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PROTECTION SCHEME FOR DOUBLE CIRCUIT TRANSMISSION LINES BASED ON WAVELET TRANSFORM

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Abstract

In this paper, a wavelet transform based technique is introduced to detect and classify shunt faults in a double circuit transmission line which uses single end fault current data only. Simulation studies have been carried out on a double circuit transmission line test system using MATLAB for justification of the proposed technique. The simulation results of the proposed technique show that wavelet transform based proposed scheme correctly detects and classifies the shunt faults.

Keywords:

Wavelet Transform, Double Circuit Transmission Line Protection, Fault Detection and Classification

1. INTRODUCTION

Double circuit transmission lines have been far and wide utilized in power transmission systems due to their numerous advantages over single circuit transmission lines. The protection of double circuit transmission lines is a very complicated task. A variety of designs of double circuit transmission lines in combination with mutual coupling consequences create the protection of double circuit transmission line a demanding trouble. Various techniques to fault detection and classification on double circuit transmission lines have been introduced by several researchers. Along with the various schemes reported, wavelet transform in combination with multi-layer perceptron was used for short circuit fault location in double circuit transmission line [1]. A combination of wavelet transform and artificial neural network was used for the detection, classification and location of transmission line faults [2]. A New Harmony search algorithm was introduced for the classification of transmission line faults in [3]. A combination of wavelet entropy and artificial neural network was used for the classification of faults in series compensated transmission lines in [4]. Adaptive continuous wavelet transform based protection scheme was recommended for the differential protection of transmission line in [5]. A fault loop model had been introduced for the inter-circuit fault location on double circuit transmission line [6]. A protection scheme based on one end current measurement, for detecting the faulty circuit in parallel transmission lines was proposed in [7]. Wavelet transform was used for the location of faults in double circuit transmission line in [8]. Wavelet transform and artificial intelligence was used for the detection and classification of faults in EHV transmission lines [9]. A faulty phase selector, based on adaptive cumulative sum, was introduced in [10] for double circuit transmission lines protection. Artificial neural network was used for the location and classification of faults in double circuit transmission line [11]. A superimposed based scheme for the protection of series compensated transmission lines was reported in [12]. Wavelet transform was used for the protection of EHV teed circuits in [13]. Artificial neural network was used for the classification and distance location of phase to phase faults of double circuit transmission lines using one terminal data only [14]. A combination of wavelet transform and artificial neural network was used for the selection of faulty phase on double circuit transmission line [15]. In [16], fault classification of double circuit transmission line was done using artificial neural network. In [17], an adaptive non communication protection scheme for double circuit transmission line protection was introduced. Digital relaying method using synchronized phasor measurement units for double circuit transmission line protection was introduced in [18]. Wavelet transform was used in literatures [19]-[20] for the detection of high impedance arching faults and partial discharge image denoising.

This paper presents an application of wavelet transform for the detection and classification of shunt faults in double circuit transmission lines using single end fault current data only. The performance of the proposed scheme has been tested for different types of shunt faults. The simulation results demonstrate that shunt faults can be appropriately detected and classified by using the proposed technique.

This paper is organized as follows: section 2 of the paper is devoted to the simulation of double circuit transmission line using MATLAB software. Section 3 presents fault detection and classification technique based on wavelet transform. Section 4 describes the simulation results and discussions of the proposed technique. Conclusion of the proposed research work is presented in section 5. Section 6 presents list of symbols and abbreviations used in this paper.

2. DOUBLE CIRCUIT TRANSMISSION LINE

The single line diagram of proposed double circuit transmission line model is shown in Fig.1. The power system is composed of a 400kV, 50Hz double circuit transmission line of 200km in length, connected to three phase voltage source of 400kV at each end. The proposed simulation model of a double circuit transmission line is modeled and simulated with distributed parameter transmission line block using Simscape Power Systems toolbox of Matlab.

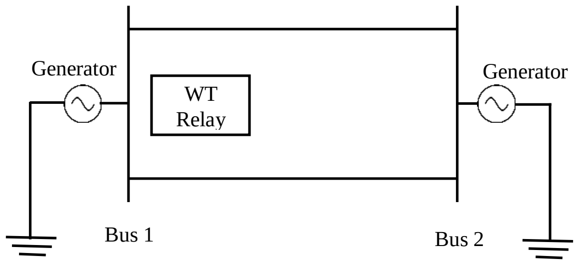

Fig.1. Single line diagram of proposed test system

List of Symbols and Abbreviations

A_1, B_1, C_1, A_2, B_2, C_2 - Phases of double circuit transmission line,

g - Ground,

DCTL- Double circuit transmission line,

A_{ia} - Norm of phase - A_1 or A_2,

A_{ib} - Norm of phase - B_1 or B_2,

A_{ic} - Norm of phase - C_1 or C_2,

$C_{ia}D_1$- Detail coefficients of phase - A_1 or A_2 at level-1,

$C_{ib}D_1$- Detail coefficients of phase - B_1 or B_2 at level-1,

$C_{ic}D_1$- Detail coefficients of phase - C_1 or C_2 at level-1,

L_f - Location of fault from bus-1 in kilometer,

R_f - Fault resistance in Ω,

R_g - Ground Resistance in Ω and

FIT - Fault inception time in seconds.

