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Wavelet Transform Approach for Fault Detection of Three Phase Transmission Line Compensated with Series Capacitor

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Abstract **- This paper proposes fault detection technique for the protection of series capacitor compensated three phase transmission line using wavelet transform. Three phase series capacitor compensated transmission line is modeled and the proposed fault detection technique has been developed and tested using Simscape Power Systems toolbox of MATLAB software. Proposed scheme is tested by variations of parameters like fault type, fault resistance, ground resistance, fault location and fault inception time. The test results confirmed successful detection of fault.**
Keywords: **Wavelet transform, fault detection and series compensated transmission line.**

I. INTRODUCTION

Protection of transmission lines using a rapid and consistent fault detection scheme is a significant requirement in electrical power transmission and distribution networks to maintain dependable supply of power flow. For the protection of transmission line from faults, many researchers proposed numerous techniques. Along with the numerous techniques illustrated so far, discrete wavelet transform based relaying scheme was used by the researchers in [1]. Various other techniques such as hybrid wavelet transform and artificial neural network, support vector machine, fuzzy logic, naïve based classifier, Hilbert huang transform and mathematical morphological filter also used for transmission line protection. Artificial neural network based technique was introduced for the protection of three phase transmission line in [2]. Wavelet transform in combination with artificial neural network was used for the transmission line fault classification in [3]. Wavelet singular entropy was used for the detection and classification of transmission line faults in [4]. A three phase series compensated transmission line protection scheme based on fuzzy logic had been proposed in [5]. Support vector machine had been introduced for the detection, classification and location of HVDC transmission line faults in [6]. In [7] a combined scheme based on wavelet transform and artificial neural network had been introduced for the location of faults in thyristor controlled series capacitor compensated three phase transmission line. Artificial neural network based transmission line fault detection and classification scheme had been proposed in [8]. In [9] combination of discrete wavelet transform and naïve bayes classifier had been used for fault classification in double circuit transmission line. Wavelet transform in combination with artificial neural network had been proposed for the detection and classification of faults in EHV transmission line [10]. Wavelet transform had been used for the protection of teed transmission line network in [11]. Xiao'an Qin, *et al.* in [12] used Hilbert huang transform based approach for the protection of transmission line with the help of travelling waves. Hilbert huang transform in combination with morphological filter was used for selecting a faulty line in distribution network [13]. X.Z dong, *et al.* in [14] proposed a protection scheme for ultra-high voltage transmission line protection which was based on adaptive directional relay. Wavelet transform was used for the protection of parallel transmission in [15].

In this paper, wavelet transform based fault detection technique is proposed for a three phase series capacitor compensated transmission line protection. The performance of proposed technique has been tested at different locations on transmission line with variation in fault type, fault resistance, ground resistance, and fault inception time. This paper is organized as follows: section II of the paper is devoted to the simulation of three phase series capacitor compensated transmission line using MATLAB software. Section III presents wavelet transform based fault detection technique. Section IV illustrates the analysis of simulation results and brief discussions associated with the results. Conclusion of the proposed research work is presented in section V.

II. SIMULATION STUDIES

The power transmission system studied is represented in Fig. 1. The power system consists of 400 kV, 50 Hz series capacitor compensated transmission line bifurcated into two sections each of 100 km length connected between three phase source and load. The three phase series capacitor compensated transmission line model is modeled and simulated using Simcape Power Systems toolbox of MATLAB software.

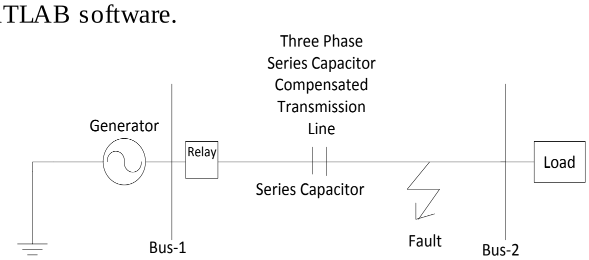

Fig. 1 Single line diagram of proposed power system

III. PROPOSED TECHNIQUE

In the proposed work, wavelet transform is used for the detection of series compensated transmission line faults by analyzing the measured three phase fault current using daubechies-4 wavelet. Fault detection has been done by calculating sum of square of detail coefficients of three phase fault current at level-1. The phase is called to be as faulty if the magnitude of sum of square of detail coefficients of faulted phase is found larger than the magnitude of sum of square of detail coefficients of an un-faulted phase. The proposed fault detection scheme is demonstrated in Fig. 2.

