Fifteen phase transmission line protection using daubechies-4 wavelet transform

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Abstract

In this work, the daubechies-4 wavelet transform (Db4WT) is utilized for fault detection and faulted phase recognition in a fifteen phase transmission line (FPTL). The daubechies-4 wavelet transform has been widely investigated using the MATLAB model of a 765 kV, 200 km long fifteen phase transmission line. The fifteen phase fault currents measured by the current measurements blocks connected at the bus-1 of the fifteen phase transmission line are entered to the wavelet transform algorithm. The first level detail coefficients of the fifteen phase currents are then calculated. The fault detection is carried out with great correctness.

Keywords: fault detection, faulty phase recognition, fifteen phase transmission line protection, wavelet transform.

1. Introduction

The chance of fault occurrence on the fifteen-phase transmission line is more when comparing with the six-phase transmission line. Thus, exact detection of the faults in the fifteen-phase transmission line turns out to be very influential for extenuating the loss of gain and providing rapid renovates.

Quite a few newly reported research studies addressed the issues related to fault detection and classification in transmission lines. Some important research efforts are reported in brief in this section. A fault detection technique based on wavelet transform for series capacitor compensated double circuit transmission line has been proposed in (Gautam *et al.*, 2018). Wavelet transform has been applied for the protection of a 400 kV series capacitor compensated double circuit transmission line (Gautam *et al.*, 2018). Hilbert Huang transform has been used for the detection and classification of single line to ground near-in and far-end faults in a 138 kV six-phase transmission line (Kapoor, 2019). Wavelet transform based protection technique has been presented for the detection of inter-circuit and cross-country faults in a 400 kV series capacitor compensated double circuit transmission line (Kapoor, 2019). In (Kapoor, 2019), discrete Walsh Hadamard transform has been used for the protection of wind farm connected series capacitor compensated three phase transmission line. Hilbert Huang transform based three phase to ground fault detection and classification scheme has been presented in (Kapoor, 2019) for the protection of a 138 kV six-phase transmission line. A wavelet transform based fault detection of phase to phase faults in a six-phase series capacitor compensated transmission line has reported in (Kapoor, 2018). Mathematical morphology has been applied for the detection of near-in and remote-end faults in six-phase transmission line (Kapoor, 2018). A discrete wavelet transform based protection technique has been proposed for the twelve –phase series compensated transmission line (Kapoor, 2018). A discrete wavelet transform based fault location method has been proposed for the three terminal transmission line (Kapoor, 2018). A wavelet transform based fault detector has been proposed for series capacitor compensated three phase transmission line (Kapoor, 2018). Detection and classification of multi-location three phase to ground faults in a twelve phase transmission line using wavelet transform has been reported in (Kapoor, 2018). Discrete wavelet transform has been used for the location of faults in a 330 kV three phase transmission line (Kapoor, 2018). Detection of phase to phase faults in a series capacitor compensated six-phase transmission line using wavelet transform has been presented in

(Kapoor, 2018). Detection and classification of near-in and far-end faults in a six-phase transmission line using wavelet transform has been reported in (Kapoor, 2018). A combination of modular artificial neural network and wavelet transform has been used for the recognition of faulty zone and fault location in six-phase transmission line (Koley *et al.*, 2017). Haar wavelet transform in conjunction with the artificial neural network has been for the classification of phase to phase to faults in a six-phase transmission line (Kumar *et al.*, 2014). Walsh Hadamard transform has been used for the detection of faults in a series capacitor compensated transmission line (Sharma *et al.*, 2018). Mathematical morphology has been utilized for the boundary protection of a six-phase transmission line (Sharma *et al.*, 2017). A numerical relay based over-current protection technique has been proposed for a six-phase transmission line (Warathe and Patel, 2015).
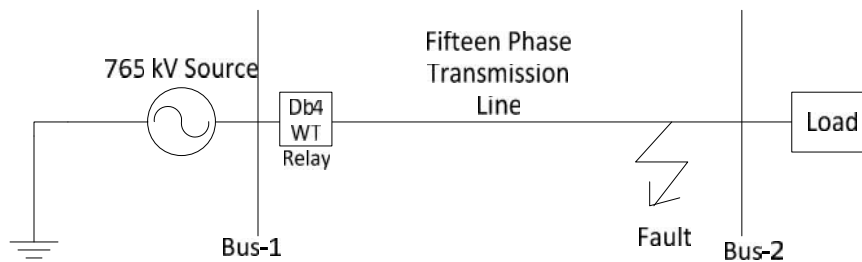
In this work, a daubechies-4 wavelet transform (Db4WT) is executed for the detection and classification of faults in a fifteen-phase transmission line. Such type of research has not been depicted so far to the best of the information of the author. The results points up that the Db4WT capably detects the faults, and the consistency of the Db4WT is not susceptible to the variations in the fault factors.

This article is structured as: Section 2 presents the specifications of fifteen-phase transmission line. Section 3 describes the process for fault detection using Db4WT. Section 4 reports the simulation results of the investigations carried out in this study. Section 5 concludes the article.

2. The Specifications of Fifteen-Phase Transmission Line

Figure 1 shows the schematic of fifteen-phase power transmission system. The power transmission system consists of a 765 kV, 50 Hz, 200 km long fifteen-phase transmission line which is divided into two zones. Each zone has a length of 100 km. The fifteen-phase transmission line is fed from a 765 kV source at the sending end and connected to a load at the receiving end. The model of fifteen-phase transmission line is developed and simulated for different types of faults using the simscape power system toolbox of MATLAB.

As shown in Figure 1, the current measurement blocks for the relay are connected at bus-1 to protect the entire length of fifteen-phase transmission line.

Figure 1. The schematic of fifteen-phase transmission line

3. Db4 Wavelet Transform Based Protection Technique

The daubechies-4 wavelet transform is formulated as:

$$W (j, k) = \sum_j \sum_k x (k) \, 2^{-j/2} \quad (2^{-j}n-k) \tag{1}$$

where a mother wavelet is designated as (t) having finite energy.