3. PROPOSED SCHEME

Wavelet transform [3], [4] is defined as:

$$W(j,k)=\sum_j\sum_k x(k)2^{-0.5j}\varphi\left(2^{-j}n-k\right) \quad (1)$$

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

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

$$y_{high}(k)=\sum_n x(n)g(2k-n) \quad (2)$$

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

$$y_{low}(k)=\sum_n x(n)h(2k-n) \quad (3)$$

The three phase current of both circuits of a double circuit transmission line is measured at the relay location i.e. at Bus-1 and then decomposed using ‘daubechies-5’ wavelet to obtain the magnitudes of approximate (A_1) and detail (D_1) coefficients at first level. Further, the magnitude of norm (D_1 norm) of D_1 coefficients is calculated. During no-fault, the magnitude of D_1 norm of three phase current of both circuits would have same magnitude. During the occurrence of a fault, the magnitude of D_1 norm of faulty phase would differ from that of no-fault condition. The magnitude of D_1 norm of a faulty phase would have magnitude greater than the healthy phase. The flow chart of proposed fault detection and classification technique for double circuit transmission line has been depicted in Fig.2.

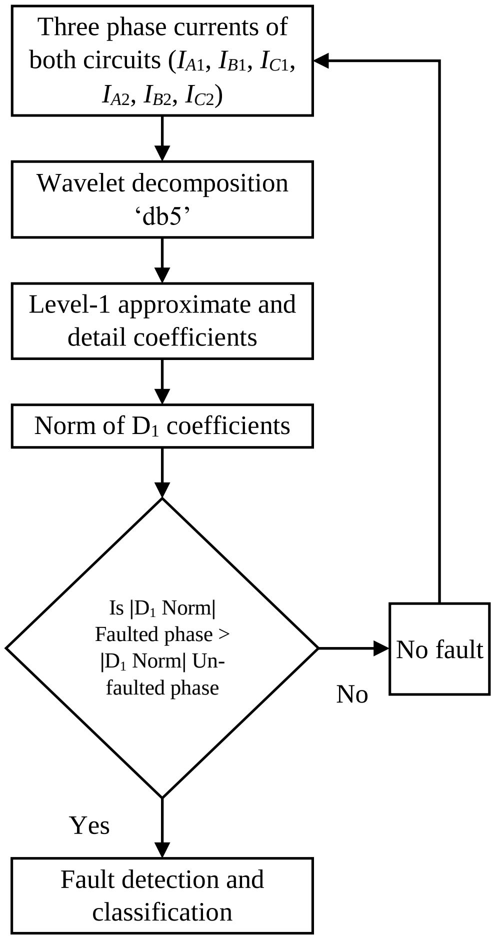

Fig.2. Proposed wavelet transform based fault detection and classification scheme

4. PERFORMANCE EVALUATION

To inspect the correctness of the proposed fault detection and classification technique, a widespread simulation studies have been carried out for various types of faults. Simulation results of the proposed technique have been discussed in the subsequent subsections.

4.1 PERFORMANCE DURING NO-FAULT IN CIRCUIT-1

The performance of the proposed technique is checked during no-fault in circuit-1 of a double circuit transmission line. The Fig.3 shows the three phase current of circuit-1 during no-fault. The Fig.4 depicts the D_1-norm of phase-A_1, B_1 and C_1 during no fault. The detail coefficients of phase-A_1, B_1 and C_1 of circuit-1 at level-1 during no-fault have been shown in Fig.5-Fig.7. Results of fault detection and classification for no-fault in circuit-1 are reported in Table.1. From Table.1, it is clear that the magnitudes of norm of phases-A_1, B_1 and C_1 have equal values and this explains that the double circuit transmission line has no fault in circuit-1.