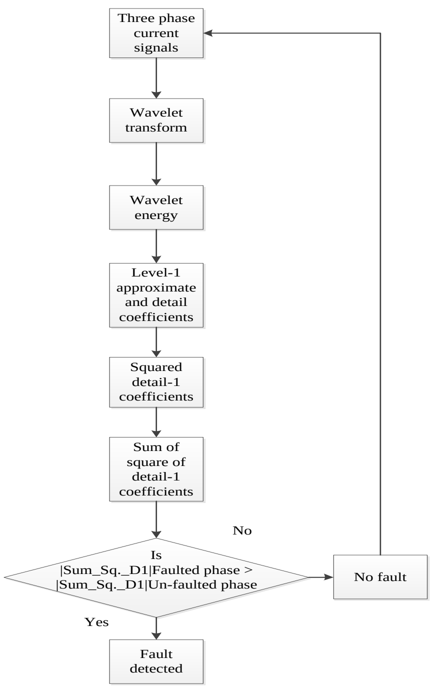

Fig. 2 Proposed fault detection technique

IV. SIMULATION RESULTS AND DISCUSSIONS

The performance of the proposed technique has been tested for numerous fault cases. The performance of the proposed technique is checked with variations done in fault type, fault resistance, fault inception time, ground resistance and fault location. Simulation results of the proposed work have been described in the subsequent subsections.

A. Performance during Fault Type Variation

The performance of the proposed scheme is examined for fault type variation. The three phase current during phase-'AB-g' fault occurring at 50% from bus-1 is shown in Fig. 3. The approximate-1, detail-1 and squared detail-1 coefficients of phase – A, B and C for the duration of phase-'AB-g' fault are shown in Fig. 4, 5 and 6. The procedure of fault detection using wavelet transform during phase- 'AB-g' fault occurring at 50% from bus-1 at FIT = 0.01667 seconds with R_f= 0.001Ω and R_g = 0.001Ω can be seen in Fig. 4-6.

The performance of the proposed scheme is examined for several fault type occurring at 50% from bus-1 with R_f= 0.001Ω, R_g = 0.001Ω and FIT = 0.01667 seconds and the test results for phase-'AB-g' fault are depicted in Table I. From Table I, it can be seen that the magnitude of sum of square of detail-1 coefficients of faulted phase is larger than the magnitude of sum of square of detail-1 coefficients of un-faulted phase and this exemplifies that the proposed wavelet transform based fault detection scheme effectively detects the fault. Based on a variety of test results, it is established that the variation in fault type has no major effect on the relay performance.

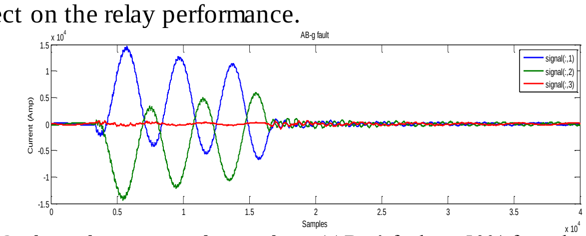

Fig. 3 Three phase current during phase-'AB-g' fault at 50% from bus-1

TABLE I RELAY OUTPUT FOR PHASE-'AB-G' FAULT AT 50%

Outputs	Phases		
	A	B	C
Approximate Coefficient	2.0626*10^4	8.0741*10^3	827.5873
Detail Coefficient	202.1464	329.1807	30.8882
Energy	99.2150	99.2498	86.7532
Squared Detail coefficients	3.6518*10^4	5.9069*10^4	499.7296
Sum of Square of Detail coefficients	4.1567*10^5	4.1979*10^5	1.9031*10^4