High pass filter gain after sub-sampling twice is defined as:

$$y_H (k) = \sum_n x(n)g (2k-n) \tag{2}$$

Low pass filter gain after sub-sampling twice is defined as:

$$y_L (k) = \sum_n x(n)h (2k-n) \tag{3}$$

Figure 2 shows the process of daubechies-4 wavelet transform for fault detection and classification. The steps for the same are shown below.

Step 1   Simulate the model for different types of faults and generate the fifteen-phase fault current signals.
Step 2   Analyze the fifteen-phase currents using daubechies-4 wavelet transform for the removal of their characteristics.
Step 3   Calculate the amplitudes of Db4WT coefficients for each fault current signal.
Step 4   The phase will be declared as the faulted phase if its Db4WT coefficient has the larger amplitude in comparison with the healthy phase.
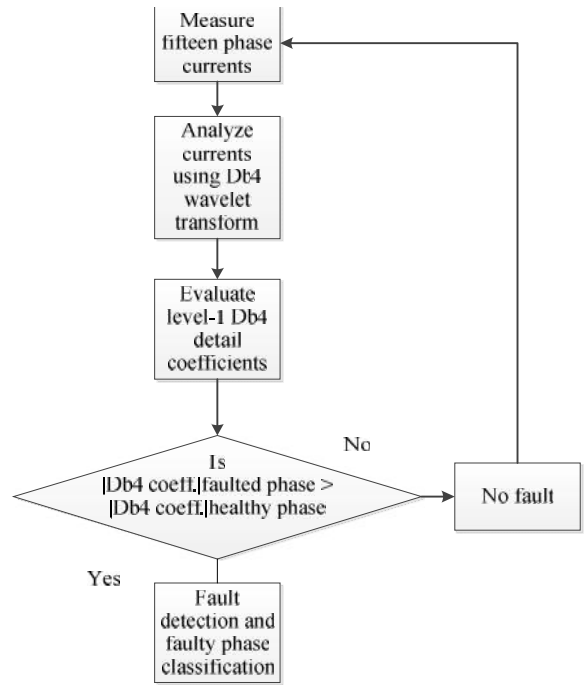
Figure 2. The schematic of fault detection technique using Db4 wavelet transform

4. Results and Discussion

The effectiveness of Db4 wavelet transform has been checked for various types of fault cases. The fault factors of the simulation model are varied in each case. The results are shown in the subsequent subsections.

4.1 Response for No-Fault: The Db4 wavelet transform is tested for no-fault condition. Figure 3 shows the fifteen-phase current for no fault. Figure 4 depicts the Db4 coefficients for no-fault. Table 1 reports the amplitudes of Db4 coefficients of fifteen-phase current for no-fault condition. It can be observed from Table 1 that the Db4 coefficients of all the phases have approximately same amplitudes for no-fault condition. The Db4 coefficients are also below the line of threshold. This verifies that the fifteen-phase transmission line has no-fault.
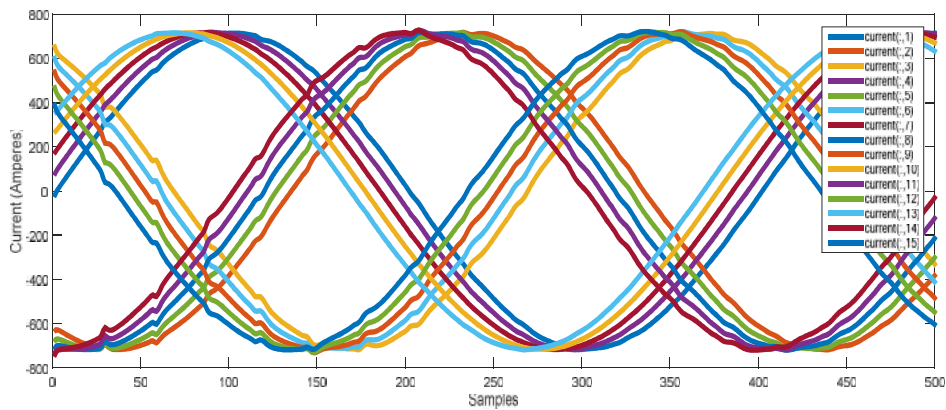

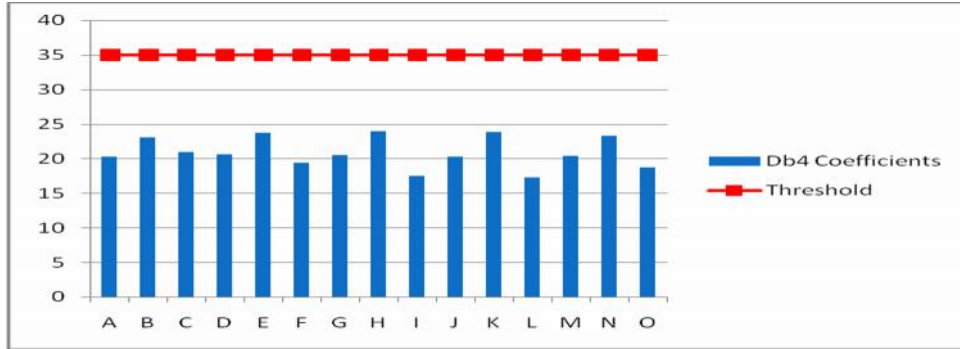**Figure 3.** Diagram showing fifteen phase current for no-fault

Figure 4. Db4 coefficients for no-fault

Table 1. Response of Db4WT for no-fault

Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	20.2428	F	19.3585	K	23.8020
B	23.0169	G	20.5351	L	17.2858
C	20.9093	H	23.9486	M	20.3973
D	20.5649	I	17.4766	N	23.2481
E	23.6854	J	20.3316	O	18.7622

