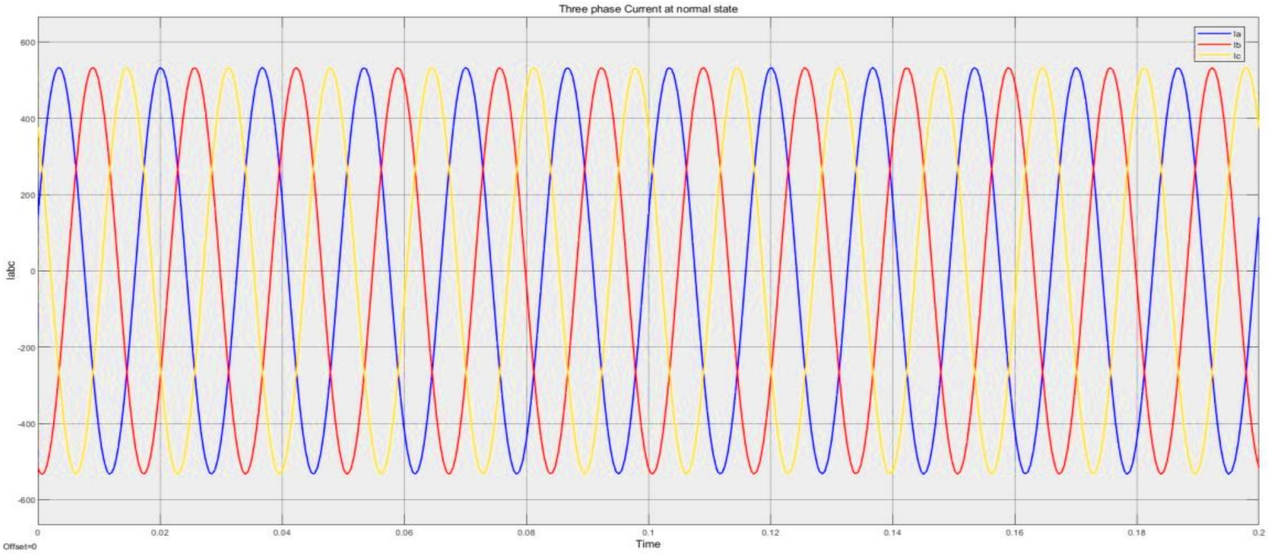

Figure 15. Waveform of Phase Currents in Normal Condition

4.3 Maximum Value of Detailed Coefficients in IEEE 5 Bus System

Table 4. Maximum Value of Detailed Coefficients in IEEE 5-Bus System

Type of Faults	**Max. coefficient of Phase A Current**	**Max. coefficient of Phase B Current**	**Max. coefficient of Phase C Current**	**Max. coefficient of Ground Current**
Three-phase to ground Fault	1.95e+5	1.677e+6	6.77e+5	175.46
Three phase Fault	1.94e+5	1.67e+6	6.75e+5	0.032
Double Line to Ground Fault (AB-G)	2.57e+5	8.06e+5	35.42	585.98
Double Line to Ground Fault (AC-G)	1.01e+6	51.29	3.9e+5	651.47
Double Line to Ground Fault (BC-G)	43.78	1.77e+6	6.44e+5	256.49
Line to Line (A-B) Fault	2.714e+5	7.63e+5	43.6	0.0968

Line to Line (A-C) Fault	1.05e+6	43.21	3.77e+5	0.039
Line to Line (B-C) Fault	43.77	1.77e+6	6.41e+5	0.1276
Single Line to Ground Fault (A-G)	1.93e+4	37.47	43.12	1.01e+3
Single Line to Ground Fault (B-G)	43.38	1.5e+5	48.44	1.25e+3
Single Line to Ground Fault (C-G)	45.11	43.78	6.08e+4	1.16e+3
System without Fault	29.22	37.44	43.34	0.0015

The table.4 displays maximum coefficient values for phase and ground currents at different fault conditions using wavelet transform. MATLAB data is used to classify faults based on first-level breakdown of currents. Phases in fault condition are those with a threshold value of 55, otherwise, healthy.

4.4 Short Circuit MVA (Mega Volt-Amperes) and Circuit Breaker Rating in IEEE Five Bus System

Maximum fault current arises during three-phase fault. So, the circuit breaker should be designed in such a way that it can handle maximum fault current occurring in the system. The rating of circuit breaker is estimated in five bus system for maximum fault current occurring in the system.

The pu value of short circuit fault current is obtained from the rms block in simulation diagram of five bus system.

Base MVA=100 MVA , Base MVA = 11 KV

Table 5. Three Phase Short Circuit Fault

Bus number	**Fault current (pu)**	**Prefault voltage (pu)**
1	2.017	1.06
2	6.67	1.047

3	0.26	1.024
4	0.22	1.0236
5	0.39	1.0179

$short\ circuit\ MVA = prefault\ voltage(pu)$ × short circuit current(pu) × base MVA

For bus 1,

$short\ circuit\ MVA$ = 1.06 × 2.017 × 100 = 213.802 MVA

Similarly, SC-MVA for other buses are calculated and Circuit Breaker rating is determined for each bus as represented in table 4-6.

Table 6. Short Circuit MVA and Circuit Breaker Rating

Bus number	**Current magnitude (pu)**	**Short circuit MVA**	**Circuit Breaker Rating**
1	2.017	213.802	250
2	6.67	698.349	700
3	0.26	26.62	30
4	0.22	22.44	30
5	0.39	39.69	40

4.5 Advantages of Wavelet Transform in Fault Analysis over Conventional Methods

1. Multiresolution Analysis: Wavelet Transform provides a multiresolution analysis of signals, allowing for the detection of faults at different time scales. This can be valuable for identifying both fast transients and slower disturbances in power systems.