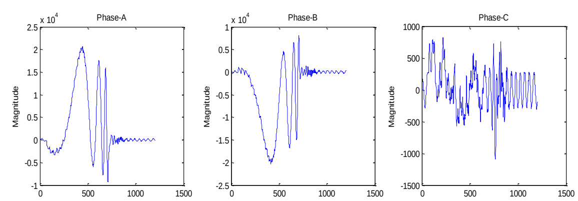

Fig. 4 Approximate-1 coefficient during phase- 'AB-g' fault

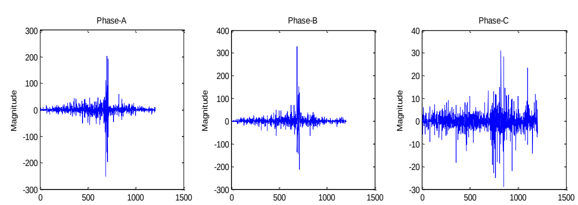

Fig. 5 Detail-1 coefficient during phase- 'AB-g' fault

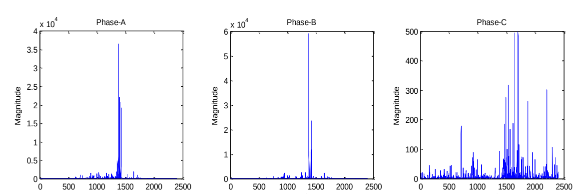

Fig. 6 Squared detail-1 coefficient during phase-'AB-g' fault

B. Performance during Fault Location Variation

By simulating the test system for various fault cases, the performance of the proposed scheme is tested for fault location variation. The three phase current during phase-'A-g' fault occurring at 40% from bus-1 at FIT = 0.01667 seconds is illustrated in Fig. 7. The approximate-1, detail-1 and squared detail-1 coefficients of phase – A, B and C for the duration of phase-'A-g' fault at 40% from bus-1 are shown in Fig. 8, 9 and 10. The method of fault detection using wavelet transform during phase- 'A-g' fault occurring at 40% from bus-1 at FIT = 0.01667 seconds with R_f= 0.001Ω and R_g = 0.001Ω can be seen in Fig. 8-10. The performance of the proposed scheme is observed for numerous fault locations from bus-1 with R_f= 0.001Ω, R_g = 0.001Ω and FIT = 0.01667 seconds and the test results for phase-'A-g' fault are depicted in Table II. From Table II, it can be definitely seen that the magnitude of sum of square of detail-1 coefficients of the faulted phase is larger than the magnitude of sum of square of detail-1 coefficients of un-faulted phase and this illustrates that the proposed wavelet transform based fault detection scheme efficiently detects the fault. Based on a variety of test results, it is recognized that the variation in fault location has no major effect on the relay performance.

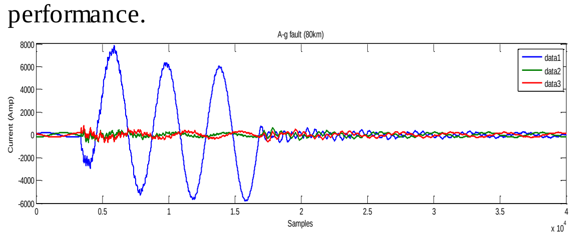

Fig. 7 Three phase current during phase-'A-g' fault at 40% from bus-1

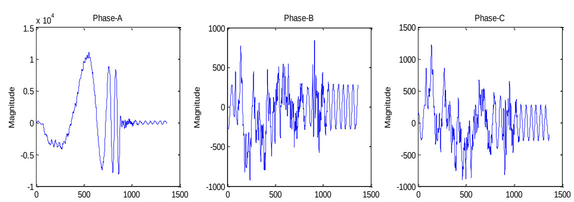

Fig. 8 Approximate-1 coefficient during phase- 'A-g' fault at 40% from bus-1

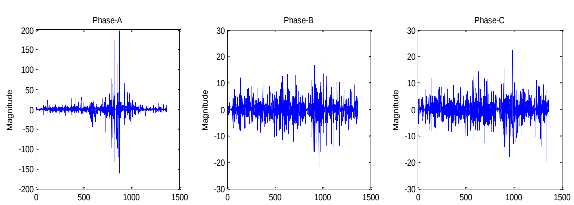

Fig. 9 Detail-1 coefficient during phase- 'A-g' fault at 40% from bus-1

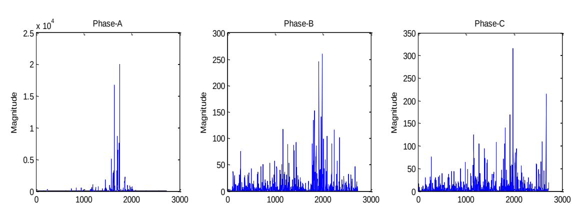

Fig. 10 Squared detail-1 coefficient during phase-'A-g' fault at 40% from bus-1

TABLE II RELAY OUTPUT FOR PHASE-'A-G' FAULT AT 40%

Outputs	Phases		
	A	**B**	**C**
Approximate Coefficient	1.1091*10^4	838.9102	1.2333*10^3
Detail Coefficient	198.1886	20.2473	22.3636
Energy	99.3574	83.9897	87.7811
Squared Detail coefficients	2.0080*10^4	260.5443	316.0240
Sum of Square of Detail coefficients	2.8707*10^5	1.5827*10^4	1.6122*10^4