4.2 Response in Case of Wind Farm Integrated Fifteen-Phase Transmission Line: The performance of the proposed technique has been explored for the wind farm integrated fifteen-phase transmission line for the ten phase fault. Figure 5 shows the fifteen-phase current for 'BCFGHIJKLM-g' ten phase fault. Figure 6 illustrates the Db4 coefficients for 'BCFGHIJKLM-g' fault. Table 2 depicts the response of Db4WT for 'BCFGHIJKLM-g' ten phase fault at 65% from bus-1 at FIT = 0.2 seconds with $R_f = R_g = 15$. From Table 2, it can be seen that the amplitudes of Db4WT coefficients of faulted phases 'BCFGHIJKLM' are larger than the amplitudes of Db4WT coefficients of the un-faulted phases and this shows that the proposed fault detection technique correctly detects and identifies the ten phase fault which is triggered on the wind farm connected fifteen phase transmission line.
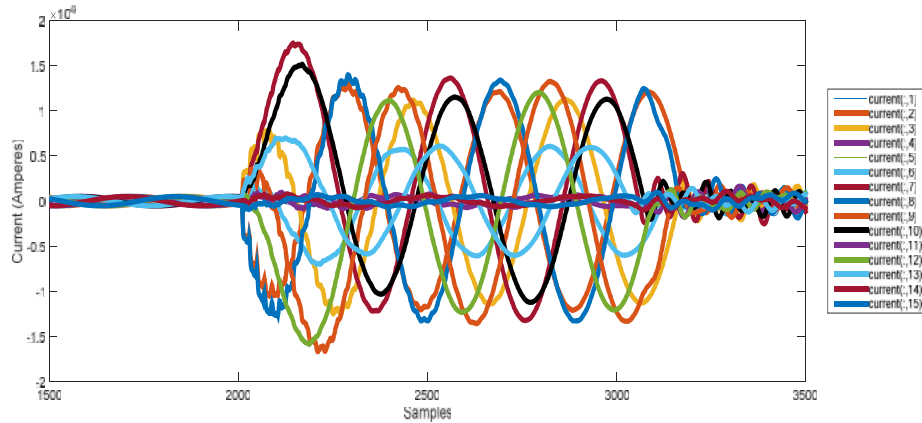

Figure 5. Fifteen phase current for 'BCFGHIJKLM-g' fault at 65% from bus-1 at FIT = 0.2 seconds with $R_f = R_g = 15$
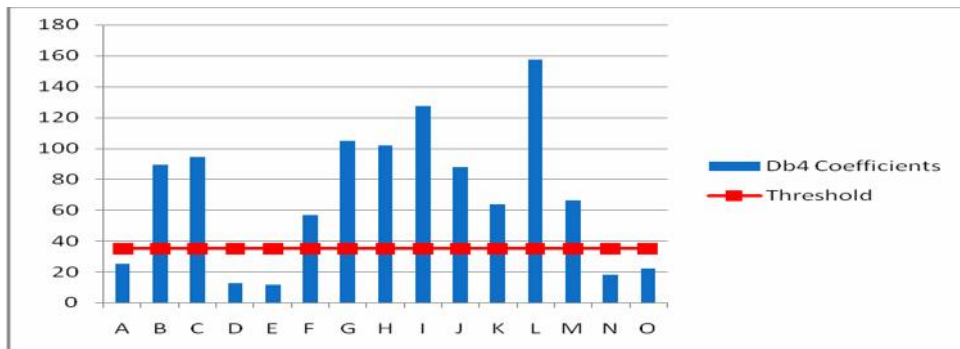

Figure 6. Db4 coefficients for 'BCFGHIJKLM-g' fault at 65% from bus-1

Table 2. Response of Db4WT for 'BCFGHIJKLM-g' fault at 65% from bus-1 at FIT = 0.2 seconds with $R_f = R_g = 15$

Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	24.8194	F	**56.5696**	K	**63.8005**
B	**89.4654**	G	**105.0407**	L	**157.3431**
C	**94.2187**	H	**101.9024**	M	**66.2042**
D	12.3217	I	**127.1126**	N	18.0093
E	11.7320	J	**87.5956**	O	21.9660

4.3 Response in Case of Inter-Circuit Fault: The simulation study has been conducted to examine the performance of the proposed technique for the inter-circuit fault. Figure 7 depicts the Db4 coefficients for 'AEIKO-g' five phase to ground inter-circuit fault. The result of wavelet transform for 'AEIKO-g' inter-circuit fault simulated at 45% from bus-1 at FIT=0.35 seconds with $R_f = R_g = 0.001$ is reported in Table 3. From Table 3, it can be seen that the amplitudes of Db4WT coefficients of the faulted phases are greater than the amplitudes of Db4WT coefficients of the un-faulted phases which shows that the proposed scheme correctly detects and identifies the inter-circuit fault.
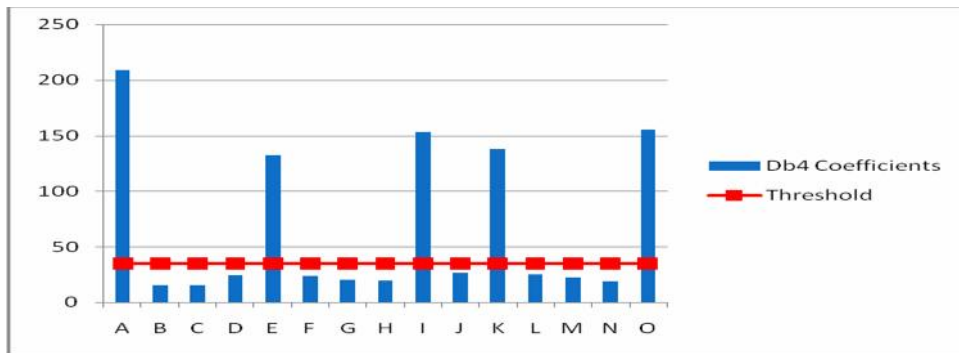

Figure 7. Db4 coefficients for 'AEIKO-g' inter-circuit fault at 45% from bus-1

Table 3. Response of Db4WT for 'AEIKO-g' inter-circuit fault at 45% from bus-1 at FIT=0.35 seconds with $R_f = R_g = 0.001$

Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	**208.5663**	F	23.3426	K	**138.1582**
B	15.5591	G	20.3954	L	25.2641
C	15.2882	H	19.3108	M	22.2071
D	24.3561	I	**153.4394**	N	18.6097
E	**132.3935**	J	26.2368	O	**154.9574**

4.4 Response in Case of Fault Resistance Variation: The Db4 wavelet transform has been investigated for variation in fault resistance. The fault resistances are varied from 0.5   to 145   . All the faults were simulated at a distance of 50% from bus-1. Figures 8-12 shows the Db4 coefficients for different faults with different fault resistances. The results of Db4WT for fault resistance variation are reported in Tables 4-8. It is examined from Tables 4-8 that all the faults have been correctly detected and the faulty phases have been correctly identified with the help of Db4 wavelet transform.
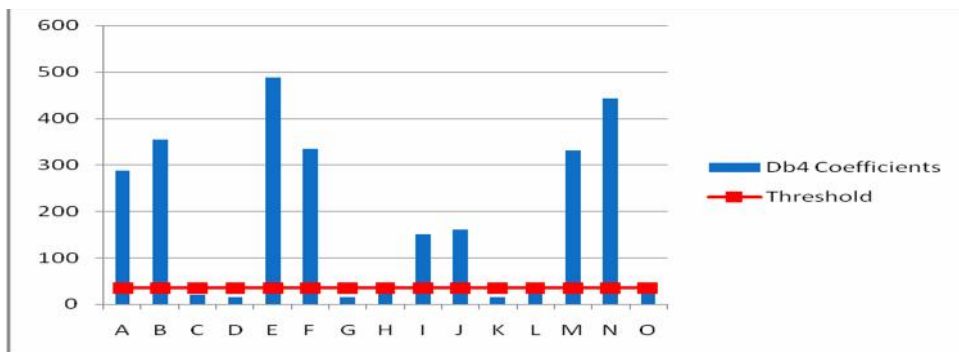
Figure 8. Db4 coefficients for 'ABEFIJMN-g' fault at 50% from bus-1 with $R_f = 0.5$

Table 4. Response of Db4WT for 'ABEFIJMN-g' fault with $R_f = 0.5$, $R_g = 0.001$, FIT = 0.1 seconds and $F_l = 50\%$

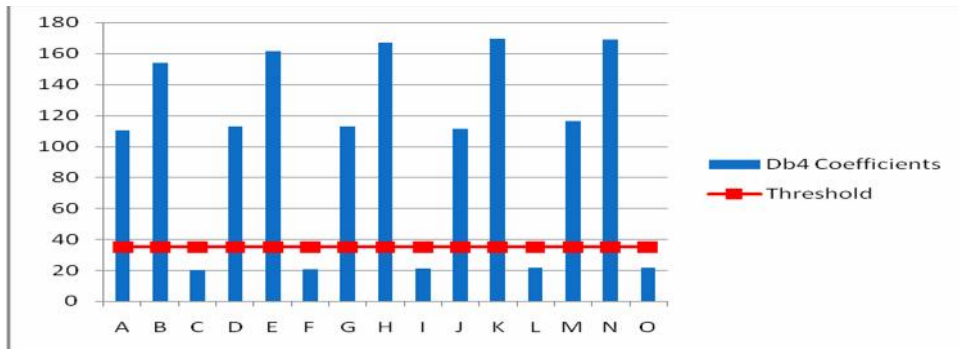| Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	**287.8500**	**F**	**334.3511**	**K**	14.5572
B	**354.3502**	**G**	15.8225	**L**	23.6324
C	20.2261	**H**	21.6168	**M**	**330.4511**
D	14.7688	**I**	**150.3564**	**N**	**442.2578**
E	**487.7033**	**J**	**159.8848**	**O**	21.6074
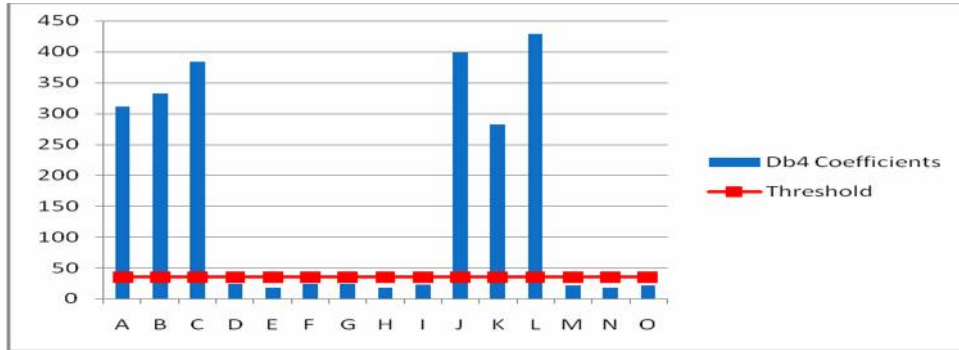
Figure 9. Db4 coefficients for 'ABCJKL-g' fault at 50% from bus-1 with $R_f = 25$

Table 5. Response of Db4WT for 'ABCJKL-g' fault with $R_f = 25$, $R_g = 0.001$, FIT = 0.3 seconds and $F_l = 50\%$

Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	**310.9282**	**F**	23.3692	**K**	**282.5905**
B	**332.6433**	**G**	23.2525	**L**	**428.2299**
C	**383.3425**	**H**	18.0868	**M**	21.6253
D	23.4746	**I**	22.8626	**N**	17.4600
E	17.9373	**J**	**398.8454**	**O**	21.7084

Figure 10. Db4 coefficients for 'ABDEGHJKMN-g' fault at 50% from bus-1 with $R_f = 65$

Table 6. Response of Db4WT for 'ABDEGHJKMN-g' fault with $R_f = 65$, $R_g = 0.001$, FIT = 0.4 seconds and $F_l = 50\%$