2. Localization: Wavelet Transform is known for its ability to localize features in time and frequency domains. It can help pinpoint the exact time and frequency components where faults occur, aiding in fault identification and classification.

3. Noise Robustness: Wavelet Transform can be robust against noise, making it suitable for analyzing power system signals, which can be noisy due to various factors. It can separate genuine fault-related signals from background noise.

4. Feature Extraction: It can effectively extract relevant features from signals, which can be used for fault detection and classification. This feature extraction can simplify the subsequent analysis.

5. Real-time Implementation: Wavelet Transform can be implemented in real-time or near-real-time systems, making it suitable for applications where quick fault detection is critical.

5. Conclusion

The research presents a wavelet-based fault identification methodology using MATLAB program to study faults at various points in a system. The Daubechies wavelet function is used for fault detection, with high detail coefficient values during faults and normal values at other times. The coefficients differ for different fault types, allowing for accurate fault detection. The highest degree of decomposition's detail coefficient values are most effective in distinguishing faults and analyzing current magnitude during faulty situations. The DWT transform is concluded to be effective in detecting power system faults, aiding in designing suitable online protection relaying systems. Circuit breaker ratings are estimated based on short circuit MVA rating, faults are identified at different points, and fault current waveforms are analyzed for various fault types.

References

[1] J. Upendar, C. P. Gupta, and G. K. Singh, “Modified PSO and wavelet transform-based fault classification on transmission systems,” IJBIC, vol. 2, pp. 395–403, Jan. 2010, doi: 10.1504/IJBIC.2010.037019.

[2] S. Devi, N. Swarnkar, S. Ola, and O. Mahela, Detection of transmission line faults using discrete wavelet transform. 2016. doi: 10.1109/CASP.2016.7746152.

[3] Z. Wang and L. Xu, “Fault detection of the power system based on the chaotic neural network and wavelet transform,” Complexity, vol. 2020, 2020, doi: 10.1155/2020/8884786.

[4] Š. Džakmic, T. Namas, and I. Džafić, “Fault classification using multi-resolution analysis and discrete wavelet transforms,” in 2017 XXVI International Conference on Information, Communication and Automation Technologies (ICAT), 2017, pp. 1–6. doi: 10.1109/ICAT.2017.8171647.

[5] F. Costa, K. Silva, B. A. Souza, K. Dantas, and N. S. D. Brito, A Method for Fault Classification in Transmission Lines Based on ANN and Wavelet Coefficients Energy. 2006. doi: 10.1109/IJCNN.2006.1716607.

[6] A. Bhandakkar and L. Mathew, “Real-Time-Simulation of IEEE-5-Bus Network on OPAL-RT-OP4510 Simulator,” in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, Mar. 2018. doi: 10.1088/1757-899X/331/1/012028.

[7] N. Prashanth and K. Srinivas, “Radial Basis Function Neural Network with Wavelet Transform for Power System Fault Identification and Classification.”

[8] K. H. Kashyap and U. J. Shenoy, “Classification of power system faults using wavelet transforms and probabilistic neural networks,” in Proceedings of the 2003 International Symposium on Circuits and Systems, 2003. ISCAS ’03., 2003, pp. III–III. doi: 10.1109/ISCAS.2003.1205046.

[9] Prasad and J. B. Edward, “Application of Wavelet Technique for Fault Classification in Transmission Systems,” Procedia Comput Sci, vol. 92, pp. 78–83, 2016, doi: https://doi.org/10.1016/j.procs.2016.07.326.

[10] P. S. Jose, “Wavelet-Based Transmission Line Fault Analysis,” 2014. [Online]. Available: https://api.semanticscholar.org/CorpusID:10083423

[11] P. Balakrishnan and K. Sathiyasekar, “Transmission line fault detection, classification and location using wavelet transform,” Int J Eng Adv Technol, vol. 8, no. 6 Special Issue 3, pp. 1770–1775, Sep. 2019, doi: 10.35940/ijeat.F1337.0986S319.

[12] K. Krishna Kumari, V. Vanitha, and M. G. Hussien, “Framework for Transmission Line Fault Detection in a Five Bus System Using Discrete Wavelet Transform,” Distributed Generation and Alternative Energy Journal, vol. 37, no. 3, pp. 525–536, 2022, doi: 10.13052/dgaej2156-3306.3737.

[13] G. A. Adepoju, O. A. Komolafe, M. A. Tijani, and A. O. Bisiriyu, “FAULT ANALYSIS FOR CIRCUIT BREAKERS RATINGS DETERMINATION ON NIGERIAN 330kv TRANSMISSION GRID,” 2013. [Online]. Available: www.theijes.com

[14] T. Sayed and A. A. Sewilam, “AUTOMATED WAVELET-BASED FAULT DETECTION AND DIAGNOSIS FOR SMART DISTRIBUTION SYSTEMS AND MICROGRIDS,” 2017.

[15] L. S. Azuara Grande, R. Granizo, and S. Arnaltes, “Wavelet Analysis to Detect Ground Faults in Electrical Power Systems with Full Penetration of Converter Interface Generation,” Electronics (Switzerland), vol. 12, no. 5, Mar. 2023, doi: 10.3390/electronics12051085.