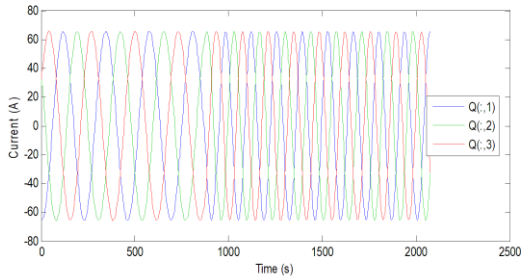

Fig.3. Three phase current of circuit-1 during no-fault

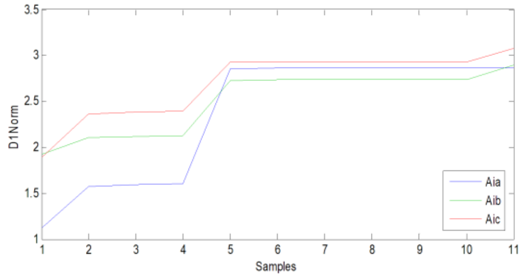

Fig.4. D_1 norm of phase-A_1, B_1, C_1 during no-fault

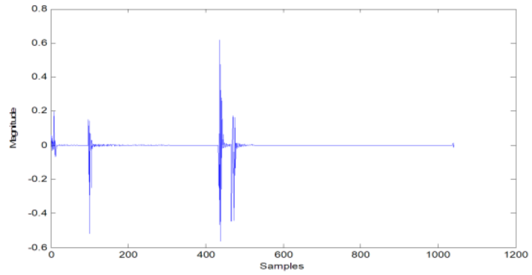

Fig.5. Phase-A_1 detail-1 coefficient during no-fault

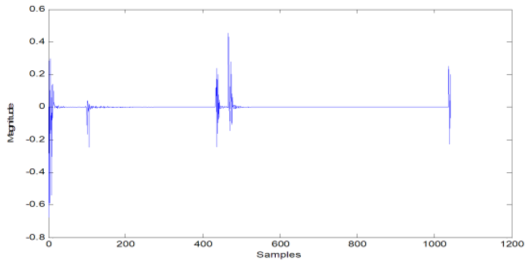

Fig.6. Phase-B_1 detail-1 coefficient during no-fault

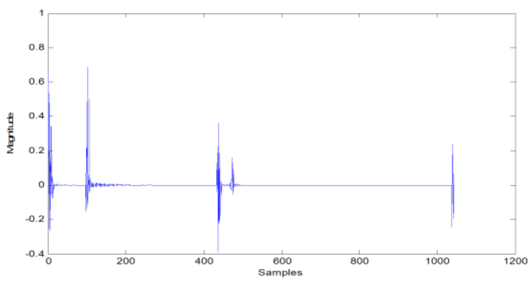

Fig.7. Phase-C_1 detail-1 coefficient during no-fault

4.2 PERFORMANCE DURING PHASE - 'A_1-G' FAULT IN CIRCUIT-1

With the plan of validating the suitability of the proposed method against single line to ground fault, the performance of the proposed technique is tested during phase-'A_1-g' fault in circuit-1 to check the effectiveness of wavelet transform. The Fig.8 depicts the three phase current of circuit-1 during phase-'A_1-g' fault at L_f = 100km, R_f = R_g = 0.001Ω and FIT = 0.01666s. The Fig.9 depicts the D_1-norm of phase-A_1, B_1 and C_1 during phase-'A_1-g' fault. The detail coefficients of phase-A_1, B_1 and C_1 of circuit-1 at level-1 during phase-'A_1-g' fault have been shown in Fig.10 - Fig.12. Results of fault detection and classification for phase-'A_1-g' fault are illustrated in Table.1. From Table.1, it is clear that the magnitude of D_1-norm of faulted phase-A_1 is greater than the magnitude of D_1 norm of un-faulted phases-B_1 and C_1 and this verifies that the double circuit transmission line has phase-'A_1-g' fault.