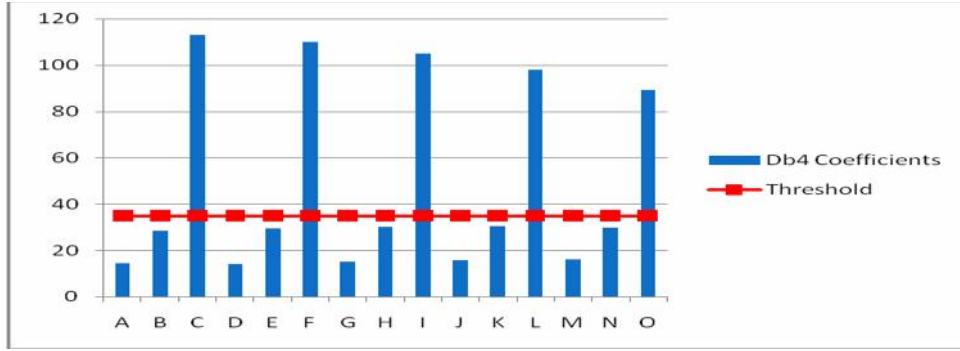| Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	**110.2973**	**F**	20.5578	**K**	**169.2681**
B	**153.6900**	**G**	**112.9737**	**L**	21.6245
C	20.2074	**H**	**166.9014**	**M**	**116.5583**
D	**112.5988**	**I**	21.2460	**N**	**168.7387**
E	**161.6789**	**J**	**111.4156**	**O**	21.6074

Figure 11. Db4 coefficients for 'CFILO-g' fault at 50% from bus-1 with $R_f = 105$

Table 7. Response of Db4WT for 'CFILO-g' fault with $R_f = 105$, $R_g = 0.001$, FIT = 0.1 seconds and $F_l = 50\%$

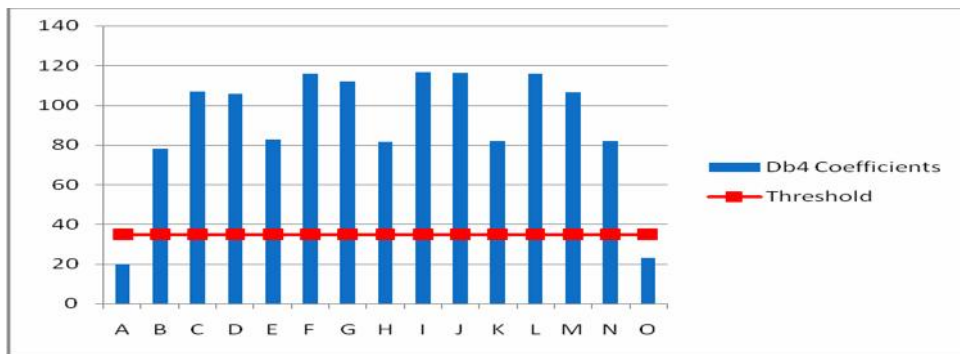| Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	14.5230	**F**	**109.9017**	**K**	30.2519
B	28.2698	**G**	14.8870	**L**	**97.9285**
C	**113.1112**	**H**	30.1024	**M**	16.0306
D	13.9271	**I**	**104.8118**	**N**	29.8837
E	29.4379	**J**	15.5922	**O**	**89.3696**

Figure 12. Db4 coefficients for 'BCDEFGHIJKLMN-g' fault at 50% from bus-1 with $R_f = 145$

Table 8. Response of Db4WT for 'BCDEFGHIJKLMN-g' fault with $R_f = 145$, $R_g = 0.001$, FIT = 0.25 seconds and $F_l = 50\%$

Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	19.8395	**F**	**115.6398**	**K**	**81.9076**
B	**77.9940**	**G**	**111.9870**	**L**	**115.8395**
C	**106.9172**	**H**	**81.6725**	**M**	**106.4703**
D	**105.7298**	**I**	**116.7383**	**N**	**81.7021**
E	**82.4843**	**J**	**116.3280**	**O**	22.9223

4.5 Response in Case of Ground Resistance Variation: The Db4 wavelet transform has been explored for variation in ground resistance. The ground resistances are varied from 5 to 155. All the faults were simulated at a distance of 50% from bus-1. Figures 13-17 exemplifies the Db4 coefficients for different faults with different ground resistances. Tables 9-13 report the results of Db4WT for different ground resistances. From Tables 9-13, it can be observed that the performance of the Db4 wavelet transform is not affected by ground resistance variation.
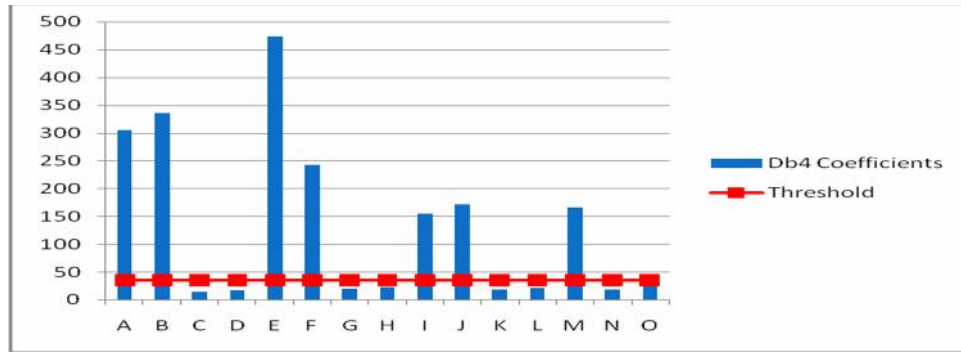
Figure 13. Db4 coefficients for 'ABEFIJM-g' fault at 50% from bus-1 with $R_g = 5$

Table 9. Response of Db4WT for 'ABEFIJM-g' fault with $R_g = 5$, $R_f = 0.001$, FIT = 0.1 seconds and $F_l = 50\%$

