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Protection technique for series capacitor compensated three phase transmission line connected with distributed generation using discrete Walsh Hadamard transform

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Abstract

This study proposes a discrete Walsh Hadamard transform (DWHT) based protection technique for the detection of fault and identification of faulty phase in series capacitor compensated three phase transmission line connected with distributed generation (DG). DWHT has been used for processing of the three phase current signals. To recognize the reliability of the proposed protection technique, it is tested for variation in fault type, fault location, fault resistance, ground resistance and fault inception time. Simulation results of DWHT-based proposed technique exemplify that the proposed technique correctly detects the faults and identifies the faulty phase accurately.

Keywords: Discrete Walsh Hadamard transform, distributed generation connected series capacitor compensated three phase transmission line, fault detection, faulty phase identification.

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1. Introduction

Accurate fault detection and faulty phase identification are the two important aspects of power system protection. Over the years, researchers have been in the search to recognize fast and perfect fault detection and faulty phase identification of the transmission line using various protection techniques, so that the faulted phase can be protected from feasible dangerous effects caused by the fault. Therefore, it is very essential to have a capable fault detection scheme for detecting the transmission line faults and identifying the fault phase. Various fault detection and faulty phase identification schemes have been proposed in the recent years. The survey of some fault detection techniques which are recently proposed by the researchers is described hereafter. An impedance-based fault location method for the protection of a 500 kV, 350 km long series capacitor compensated transmission line has been proposed in (Bains *et al*., 2018). However, the proposed scheme has been analyzed for only single line to ground and double line to ground faults. Current differential protection scheme based on sequence component has been proposed for the protection of transmission lines connected with inverter interfaced generators (Chen *et al*., 2018). A travelling wave based protection technique has been proposed for the medium transmission lines connected to distribution generation (Davydova and Hug, 2018). Standalone discrete wavelet transform and in conjunction with power spectral density has been used as a very effective tool for fault detection and classification in transmission lines (Guillen, 2018). Fault detection in a series capacitor compensated double circuit transmission line using wavelet transform has been reported in (Gautam *et al*., 2018). Continuous wavelet transform is applied for the differential protection of transmission line (Govar and Seyedi, 2016). Furthermore, a phase angle of positive sequence integrated impedance (PAPSII) based wide area back-up protection technique has been proposed for the protection of a 400 kV series compensated transmission line (Jena *et al*., 2017). Location of faults on series compensated double circuit transmission line using distributed parameter transmission line model has been described in (Kang *et al*., 2015). Mathematical morphology has been used as a very helpful tool for fault detection in a double circuit transmission line (Kapoor, 2018). Wavelet transform is applied for fault detection in a series capacitor compensated three phase transmission line (Kapoor, 2018). Wavelet transform based protection scheme has been used for double circuit transmission lines (Kapoor, 2018). Recently, one terminal travelling wave based cross differential protection technique has also been used for the protection of double circuit transmission line (Monteiro *et al.*, 2018). Fault location in STATCOM compensated double circuit transmission line using artificial neural network has been presented in (Nagam *et al.*, 2017). In the study presented in (Perera and Rajapakse, 2013), DWT-based single ended protection technique has been investigated for the protection of 500 kV series compensated double circuit transmission line. In the same way, discrete Fourier transform in conjunction with sequence space aided support vector machine classifier are employed for disturbance detection in a series compensated transmission lines (Patel, 2018). Artificial neural network has been utilized for fault classification and location in double circuit transmission line (Saravanan and Rathinam, 2012). Wavelet packet transform has been used for the protection of series compensated transmission line (Samantaray and Dash, 2007). Walsh Hadamard transform has been used (Sharma *et al.*, 2018) for fault detection and faulty phase identification in series capacitor compensated three phase transmission line.

The proposed work reports a single ended discrete Walsh Hadamard transform based fault detection and faulty phase identification technique for wind farm connected series capacitor compensated three phase transmission line against different types of shunt faults with varying various fault parameters such as fault type, fault location, fault inception time, fault resistance and ground resistance. Test results demonstrate that the proposed fault detection scheme effectively detects the fault and identifies faulty phase and the dependability of this scheme is robust to the fault parameters variations.

This paper is structured as follows: the specifications of proposed power system are presented in Section-2. A brief introduction of the Walsh Hadamard transform (WHT) and the proposed WHT-based fault detection and faulty phase identification technique have been presented in Section-3. Test results are analyzed in Section-4. Finally, conclusion of the work is declared in section-5.