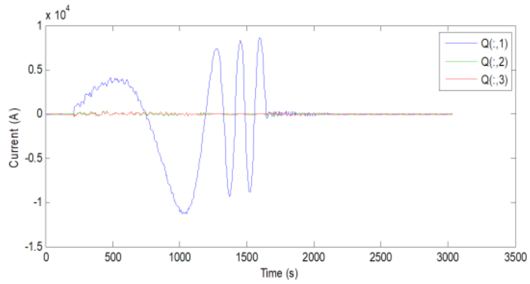

Fig.8. Three phase current during phase-'A_1-g' fault

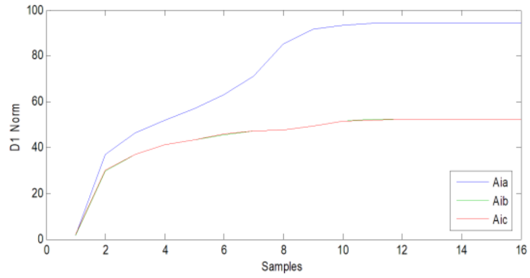

Fig.9. D_1 norm of phase- A_1, B_1, C_1 during phase-'A_1-g' fault

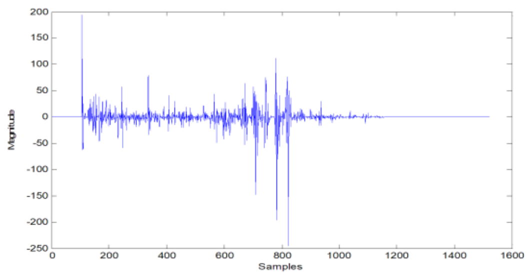

Fig.10. Phase-A_1 detail-1 coefficient during phase-'A_1-g' fault

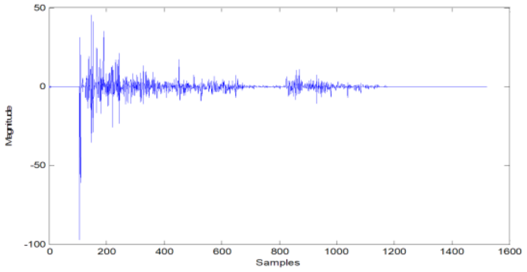

Fig.11. Phase-B_1 detail-1 coefficient during phase-‘A_1-g’ fault

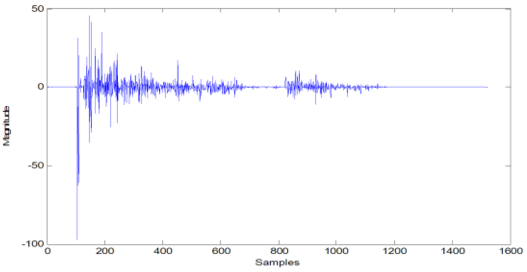

Fig.12. Phase-C_1 detail-1 coefficient during phase-‘A_1-g’ fault

4.3 PERFORMANCE DURING PHASE - ‘A_1B_1-G’ FAULT IN CIRCUIT-1

The performance of the proposed technique is tested during phase-‘A_1B_1-g’ fault. The Fig.13 depicts the three phase current of circuit-1 during phase-‘A_1B_1-g’ fault at L_f = 100 km, R_f = R_g = 0.001Ω and FIT = 0.01666 seconds. The Fig.14 depicts the D1-norm of phase-A_1, B_1 and C_1 during phase-‘A_1B_1-g’ fault. The detail coefficients of phase- A_1, B_1 and C_1 of circuit-1 at level-1 during phase-‘A_1B_1-g’ fault have been shown in Fig.15-Fig.17. Results of fault detection and classification for phase-‘A_1B_1-g’ fault are exemplified in Table.1. From Table.1, it is clear that the DCTL has phase-‘A_1B_1-g’ fault.

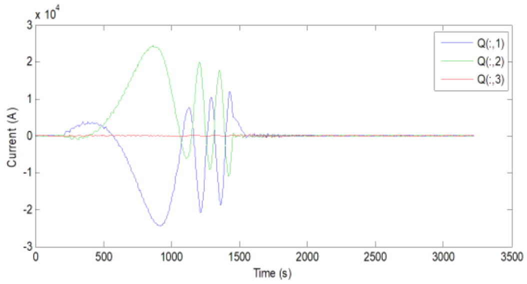

Fig.13. Three phase current during phase-‘A1B1-g’ fault

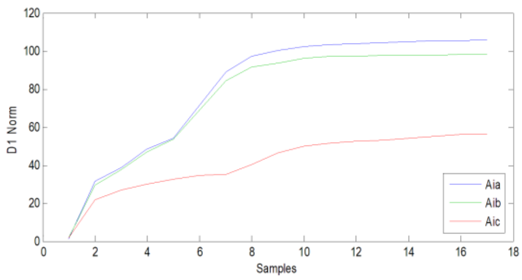

Fig.14. D1 norm of phase- A_1, B_1, C_1 during phase-‘A_1B_1-g’ fault

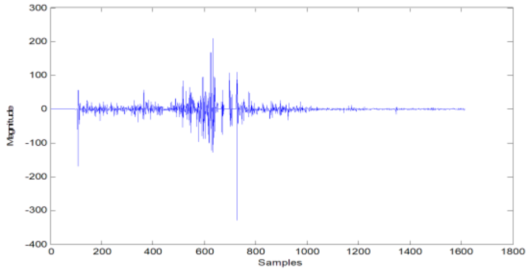

Fig.15. Phase-A_1 detail-1 coefficient during phase-‘A_1B_1-g’ fault

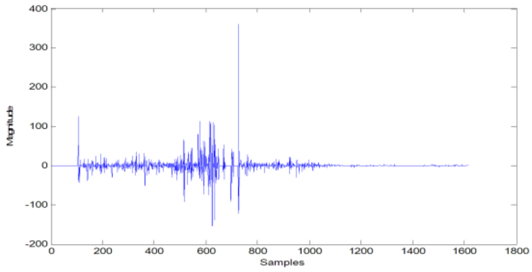

Fig.16. Phase-B_1 detail-1 coefficient during phase-‘A_1B_1-g’ fault

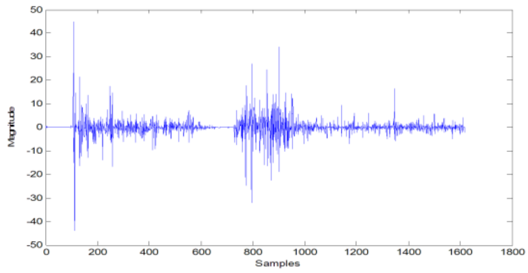

Fig.17. Phase-C1 detail-1 coefficient during phase-‘A1B1-g’ fault

4.4 PERFORMANCE DURING PHASE - ‘$A_1B_1C_1$-G’ FAULT IN CIRCUIT-1

The performance of the proposed technique is tested during phase-‘$A_1B_1C_1$-g’ fault in circuit-1 to check the effectiveness of proposed technique. The Fig.18 depicts the three phase current of circuit-1 during phase-‘$A_1B_1C_1$-g’ fault at L_f = 100 km, R_f = R_g = 0.001Ω and *FIT* = 0.01666 seconds. The Fig.19 depicts D_1-norm of phase-A_1, B_1 and C_1 during phase-‘$A_1B_1C_1$-g’ fault. The detail coefficients of phase-A_1, B_1 and C_1 of circuit-1 at level-1 during phase-‘$A_1B_1C_1$-g’ fault have been shown in Fig.20-Fig.22. Results of fault detection and classification for phase-‘$A_1B_1C_1$-g’ fault are shown in Table.1. From Table.1, it is clear that the magnitude of D_1-norm of phase-A_1, B_1 and C_1 during phase-‘$A_1B_1C_1$-g’ fault increases and this confirms that the double circuit transmission line has phase-‘$A_1B_1C_1$-g’ fault.