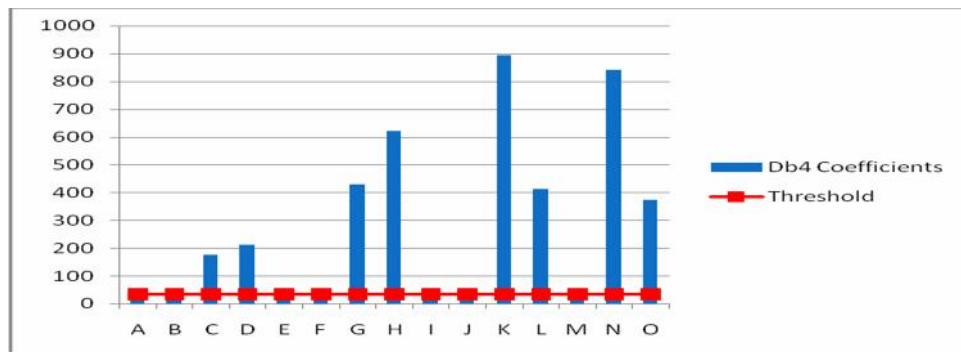| Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	**305.1066**	**F**	**242.3277**	**K**	18.0085
B	**335.7194**	**G**	19.6527	**L**	20.4323
C	13.4456	**H**	22.2776	**M**	**165.2601**
D	17.1818	**I**	**154.3056**	**N**	18.0175
E	**472.9176**	**J**	**170.8834**	**O**	23.2581

Figure 14. Db4 coefficients for 'CDGHKLNO-g' fault at 50% from bus-1 with $R_g = 35$

Table 10. Response of Db4WT for 'CDGHKLNO-g' fault with $R_g = 35$, $R_f = 0.001$, FIT = 0.1 seconds and $F_l = 50\%$

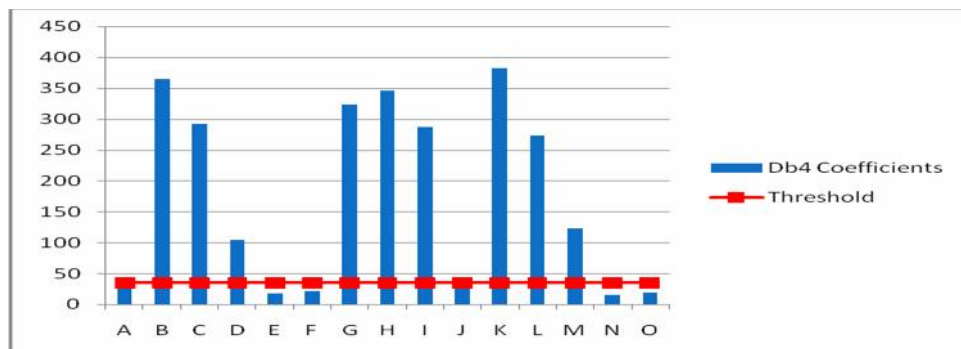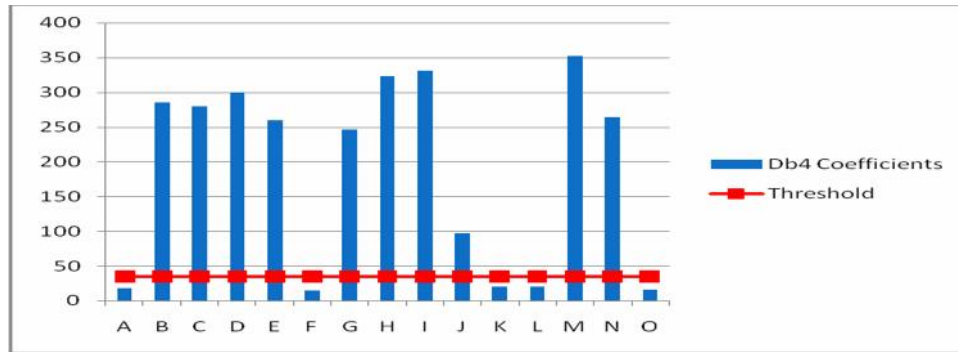| Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	21.2112	**F**	40.0141	**K**	**893.7703**
B	39.5643	**G**	**429.8625**	**L**	**412.1715**
C	**174.6299**	**H**	**621.9928**	**M**	30.7047
D	**212.5646**	**I**	20.3387	**N**	**842.5915**
E	24.0427	**J**	31.2305	**O**	**373.1382**

Figure 15. Db4 coefficients for 'BCDGHIKLM-g' fault at 50% from bus-1 with $R_g = 75$

Table 11. Response of Db4WT for 'BCDGHIKLM-g' fault with $R_g = 75$, $R_f = 0.001$, FIT = 0.1 seconds and $F_l = 50\%$
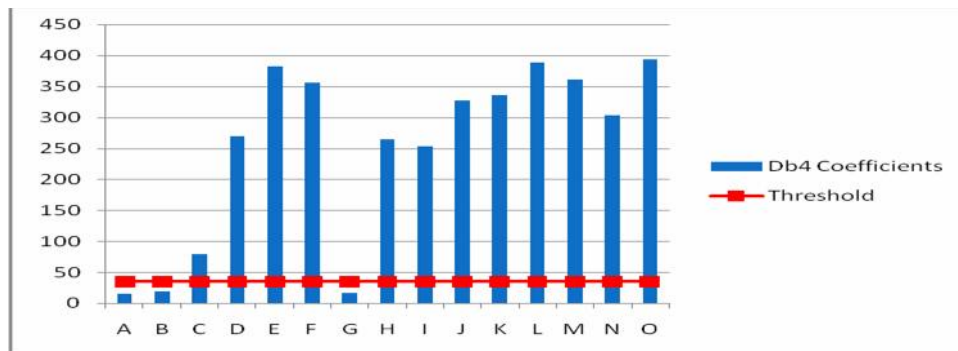
Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	25.7099	F	21.1927	K	**382.2443**
B	**364.6058**	G	**323.3755**	L	**273.3654**
C	**292.1009**	H	**345.9017**	M	**123.0314**
D	**103.7848**	I	**287.0608**	N	15.1812
E	17.1320	J	32.5759	O	18.6668

