Six Phase Transmission Line Protection Using Wavelet Transform

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***Abstract*— In this paper, a novel concept of wavelet transform-based technique is introduced to detect various types of shunt faults and identify the faulty phases in a six phase transmission line. The information of fault contained in the six phase current signals is captured using wavelet transform. After that, the fifth level detail coefficients of six phase current signals are calculated, which aspires at detecting the fault and identifying the faulty phase. The simulation results of the proposed technique show that the proposed fault detection technique effectively detects all types of shunt faults. Faulted phase is identified with 100% accuracy, and the efficacy of proposed technique is validated for various symmetrical and unsymmetrical faults, and variations in the values of fault resistance, fault inception time and fault location. The proposed scheme offers primary protection to the whole length of six phase transmission line using data recorded at relaying point only. Some special fault cases such as inter-circuit faults, cross-country faults and transforming faults are also taken into account.**

Keywords—fault detection, faulty phase identification, six phase transmission line protection, wavelet transform.

I. INTRODUCTION

The present era has observed an increase in the electricity requirement and to sustain the growing need of electricity, the power transfer capability of active power transmission system should be boosted. Six phase transmission line has been proposed as a prospective substitute which has the possibilities to transfer the large amount of electrical power with no chief modification in the existing structure of power transmission system.

Due to the connections of large number of conductors, the chances of fault occurrence on six phase transmission line is more. Thus, it is also essential to develop an adequate fault detection and faulty phase identification technique, which would decide the faulty phase to drop off the restoration period and hence improve the stability of the power transmission system. The larger number of possible fault combinations in six phase transmission line makes the complexity of detecting/classifying the faults very difficult. A number of excellent works have been stated in the literatures on the topics related to the protection of six phase transmission lines. Some noteworthy researches are discussed in detail in this part. Wavelet transform in combination with artificial neural network has been used for fault detection, classification and location in six phase transmission line in [1]. Reference [2] used the wavelet transform to design the fault detection and classification tool for the boundary protection of six phase transmission line. The effectiveness of the fault detection and classification algorithm is validated through investigating the effect of variation in different fault parameters such as fault type, fault resistance, fault inception time, ground resistance and fault location. Shunt faults detection and classification in six phase transmission line using a combination of artificial neural network and wavelet transform has been presented in [3]. In [4], mathematical morphology has been applied for the boundary protection of six phase transmission line. In [5], a phase to phase fault detection technique, using wavelet transform, has been proposed for the series capacitor compensated six phase transmission line protection. They have analyzed the effect of variation in fault type, fault inception time, fault resistance, ground resistance and fault location. Protection scheme based on the combination of artificial neural network and wavelet transform has been developed for protection against shunt faults in six phase transmission line [6]. A somewhat different mathematical morphology based fault detection and faulty phase identification technique has been proposed in [7] for the boundary protection of six phase transmission line. Detection and classification of open conductor faults in six phase transmission line using a combination of discrete Fourier transform and k-nearest neighbor has been reported in [8].

 DOI : 10.18231/2454-9150.2019.0545

The norm of wavelet transform has been used in [9] for fault detection and faulty phase identification in series capacitor compensated six phase transmission line. A fault location technique using a twelve sequence component method for the protection of twelve phase transmission line was proposed in [10].

In this work, wavelet transform-based approach for fault detection and faulty phase identification is presented. Various factors, such as impact of variation of fault resistance, fault type, fault inception time, and fault location have been considered to evaluate the response of the proposed protection scheme. Test results demonstrate that the proposed technique effectively detects the fault and the faulty phase and the dependability of this technique is robust to the variations in fault parameters.

This paper is structured as follows: the six phase transmission line specifications are presented in Section II. A brief introduction of the wavelet transform and the proposed protection technique are detailed in Section III. Performance assessment for the validation of the proposed technique is described in Section IV. Finally, conclusion is acknowledged in Section V.

II. Six Phase Transmission Line Specifications

The single line diagram of the six phase transmission line under consideration is exemplified in Fig. 1. The six phase transmission system constitutes 138 kV, 60 Hz six phase transmission line of 68 km length, connected to a 138 kV source at sending end and a 138 kV source and two loads at receiving end. The proposed model of six phase transmission line is designed referring to the Springdale-Mc Calmont transmission line of Allegheny power system. The six phase transmission line is divided into two parts of length 34 km each. The relay is connected at bus-1 to protect the whole length of six phase transmission line which is depicted in Fig. 1.