C. Performance during Fault Resistance Variation

Simulation studies are conducted to examine the performance of the proposed scheme for fault resistance variation. The three phase current during phase-'AB-g' fault occurring at 50% from bus-1 with R_f = 40Ω is shown in Fig. 11. The approximate-1, detail-1 and squared detail-1 coefficients of phase – A, B and C for the period of phase-'AB-g' fault are shown in Fig. 12, 13 and 14. The method of fault detection using wavelet transform during phase- 'AB-g' fault occurring at occurring 50% from bus-1 at FIT = 0.01667 seconds with R_f= 40Ω and R $_g$ = 0.001Ω can be seen in Fig. 12-14. The performance of the proposed scheme is tested for various fault resistances during phase-'AB-g' fault occurring at 50% from bus-1 with R_f varied from 5Ω to 100Ω, R_g = 0.001Ω and FIT = 0.01667 seconds and the test results can be depicted in Table III. From Table III, it can be definitely seen that the magnitude of sum of square of detail-1 coefficients of faulted phase is larger than the magnitude of sum of square of detail-1 coefficients of un-faulted phase and this exemplifies that the proposed wavelet transform based fault detection scheme effectively detects the fault. Based on a variety of simulation results, it is established that the fault resistance variation has no major effect on the performance of the relay.

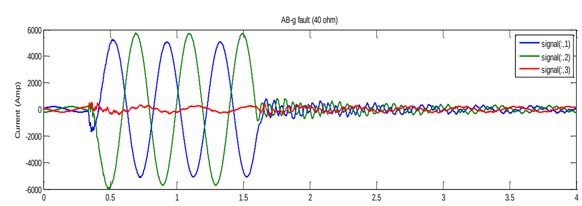

Fig. 11 Three phase current during phase-'AB-g' fault at 50% from bus-1 with R_f = 40Ω

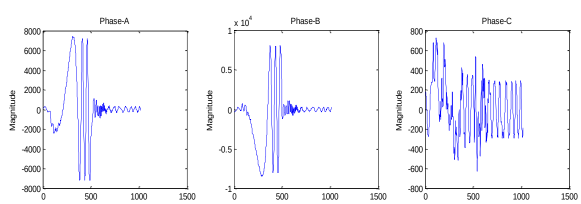

Fig. 12 Approximate-1 coefficient during phase- 'AB-g' fault at 50% from bus-1 with R_f = 40Ω

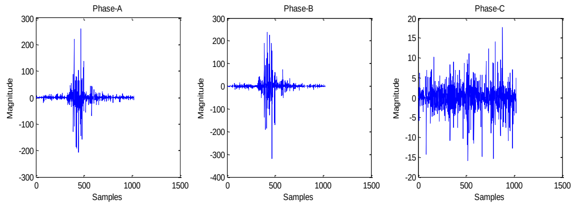

Fig. 13 Detail-1 coefficient during phase- 'AB-g' fault at 50% from bus-1 with $R_f = 40\Omega$

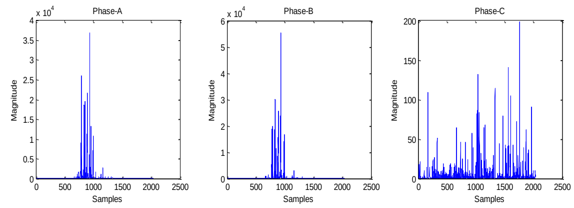

Fig. 14 Squared detail-1 coefficient during phase- 'AB-g' fault at 50% from bus-1 with $R_f = 40\Omega$

TABLE III RELAY OUTPUT FOR PHASE-'AB-G' FAULT WITH $R_F = 40\Omega$

Outputs	Phases		
	A	**B**	**C**
Approximate Coefficient	7.3991*10^3	8.0977*10^3	727.3885
Detail Coefficient	259.9956	237.9854	17.5993
Energy	97.3958	97.8925	85.4265
Squared Detail coefficients	3.6982*10^4	5.5434*10^4	198.4912
Sum of Square of Detail coefficients	5.3143*10^5	7.5918*10^5	9.6634*10^3