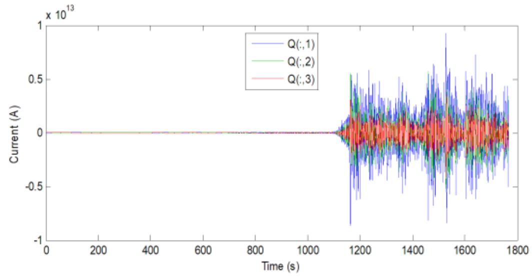

Fig.18. Three phase current during phase-‘$A_1B_1C_1$-g’ fault

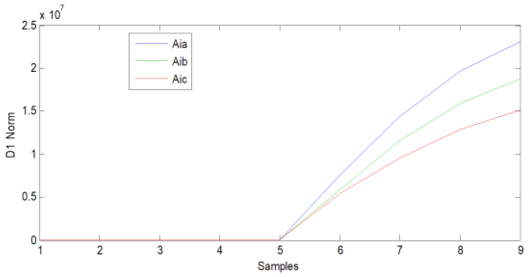

Fig.19. D_1 norm of phase-A_1, B_1, C_1 during phase-‘$A_1B_1C_1$-g’ fault

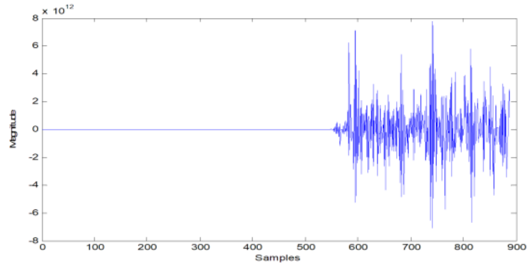

Fig.20. Phase-A_1 detail-1 coefficient during phase-‘$A_1B_1C_1$-g’ fault

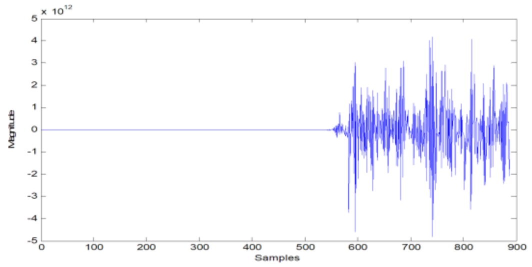

Fig.21. Phase-B_1 detail-1 coefficient during phase-‘$A_1B_1C_1$-g’ fault

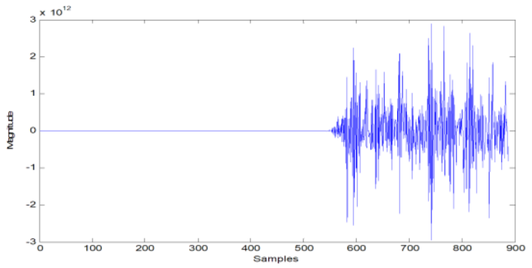

Fig.22. Phase-C_1 detail-1 coefficient during phase-‘$A_1B_1C_1$ -g’ fault

Table.1. Test Results of Fault Detection and Classification for Circuit-1

Output	Fault Type			
	No Fault	**A1-g**	**A1B1-g**	**A1B1C1-g**
A_{ia}	2.868	94.329	105.656	2.315×10^7
A_{ib}	2.893	52.489	98.1882	1.879×10^7
A_{ic}	3.074	52.471	56.2019	1.516×10^7
$C_{ia}D_1$	0.617	194.173	209.653	7.785×10^{12}
$C_{ib}D_1$	0.455	45.710	360.719	4.169×10^{12}
$C_{ic}D_1$	0.687	45.706	44.7273	2.895×10^{12}

4.5 PERFORMANCE DURING NO-FAULT IN CIRCUIT-2

With the aim of authenticating the correctness of the proposed technique during healthy operation of a double circuit transmission line, the performance of the proposed technique is evaluated during no-fault in circuit-2 of a double circuit transmission line. The Fig.23 shows the three phase current of circuit-2 during no-fault. The Fig.24 depicts D_1-norm of phase-A_2, B_2 and C_2 during no fault. The detail coefficients of phase-A_2, B_2 and C_2 of circuit-2 at level-1 during no-fault have been shown in Fig.25-Fig.27. Results of fault detection and classification for no-fault in circuit-2 are reported in Table.2. From Table.2, it is clear that, the magnitudes of norm of phase-A_2, B_2 and C_2 have equal values and this shows that the double circuit transmission line has no fault.