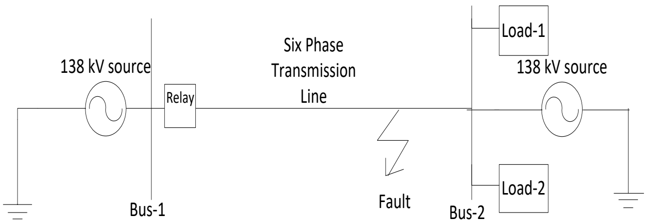

Fig. 1. Single line diagram of six phase power system

The pre-fault six phase current (I_A, I_B, I_C, I_D, I_E, I_F) and voltage (V_A, V_B, V_C, V_D, V_E, V_F) waveforms of related phases are depicted in Fig. 2. Fig. 3 demonstrates the wavelet detail coefficients of phase A, B and C current signals during no-fault. Fig. 4 shows the wavelet detail coefficients of phase D, E and F current signals during no-fault. The response of the proposed technique for no-fault operation is depicted in Table I.

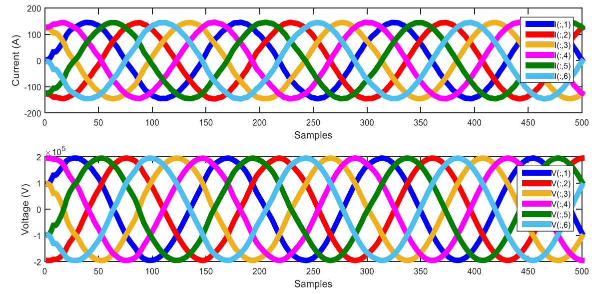

Fig. 2. Six phase current and voltage waveforms during no-fault

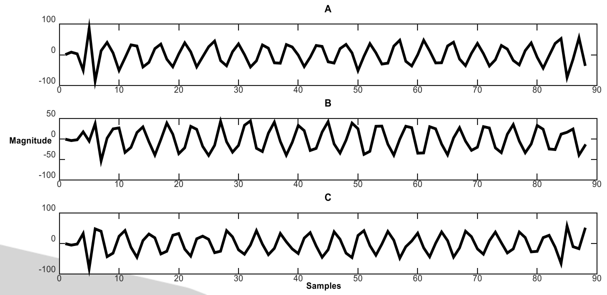

Fig. 3. Wavelet detail coefficients of phase- A, B and C currents during no-fault

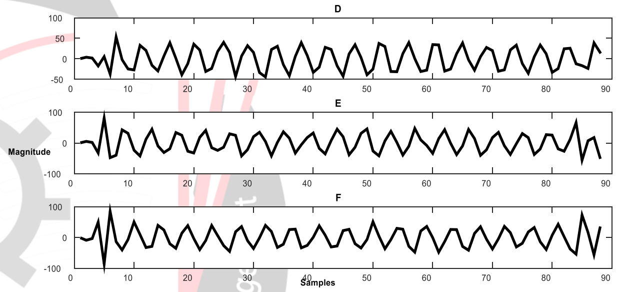

Fig. 4. Wavelet detail coefficients of phase- D, E and F currents during no-fault

TABLE I. Response of Proposed Technique for No Fault

Wavelet Fifth Level Detail Coefficients					
Phase-A	**Phase-B**	**Phase-C**	**Phase-D**	**Phase-E**	**Phase-F**
86.7705	44.1532	57.1220	53.5712	81.4040	85.0535

III. Wavelet Transform and Proposed Fault Detection and Faulty Phase Identification Technique

In a digital signal processing area, the protection schemes based on wavelet transform have become one of the most significant tools and these strategies became contemporary. As a replacement to short time Fourier transforms (STFT), the wavelet transform (WT) was developed to come up over the inadequacies related to its resolution problem.