Figure 16. Db4 coefficients for 'BCDEGHIJMN-g' fault at 50% from bus-1 with $R_g = 115$

Table 12. Response of Db4WT for 'BCDEGHIJMN-g' fault with $R_g = 115$, $R_f = 0.001$, FIT = 0.1 seconds, $F_l = 50\%$

Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	17.6909	F	14.5911	K	19.5529
B	**285.3854**	G	**246.6604**	L	19.9184
C	**279.9137**	H	**323.6642**	M	**351.9014**
D	**299.7456**	I	**330.5131**	N	**264.4864**
E	**259.1972**	J	**96.7849**	O	16.0876

Figure 17. Db4 coefficients for 'CDEFHIJKLMNO-g' fault at 50% from bus-1 with $R_g = 155$

Table 13. Response of Db4WT for 'CDEFHIJKLMNO-g' fault with $R_g = 155$, $R_f = 0.001$, FIT = 0.1 seconds, $F_l = 50\%$

Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	14.8026	F	**356.6039**	K	**335.3655**
B	18.9373	G	16.7689	L	**387.9856**
C	**78.9797**	H	**264.5742**	M	**361.3919**
D	**269.1144**	I	**252.6746**	N	**302.8036**
E	**382.8156**	J	**327.6984**	O	**393.8255**

4.6 Response in Case of Multi-Position Faults: The Db4 wavelet transform has been tested for the multi-position faults. Tables 14-18 report the results for various multi-position faults. Figures 18-22 exemplifies the Db4 coefficients for various multi-position faults simulated at different locations. The fault factors are varied in each fault case. From Tables 14-18, it can be examined that the Db4 wavelet transform effectively detects the multi-position faults.
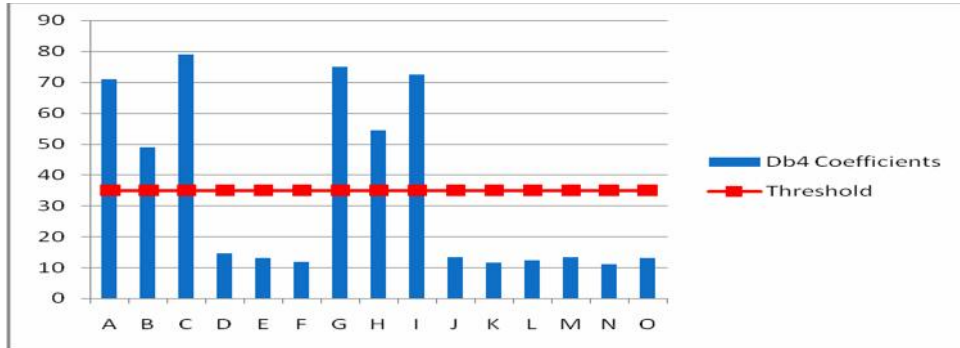

Figure 18. Db4 coefficients for 'ABC-g' fault at 40% and 'GHI-g' fault at 25% from bus-1

Table 14. Response of Db4WT for 'ABC-g' fault at 40% and 'GHI-g' fault at 25% from bus-1 with $R_f = R_g = 150$ and FIT = 0.1 seconds

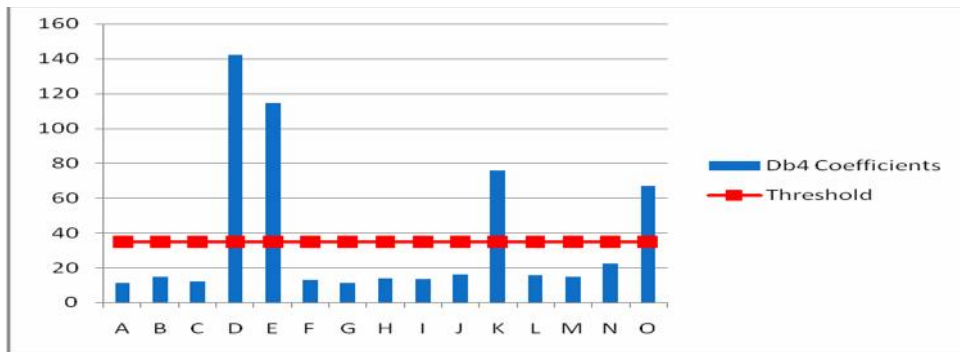| Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	**71.0509**	**F**	11.8240	**K**	11.4851
B	**49.0085**	**G**	**74.8668**	**L**	12.3672
C	**79.0031**	**H**	**54.3227**	**M**	13.1755
D	14.6216	**I**	**72.3910**	**N**	11.0796
E	13.0946	**J**	13.2363	**O**	12.9632

Figure 19. Db4 coefficients for 'DE-g' fault at 50%, 'K-g' fault at 35% and 'O-g' fault at 15% from bus-1

Table 15. Response of Db4WT for 'DE-g' fault at 50%, 'K-g' fault at 35% and 'O-g' fault at 15% from bus-1 with $R_f = R_g = 50$ and FIT = 0.3 seconds

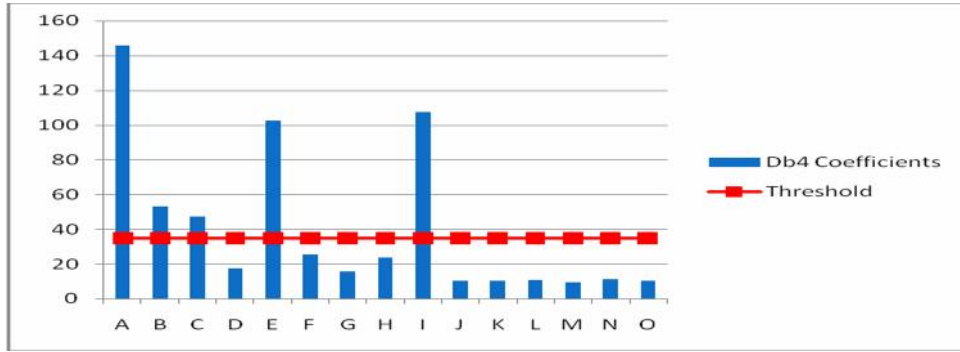| Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	11.1320	**F**	12.8357	**K**	**75.6832**
B	14.6882	**G**	11.0507	**L**	15.4747
C	11.9255	**H**	13.7271	**M**	14.5367
D	**142.2077**	**I**	13.5320	**N**	22.3039
E	**114.7391**	**J**	16.0629	**O**	**66.9315**