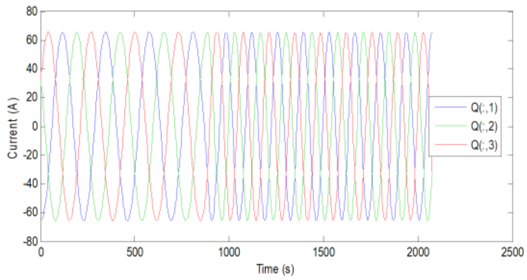

Fig.23. Three phase current during no-fault

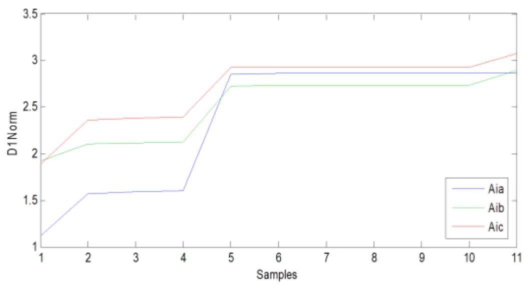

Fig.24. D_1 norm of phase-A_2, B_2, C_2 during no-fault

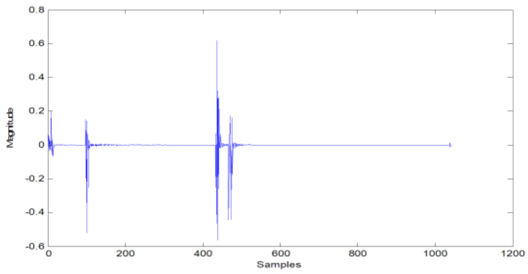

Fig.25. Phase-A_2 detail-1 coefficient during no-fault

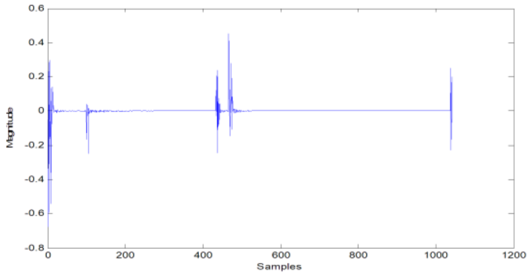

Fig.26. Phase-B_2 detail-1 coefficient during no-fault

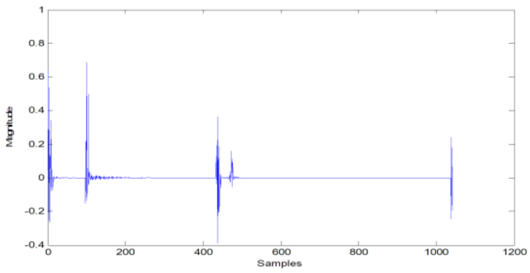

Fig.27. Phase-C_2 detail-1 coefficient during no-fault

4.6 PERFORMANCE DURING PHASE-'B2-G' FAULT IN CIRCUIT-2

To check the effectiveness of the proposed technique during single phase to ground fault, the performance of the proposed technique is tested with phase-'B_2-g' fault in circuit-2. The Fig.28 depicts the three phase current of circuit-2 during phase-'B_2-g' fault at L_f = 100 km, $R_f = R_g$ = 0.001Ω and *FIT* = 0.01666 seconds. The Fig.29 illustrates D_1-norm of phase-A_2, B_2 and C_2 during phase-'B_2-g' fault. The detail coefficients of phase-A_2, B_2 and C_2 of circuit-2 at level-1 during phase-'B_2-g' fault have been shown in Fig.30-32. Results of fault detection and classification for phase-'B2-g' fault are reported in Table.2. From Table.2, it can be seen that, the magnitude of D_1-norm of phase-B2 is greater than the magnitude of D_1 norm of phase A_2 and C_2 and this shows that the double circuit transmission line has phase-'B_2-g' fault in the circuit-2.