Wavelet transform [5] is defined as:

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

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

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

$$y_H(k) = \sum_n x(n) g(2k-n) \qquad (2)$$

 DOI : 10.18231/2454-9150.2019.0545

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

$$y_L(k) = \sum_n x(n)h(2k-n) \quad (3)$$

Fig. 5 shows the flow chart of the proposed technique with the following steps:

Step-1: Six phase currents are recorded through transducers installed at bus-1.

Step-2: Wavelet transform is employed to calculate the wavelet detail coefficients of each phase current signal.

Step-3: If the magnitude of wavelet detail coefficients of the faulted phase is greater than the magnitude of wavelet detail coefficients of the un-faulted phase, then simultaneous fault detection and faulty phase identification else no fault detection/faulty phase identification, go to step 1.

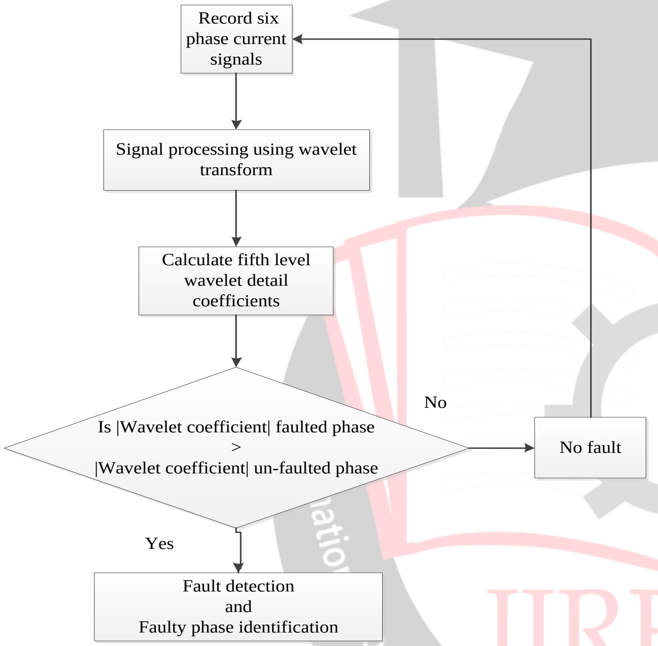

Fig. 5. Flow chart of proposed fault detection and faulty phase identification technique

IV. Performance Assessment

To validate the effectiveness of the proposed protection scheme, extensive simulation studies were carried out for various types of faults. The significance of variation in fault parameters viz. fault type (F_T), fault location (F_L), fault inception time (FIT), and fault resistance (R_f) has been examined. The test results associated to fault detection and faulty phase identification using wavelet transform are discussed in the successive subsections.

A. Response of Proposed Scheme for Variation in Fault Type

The effect of fault type variation on the performance of the proposed fault detection and faulty phase identification technique is evaluated in this section. As an example, a single line to ground AG fault at a distance of 34 km from bus-1 at FIT = 0.05 seconds with R_F = 15 Ω and R_G = 15 Ω is analyzed, and the six phase current waveform and plots of detail coefficients of associated phases are shown in Fig. 6, 7 and 8, respectively. For other faults, under fault type variation, the fault parameters are taken as FIT=0.05 seconds, F_L= 34 km, R_F = 15 Ω and R_G = 15 Ω. The fault detection results for same fault location in six phase transmission line with respect to the fault type variation are presented in Table II. As the test results confirm, the fault detection technique gives accurate results for various fault types. As the fifth level detail coefficients of fault current signals are used to verify the fault detection and faulty phase identification, the proposed technique gives reasonable accuracy for detecting faults occurring under different fault types as shown in Table II.

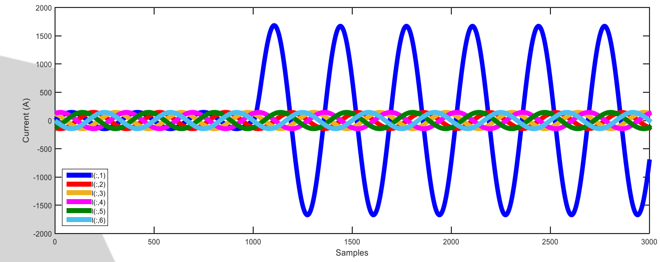

Fig. 6. Six phase current during AG fault at 34 km at FIT=0.05 seconds with R_f = 15 Ω and R_g = 15 Ω