2. Power System Specifications

Figure 1 depicts the schematic of DG (distributed generation) connected series capacitor compensated three phase transmission line under simulation. The test system consists of a 400 kV, 50 Hz DG connected transmission line of 100 km length. The transmission line is connected to a 400 kV source at the sending end. A wind farm consisting of five wind turbines each having power capacity of 2 MVA is connected at the receiving end of transmission line. The series capacitors are connected at the mid-point of the transmission line. The relay is installed at bus-1 to protect the total length of the three phase transmission line which can be seen in Figure 1. The transmission line model is simulated using MATLAB. Feature extraction of the fault current signals has been done using discrete Walsh Hadamard transform to calculate the Walsh coefficients.

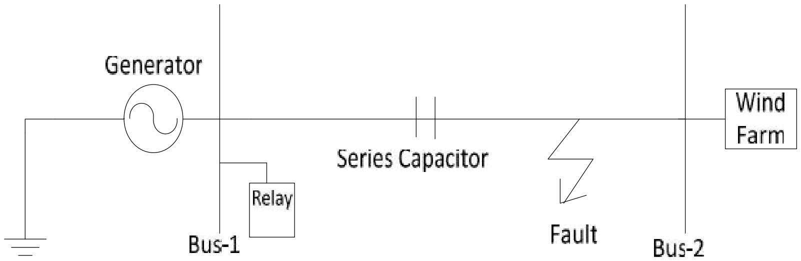

Figure 1. Schematic of proposed simulation model

3. Proposed Fault Detection and Faulty Phase Identification Technique

Discrete Walsh Hadamard transform (DWHT) is a well-organized computational mathematical approach which is used to calculate the Walsh Hadamard coefficients. The Walsh Hadamard coefficients can be calculated by using the equation-1 as given below.

$$y = fwht(x) \tag{1}$$

The output variable ‘y’ returns Walsh Hadamard coefficients of the input matrix ‘x’. The fast Walsh Hadamard transform (fwht) is computed on every column of input matrix ‘x’.

The various stages of the proposed technique as shown in Figure 2 are described in detail hereafter.

Step 1 Simulate the test system and generate post fault three phase current signals.
Step 2 Analyze the three phase current signals using Walsh Hadamard transform for feature extraction.
Step 3 Calculate the magnitude of Walsh coefficients for each fault current signal.
Step 4 If the magnitude of Walsh coefficients of the faulted phase is greater than the magnitude of Walsh coefficients of un-faulted phase, then fault else no fault, go to step 1.

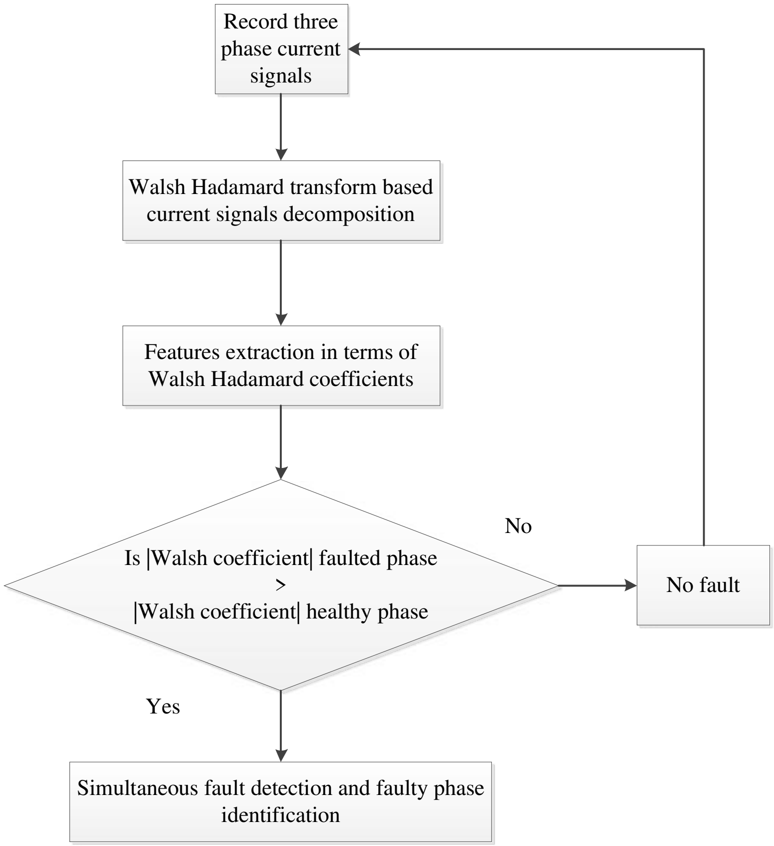

Figure 2. Schematic of proposed technique

4. Results and Discussion

To validate the effectiveness of the proposed Walsh Hadamard transform based fault detection and faulty phase identification technique, simulation studies have been carried out for various types of shunt faults. The performance of the proposed technique was investigated with variation in fault type (F_T), fault resistance (R_F), ground resistance (R_G), fault inception time (FIT) and fault location (F_L). Following the fault detection and faulty phase identification, some of the simulation results are shown and discussed in the succeeding subsections.