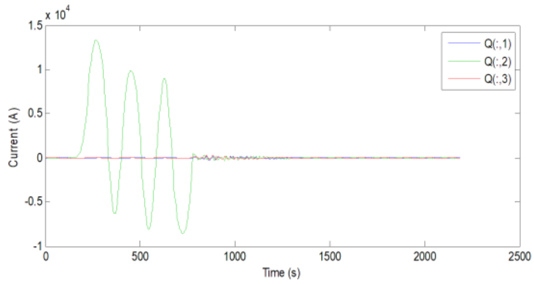

Fig.28. Three phase current during phase-'B_2-g' fault

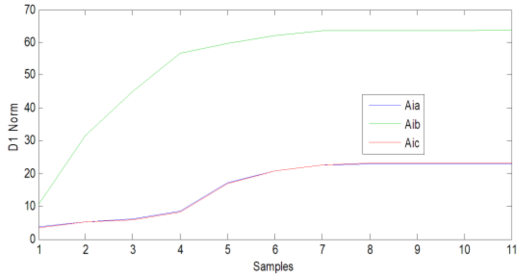

Fig.29. D_1 norm of phase-A_2, B_2, C_2 during phase-'B_2-g' fault

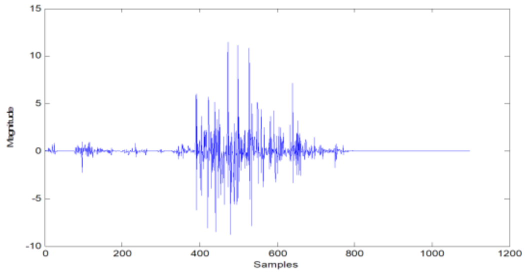

Fig.30. Phase-A_2 detail-1 coefficient during phase-'B_2-g' fault

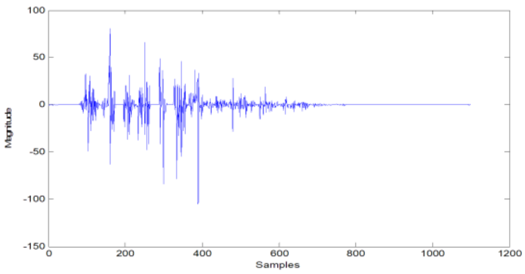

Fig.31. Phase-B_2 detail-1 coefficient during phase-'B_2-g' fault

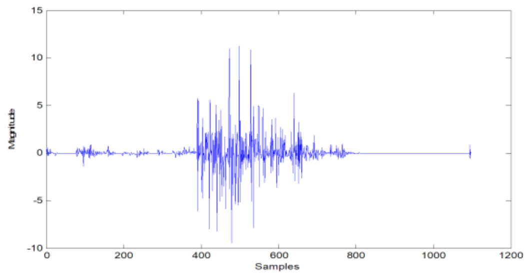

Fig.32. Phase-C_2 detail-1 coefficient during phase-'B_2-g' fault

4.7 PERFORMANCE DURING PHASE-‘B_2C_2-G’ FAULT IN CIRCUIT-2

With the plan of authenticating the suitability of the proposed method against double line to ground fault, the performance of the proposed technique is observed with phase-‘B_2C_2-g’ in circuit-2 of a double circuit transmission line. The Fig.33 shows the three phase current of circuit-2 during phase-‘B_2C_2-g’ fault at L_f = 100 km, $R_f = R_g$ = 0.001Ω and FIT = 0.01666 seconds. The Fig.34 depicts D1-norm of phase-A_2, B_2 and C_2 during phase-‘B_2C_2-g’ fault. The detail coefficients of phase-A_2, B_2 and C_2 of circuit-2 at level-1 during phase-‘B_2C_2-g’ fault have been shown in Fig.35-Fig.37. Results of fault detection and classification for phase-‘B_2C_2-g’ fault are shown in Table.2. From Table.2, it is clear that, the magnitude of D_1-norm of phase-B_2 and C_2 is greater than the magnitude of D_1 norm of phase-A_2 and this proves that the DCTL has phase-‘B_2C_2-g’ fault.