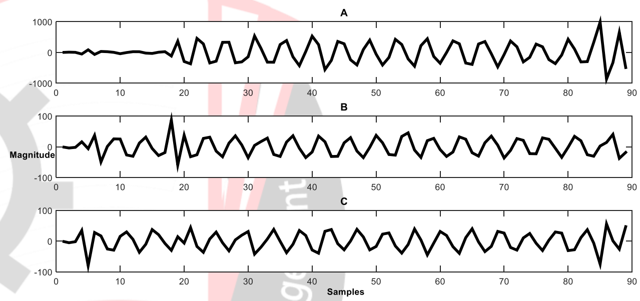

Fig. 7. Wavelet detail coefficients of phase- A, B and C currents during AG fault at 34 km at FIT=0.05 seconds with R_f = 15 Ω and R_g = 15 Ω

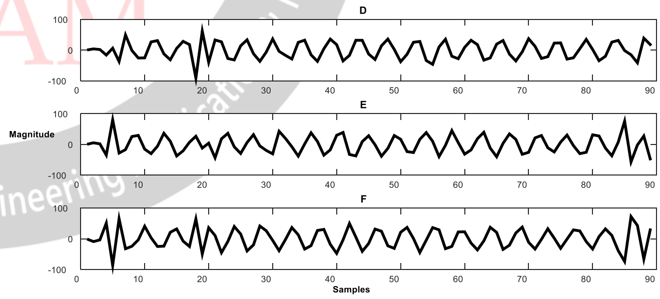

Fig. 8. Wavelet detail coefficients of phase- D, E and F currents during AG fault at 34 km at FIT=0.05 seconds with R_f = 15 Ω and R_g = 15 Ω

B. Response of Proposed Scheme for Variation in Fault Resistance

The performance of the proposed technique is evaluated for an extensive range of fault resistances. As in the case of smaller values of FIT's, high resistance faults affects the severity of the faults, resulting in smaller magnitudes of detail coefficients of fault currents. The performance of the proposed technique is tested for fault resistances varying from 5 Ω to 120 Ω. As an example, a single line to ground BG fault at a distance of 40 km from the location of relay at

 DOI : 10.18231/2454-9150.2019.0545

FIT = 0.1 seconds with R_F = 5 Ω and R_G = 10 Ω is analyzed, and the six phase current waveform and plots of detail coefficients of associated phases are shown in Fig. 9, 10 and 11, respectively. For other faults, under fault resistance variation, the fault parameters are taken as FIT=0.1 seconds, F_L= 40 km, and R_G = 10 Ω. The fault detection results for various fault resistances are exemplified in Table III for different types of faults and for same fault location. From the simulation results, it can be concluded that the proposed technique is insensitive to the variation in fault resistance.

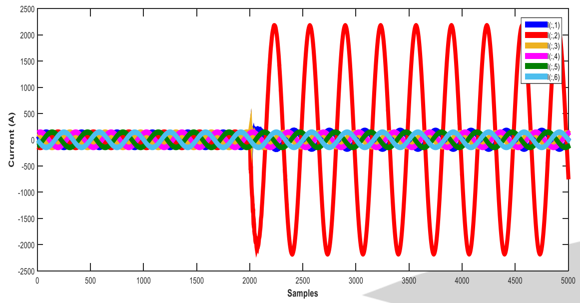

Fig. 9. Six phase current during BG fault at 40 km at FIT=0.1 seconds with R_f = 5 Ω and R_g = 10 Ω

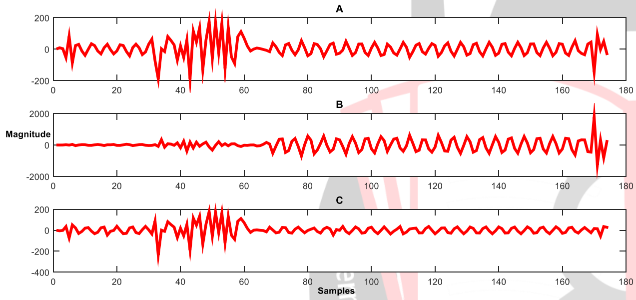

Fig. 10. Wavelet detail coefficients of phase- A, B and C currents during BG fault at 40 km at FIT=0.1 seconds with R_f = 5 Ω and R_g = 10 Ω