D. Performance during Fault Inception Time Variation

Simulation studies are carried out to look over the performance of the proposed scheme for fault inception time variation. The three phase current for the period of phase-'C-g' fault occurring at 50% from bus-1 with FIT=0.04666 seconds is shown in Fig. 15. The approximate-1, detail-1 and squared detail-1 coefficients of phase – A, B and C for the duration of phase-'C-g' fault are shown in Fig. 16, 17 and 18. The process of fault detection using wavelet transform during phase- 'C-g' fault occurring at 50% from bus-1 at FIT = 0.04666 seconds with R_f= 0.001Ω and R_g = 0.001Ω can be seen in Fig. 16-18. The performance of the proposed scheme is examined for various fault inception time during phase-'C-g' fault occurring at 50% from bus-1 with R_f= 0.001Ω, R_g = 0.001Ω and FIT varied from 0.01833 seconds to 0.05666 seconds and the test results of phase-'C-g' fault can be depicted in Table IV. From Table IV, it can be definitely seen that the magnitude of sum of square of detail-1 coefficients of faulted phase is larger than the magnitude of sum of square of detail-1 coefficients of un-faulted phase and this illustrates that the proposed wavelet transform based fault detection scheme effectively detects the fault. Based on a variety of test results, it is recognized that the variation in fault inception time has no key effect on the performance of the relay.

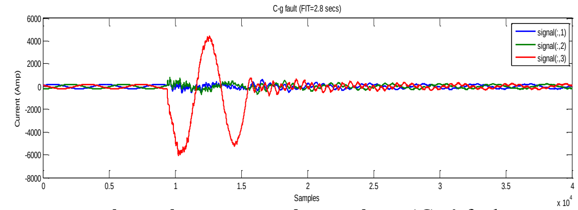

Fig. 15 Three phase current during phase-'C-g' fault at 50% from bus-1 with FIT=0.04666 seconds

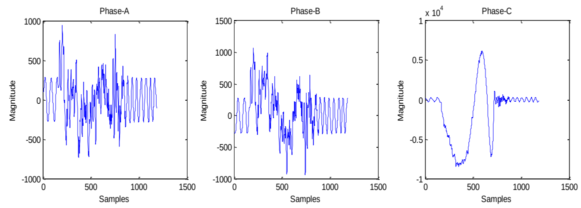

Fig. 16 Approximate-1 coefficient during phase- 'C-g' fault at 50% from bus-1 with FIT=0.04666 seconds

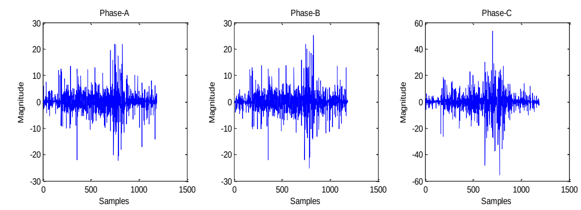

Fig. 17 Detail-1 coefficient during phase- 'C-g' fault at 50% from bus-1 with FIT=0.04666 seconds

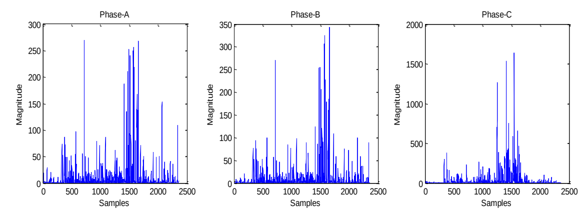

Fig. 18 Squared detail-1 coefficient during phase- 'C-g' fault at 50% from bus-1 with FIT=0.04666 seconds

TABLE IV RELAY OUTPUT FOR PHASE-'C-G' FAULT WITH FIT=0.04666 SECONDS

Outputs	Phases		
	A	**B**	**C**
Approximate Coefficient	945.8217	1.0623*10^3	6.1861*10^3
Detail Coefficient	21.8997	25.2083	53.2766
Energy	78.4197	86.0764	99.7076
Squared Detail coefficients	269.8253	343.4662	1.6405*10^3
Sum of Square of Detail coefficients	1.7936*10^4	1.8762*10^4	5.8479*10^4

E. Performance during Ground Resistance Variation

The performance of the proposed scheme is tested for ground resistance variation. The three phase current for the duration of phase-'BC-g' fault occurring at 50% from bus-1 with R_g = 35Ω is shown in Fig. 19. The approximate-1, detail-1 and squared detail-1 coefficients of phase – A, B and C for the duration of phase-'BC-g' fault are shown in

Fig. 20, 21 and 22. The procedure of fault detection using wavelet transform during phase- 'BC-g' fault occurring at 50% from bus-1 at FIT = 0.01667 seconds with R_f= 0.001Ω and R_g = 35Ω can be seen in Fig. 20-22. The performance of the proposed scheme is checked up for quite a few ground resistances for the duration of phase-'BC-g' fault at 50% from bus-1 with R_g varied from 2Ω to 95Ω, R_f = 0.001Ω and FIT = 0.01667 seconds and the test results can be seen in Table V.