Figure 20. Db4 coefficients for 'ABC-g' fault at 7.5%, 'E-g' fault at 10% and 'I-g' fault at 12.5% from bus-1

Table 16. Response of Db4WT for 'A-g' fault at 7.5%, 'E-g' fault at 10% and 'I-g' fault at 12.5% from bus-1 with $R_f = R_g = 25$ and FIT = 0.25 seconds

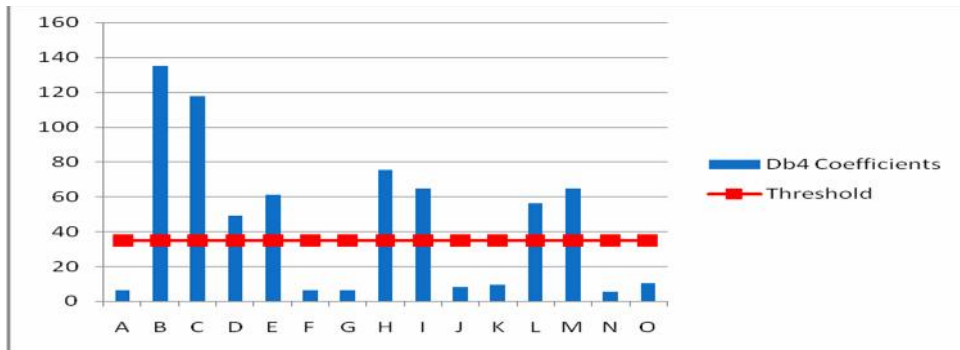| Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	**145.9290**	**F**	25.2851	**K**	10.2070
B	**52.9398**	**G**	15.6830	**L**	10.4928
C	**47.3652**	**H**	23.8180	**M**	9.4410
D	17.5109	**I**	**107.4855**	**N**	11.0584
E	**102.6604**	**J**	10.3579	**O**	10.2398

Figure 21. Db4 coefficient for 'BC-g' fault at 20%, 'DE-g' fault at 90%, 'HI-g' fault at 50% and 'LM-g' fault at 100% from bus-1

Table 17. Response of Db4WT for 'BC-g' fault at 20%, 'DE-g' fault at 90%, 'HI-g' fault at 50% and 'LM-g' fault at 100% from bus-1 with $R_f = R_g = 10$ and FIT = 0.1 seconds

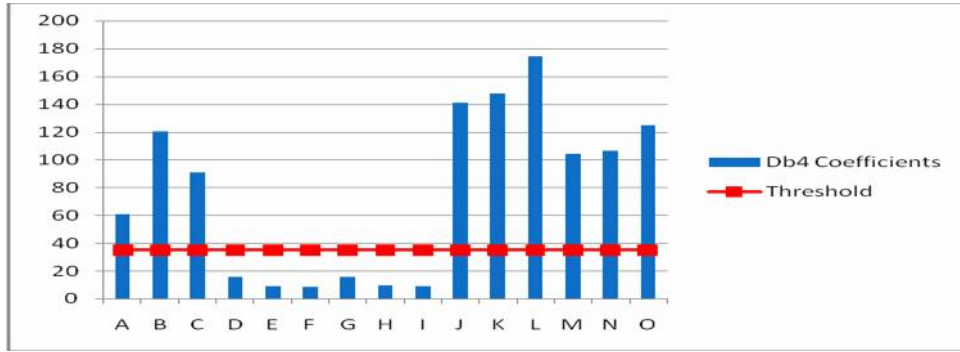| Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	6.1796	**F**	6.3126	**K**	9.3510
B	**134.8458**	**G**	6.3327	**L**	**56.0598**
C	**117.4917**	**H**	**75.5122**	**M**	**64.5881**
D	**49.0519**	**I**	**64.6127**	**N**	5.4429
E	**61.1726**	**J**	8.1871	**O**	10.1408

Figure 22. Db4 coefficients for 'ABC-g' fault at 85%, 'JKL-g' fault at 30% and 'MNO-g' fault at 45% from bus-1

Table 18. Response of Db4WT for 'ABC-g' fault at 85%, 'JKL-g' fault at 30% and 'MNO-g' fault at 45% from bus-1 with $R_f = R_g = 5$ and FIT = 0.35 seconds

Phase	Db4 Coefficients	Phase	Db4 Coefficients	Phase	Db4 Coefficients
A	**60.8858**	**F**	8.3997	**K**	**147.6284**
B	**120.4598**	**G**	15.6272	**L**	**174.4454**
C	**90.6065**	**H**	9.2306	**M**	**104.2370**
D	15.4310	**I**	8.7487	**N**	**106.1713**
E	9.1411	**J**	**141.1659**	**O**	**124.6398**

5. Conclusion

The daubechies-4 wavelet transform (Db4WT) is perceived to be very effectual under miscellaneous fault categories for the fifteen-phase transmission line. The first level Db4WT detail coefficients of the fifteen-phase fault currents are estimated. The fault factors of the simulation model are varied and it is revealed that the fault factors do not manipulate the fidelity of the Db4 wavelet transform. The results corroborate that the daubechies-4 wavelet transform has the competence to protect the fifteen-phase transmission line besides various fault categories. The future work is planned on execution of the proposed technique on a digital platform (preferably digital signal processor) and assessing the scheme for more practical conditions.

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