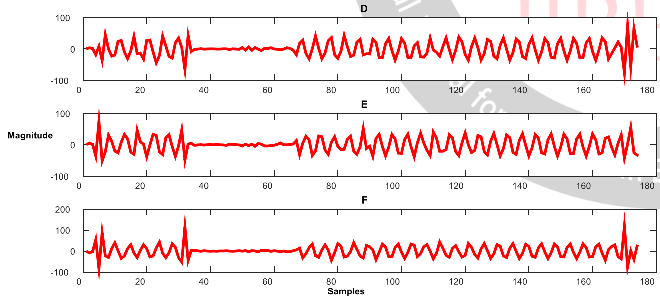

Fig. 11. Wavelet detail coefficients of phase- D, E and F currents during BG fault at 40 km at FIT=0.1 seconds with R_f = 5 Ω and R_g = 10 Ω

C. *Response of Proposed Scheme for Variation in Fault Inception Time*

The severity of fault instigated transients is influenced by different values of fault inception time. The performance of the proposed technique is tested for fault inception time variation. As an example, a double line to ground ABG fault at a distance of 30 km from the relaying point at FIT = 0.1 seconds with R_F = 5 Ω and R_G = 5 Ω is analyzed, and the six phase current waveform and plots of detail coefficients of associated phases are shown in Fig. 12, 13 and 14, respectively. For other faults, under fault inception time variation, the fault parameters are taken as R_F = 5 Ω, F_L= 30 km, and R_G = 5 Ω. The test results for five different faults with respect to different fault inception time are shown in Table IV. The results depict that the proposed fault detection technique give reasonably accurate results for an extensive range of fault inception time. The proposed technique has acceptable performance for detecting the faults occurring under different FIT's as exemplified in Table IV.

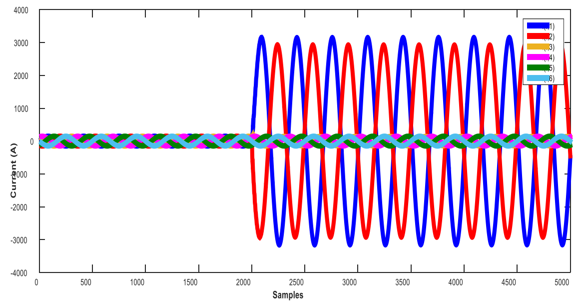

Fig. 12. Six phase current during ABG fault at 30 km at FIT=0.1 seconds with R_f = 5 Ω and R_g = 5 Ω

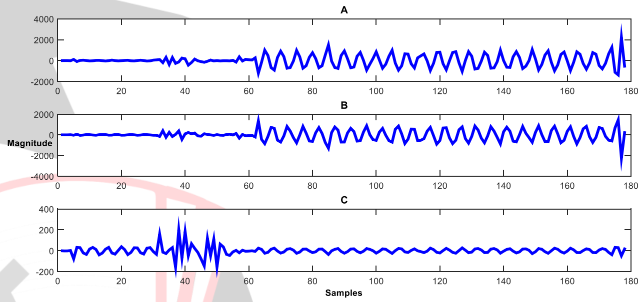

Fig. 13. Wavelet detail coefficients of phase- A, B and C currents during ABG fault at 30 km at FIT=0.1 seconds with R_f = 5 Ω and R_g = 5 Ω

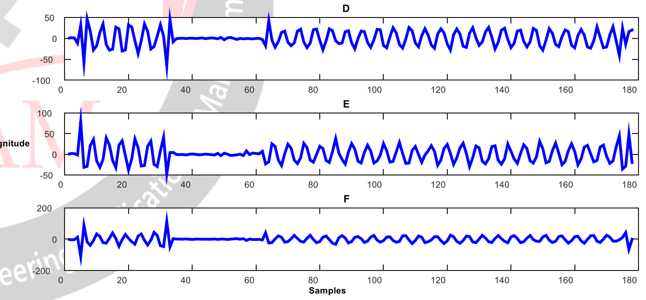

Fig. 14. Wavelet detail coefficients of phase- D, E and F currents during ABG fault at 30 km at FIT=0.1 seconds with R_f = 5 Ω and R_g = 5 Ω