From Table V, it can be positively seen that the magnitude of sum of square of detail-1 coefficients of faulted phase is larger than the magnitude of sum of square of detail-1 coefficients of un-faulted phase and this demonstrates that the proposed wavelet transform based fault detection scheme successfully detects the fault. Based on extensive simulation results, it is established that the variation in ground resistance has no major effect on the relay performance.

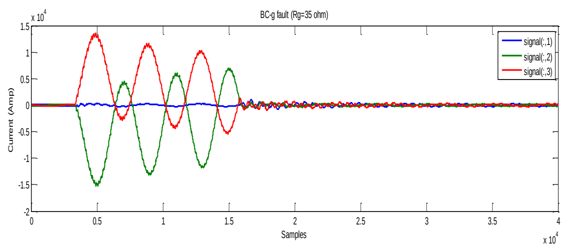

Fig. 19 Three phase current during phase-'BC-g' fault at 50% from bus-1 with R_g = 35Ω

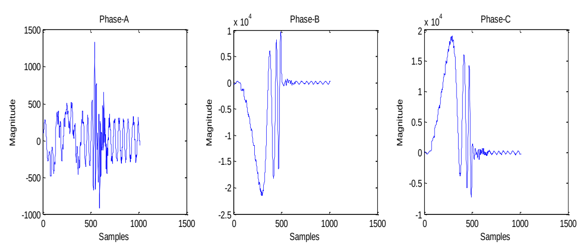

Fig. 20 Approximate-1 coefficient during phase- 'BC-g' fault at 50% from bus-1 with R_g = 35Ω

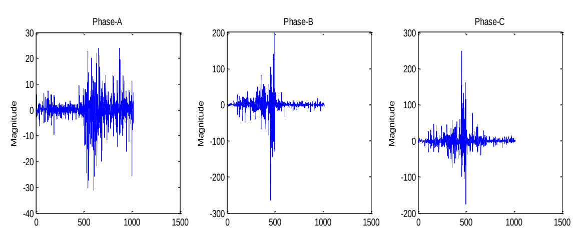

Fig. 21 Detail-1 coefficient during phase- 'BC-g' fault at 50% from bus-1 with R_g = 35Ω

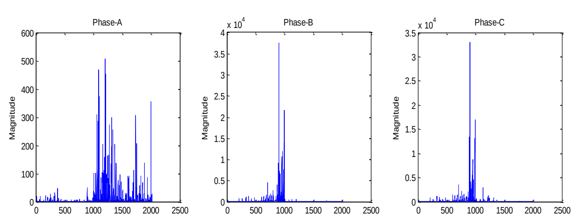

Fig. 22 Squared detail-1 coefficient during phase- 'BC-g' fault at 50% from bus-1 with R_g = 35Ω

TABLE V RELAY OUTPUT FOR PHASE-'BC-G' FAULT WITH R_G=35Ω

Outputs	Phases		
	A	B	C
Approximate Coefficient	1.3313*10^3	9.6179*10^3	1.9051*10^4
Detail Coefficient	23.8335	198.7211	248.0560
Energy	67.2423	99.3940	99.3711
Squared Detail coefficients	505.4885	3.7562*10^4	3.2968*10^4
Sum of Square of Detail coefficients	2.3997*10^4	4.5519*10^5	4.0816*10^5

V. CONCLUSION

Wavelet transform based fault detection technique for three phase series capacitor compensated transmission line is established to be very useful under numerous fault situations. The performance of the proposed technique is authenticated considering variation in fault parameters like fault type, fault location, fault resistance, fault inception time and ground resistance. The main advantage of using the proposed technique is that it uses the fault data measured at single end only. Simulation results demonstrate that the proposed technique accurately detects the fault and identifies the faulty phase for the entire situations tested.

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