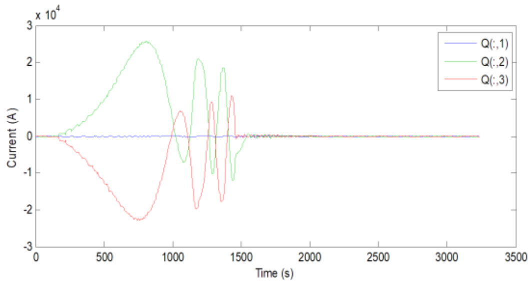

Fig.33. Three phase current during phase-‘B_2C_2-g’ fault

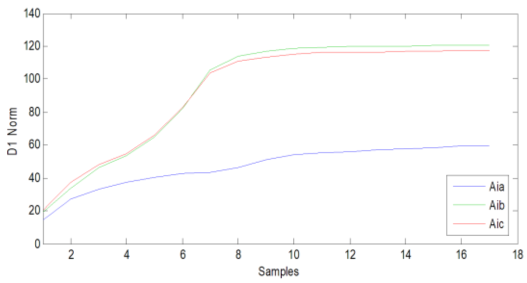

Fig.34. D_1 norm of phase-A_2, B_2, C_2 during phase-‘B_2C_2-g’ fault

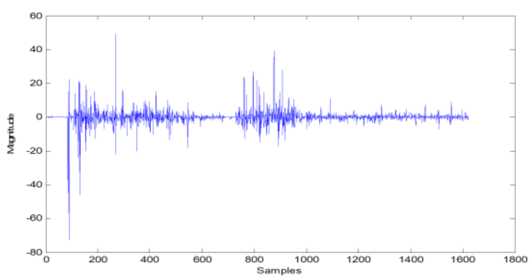

Fig.35. Phase-A_2 detail-1 coefficient during phase-‘B_2C_2-g’ fault

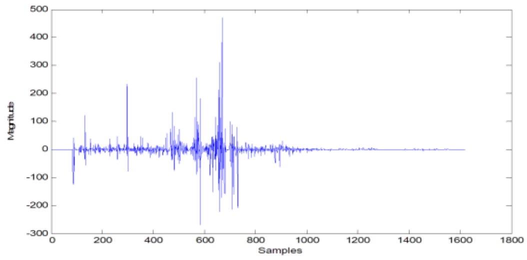

Fig.36. Phase-B_2 detail-1 coefficient during phase-‘B_2C_2-g’ fault

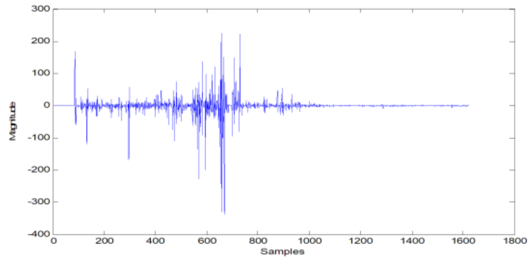

Fig.37. Phase-C_2 detail-1 coefficient during phase-‘B_2C_2-g’ fault

4.8 PERFORMANCE DURING PHASE-‘$A_2B_2C_2$-G’ FAULT IN CIRCUIT-2

The performance of the proposed technique is tested during phase-‘$A_2B_2C_2$-g’ fault in circuit-2 to check the effectiveness of proposed technique. The Fig.38 depicts the three phase current of circuit-2 during phase- ‘$A_2B_2C_2$-g’ fault at L_f = 100 km, $R_f = R_g$ = 0.001Ω and *FIT* = 0.01666 seconds. The Fig.39 depicts D_1-norm of phase-A_2, B_2 and C_2 during phase-‘$A_2B_2C_2$-g’ fault. The detail coefficients of phase-A2, B2 and C2 of circuit-2 at level-1 during phase-‘$A_2B_2C_2$-g’ fault have been shown in Fig.40-Fig.42. Results of fault detection and classification for phase-‘$A_2B_2C_2$-g’ fault are shown in Table.2. From Table.2, it can be observed that, the magnitude of D_1-norm of phase-A_2, B_2 and C_2 during phase-‘$A_2B_2C_2$-g’ fault increases and this confirms that the double circuit transmission line has phase-‘$A_2B_2C_2$-g’ fault.

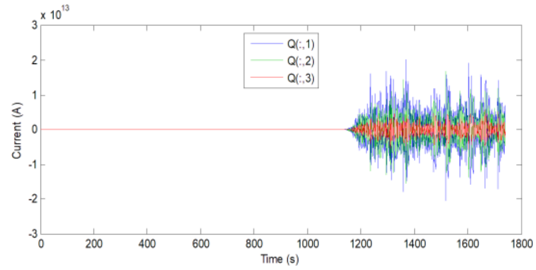

Fig.38. Three phase current during phase-‘$A_2B_2C_2$-g’ fault

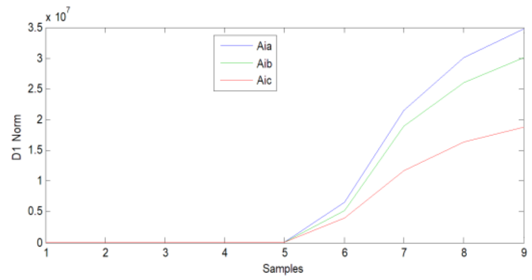

Fig.39. D1 norm of phase-A_2, B_2, C_2 during phase-‘$A_2B_2C_2$-g’ fault

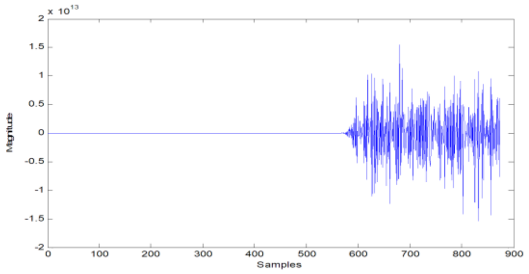

Fig.40. Phase-A_2 detail-1 coefficient during phase-‘$A_2B_2C_2$-g’ fault

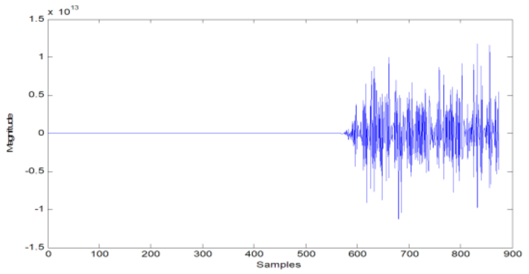

Fig.41. Phase-B_2 detail-1 coefficient during phase-‘$A_2B_2C_2$-g’ fault

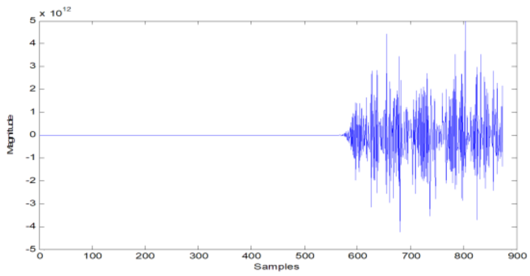

Fig.42. Phase-C_2 detail-1 coefficient during phase-‘$A_2B_2C_2$-g’ fault

Table.2. Test Results of Fault Detection and Classification for Circuit-2

Output	**Fault Type**			
	No Fault	**B_2-g**	**B_2C_2-g**	**$A_2B_2C_2$-g**
A_{ia}	2.868	23.014	59.520	3.482×10^{7}
A_{ib}	2.893	63.721	120.794	3.010×10^{7}
A_{ic}	3.074	23.104	117.384	1.879×10^{7}
$C_{ia}D_1$	0.617	11.449	49.3391	1.548×10^{13}
$C_{ib}D_1$	0.455	80.814	469.180	1.178×10^{13}
$C_{ic}D_1$	0.687	11.271	225.498	4.989×10^{12}

5. CONCLUSION

In this paper, wavelet transform based technique has been introduced for the detection and classification of shunt faults in double circuit transmission line. Three phase current signals of both the circuits are processed using ‘daubechies-5’ wavelet to extract the approximate and high frequency detail coefficients at level-1. The main advantage of proposed technique is that it uses fault current data of single end only. The simulation results demonstrate that the proposed technique correctly detects and classifies the fault and identifies the faulty phase accurately.

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