D. *Response of Proposed Scheme for Variation in Fault Location*

The effectiveness of the proposed technique has been validated for various types of faults by varying fault location from 10 km to 68 km from the relaying point. As an example, a five phase to ground ACDEFG fault at a distance of 68 km from the relay location at FIT = 0.05 seconds with R_F = 5 Ω and R_G = 5 Ω is analyzed, and the six phase current waveform and plots of detail coefficients of associated phases are shown in Fig. 15, 16 and 17, respectively. For other faults, under fault location variation, the fault parameters are taken as FIT=0.05 seconds, R_F = 5 Ω and R_G = 5 Ω. The simulation results for other fault cases with different fault locations are presented in Table V. It is clearly

 DOI : 10.18231/2454-9150.2019.0545

observed from Table V that the relay effectively detects all types of faults. From the simulation results, it can be concluded that the proposed technique is insensitive to the variation in fault location.

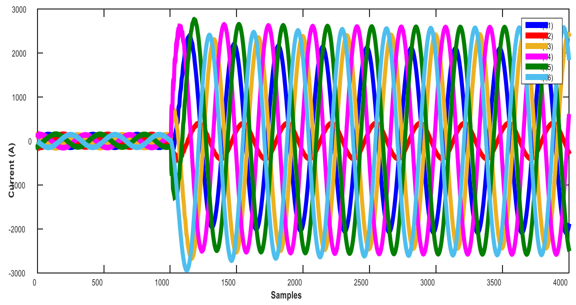

Fig. 15. Six phase current during ACDEFG fault at 68 km at FIT=0.05 seconds with R_f = 5 Ω and R_g = 5 Ω

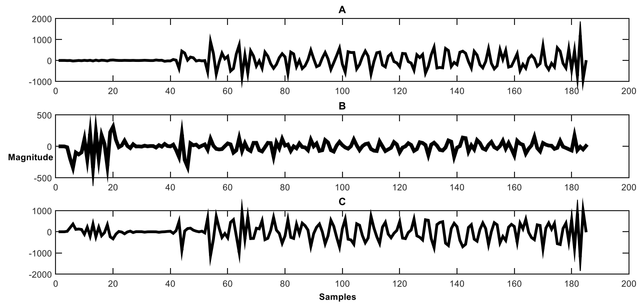

Fig. 16. Wavelet detail coefficients of phase- A, B and C currents during ACDEFG fault at 68 km at FIT=0.05 seconds with R_f = 5 Ω and R_g = 5 Ω

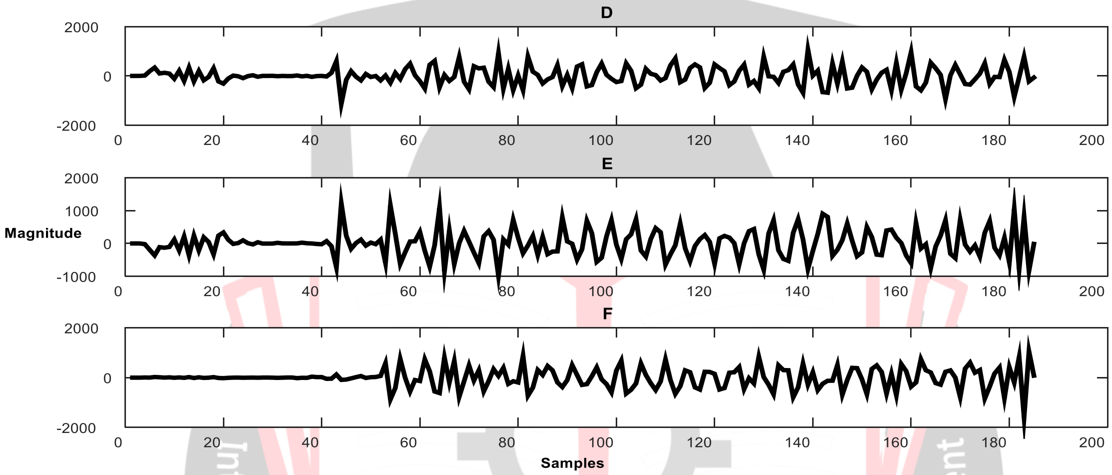

Fig. 17. Wavelet detail coefficients of phase- D, E and F currents during ACDEFG fault at 68 km at FIT=0.05 seconds with R_f = 5 Ω and R_g = 5 Ω

TABLE II. RESPONSE OF PROPOSED TECHNIQUE FOR DIFFERENT FAULT TYPES

Fault Type	Wavelet Fifth Level Detail Coefficients					
	Phase-A	Phase-B	Phase-C	Phase-D	Phase-E	Phase-F
AG	988.7686	86.8030	55.8769	61.6326	80.1384	72.1175
BDG	172.3712	884.3867	169.7540	567.8789	134.6035	132.6375
ACEG	2.2298*10^3	105.9904	1.7852*10^3	168.3993	974.6716	162.6511
BCDFG	99.4531	1.0668*10^3	927.1633	973.0917	123.3960	1.7697*10^3
ABCDEG	1.4647*10^3	2.0630*10^3	1.1539*10^3	1.3302*10^3	1.2653*10^3	103.8716

TABLE III. RESPONSE OF PROPOSED TECHNIQUE FOR DIFFERENT FAULT RESISTANCES

Fault Type	Wavelet Fifth Level Detail Coefficients					
	Phase-A	Phase-B	Phase-C	Phase-D	Phase-E	Phase-F
BG	175.8461	1.7730*10^3	177.9872	72.9539	73.6934	117.8348
AFG	781.0804	75.8924	59.0857	52.2665	101.5386	745.0213
CDEFG	175.0529	175.7747	293.7149	343.3075	390.3758	453.5159
ABCG	325.7370	335.0752	245.2446	48.3491	74.5731	108.8372
BCDEFG	101.3188	263.7134	187.1289	272.0637	320.1948	428.2718

 DOI : 10.18231/2454-9150.2019.0545

TABLE IV. RESPONSE OF PROPOSED TECHNIQUE FOR DIFFERENT FAULT INCEPTION TIME

Fault Type	Wavelet Fifth Level Detail Coefficients					
	Phase-A	Phase-B	Phase-C	Phase-D	Phase-E	Phase-F
CG	246.1730	246.3451	1.0436*10^3	54.1127	78.0622	69.0261
ABG	2.2284*10^3	1.4499*10^3	200.2491	46.6514	78.6750	112.4871
BCDG	108.1228	1.5650*10^3	991.6033	1.3737*10^3	192.8953	194.0846
ACDFG	1.6878*10^3	106.6464	1.1075*10^3	2.2588*10^3	181.0028	1.5204*10^3
ABDEFG	2.9517*10^3	1.3858*10^3	121.9752	2.6399*10^3	2.0372*10^3	2.2807*10^3

TABLE V. RESPONSE OF PROPOSED TECHNIQUE FOR DIFFERENT FAULT LOCATIONS

Fault Type	Wavelet Fifth Level Detail Coefficients					
	Phase-A	Phase-B	Phase-C	Phase-D	Phase-E	Phase-F
AG	812.7460	49.1554	29.5470	27.1474	43.1087	43.8727
BCG	41.7140	2.9192*10^3	1.5635*10^3	40.4398	163.8796	66.6824
ABCG	1.0898*10^3	1.2425*10^3	1.1132*10^3	40.7876	52.6668	36.4446
ABEFG	509.3158	380.3886	218.5581	222.4045	489.3515	385.2364
ACDEFG	1.2006*10^3	312.7948	983.1248	1.0586*10^3	1.2213*10^3	1.0464*10^3

V. CONCLUSION

A new fault detection and faulty phase identification technique for six phase transmission line based on wavelet transform in presented in the proposed work which carries out simultaneous fault detection and faulted phase identification. Test results indicate that the fault detection technique is robust for variations in the values of fault resistance, fault inception time, and fault location, having acceptable accuracy for all fault situations. Faulted phase identification is carried out with 100% accuracy. In conclusion, the proposed fault detection shows large possibility for fault detection and faulty phase identification in six phase transmission line.

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