4.1 Response of Proposed Technique for No-Fault: The performance of the proposed technique is analyzed when the transmission line has no fault. The three phase current and voltage waveforms during no-fault are shown in Figure 3. The discrete Walsh Hadamard transform coefficients of three phase current during no-fault condition can be seen in Figure 4. Thus the performance of proposed protection technique is examined for no-fault operation and the test results are exemplified in Table 1.

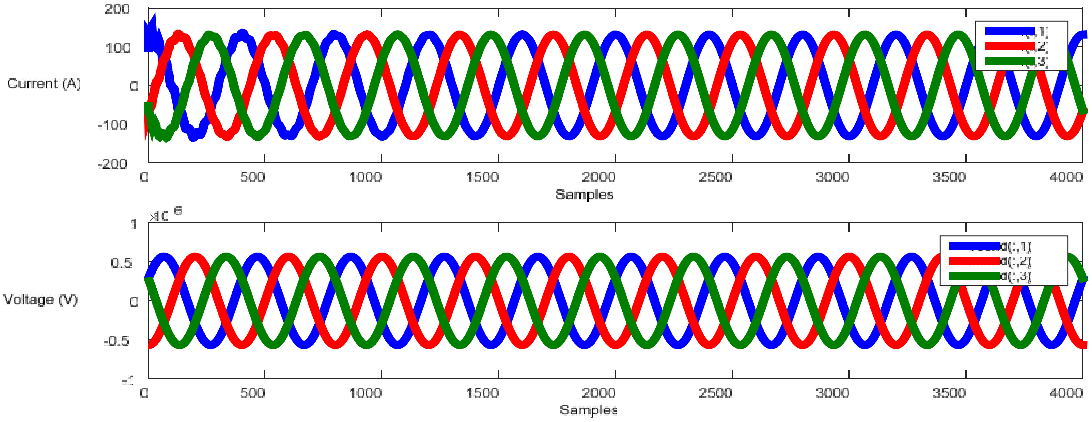

Figure 3. Three phase current and voltage during no-fault

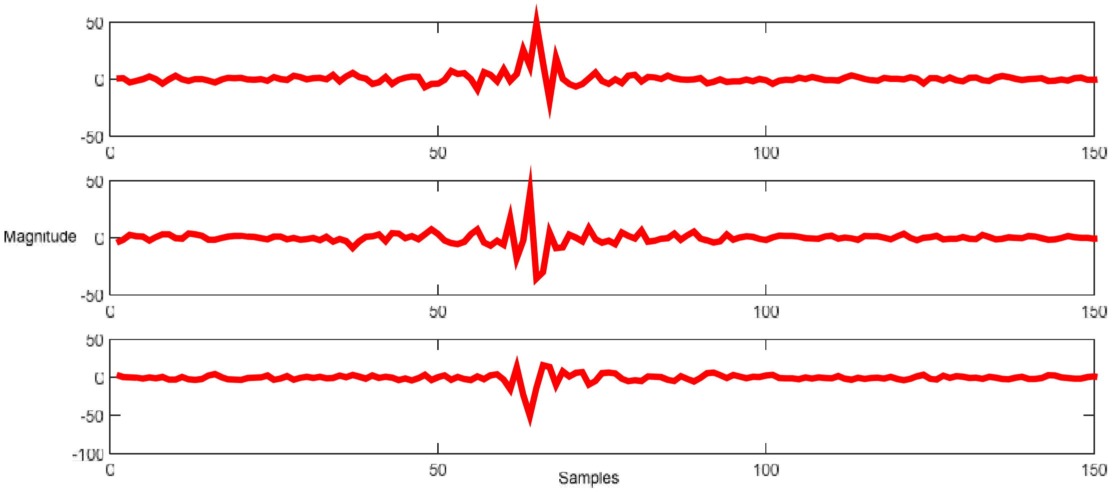

Figure 4. Walsh Hadamard coefficients of three phase current during no fault

Table 1. Test results of proposed technique for no-fault

Discrete Walsh Hadamard Transform Coefficients		
Phase-A	**Phase-B**	**Phase-C**
48.8002	38.6917	21.0011

4.2 Response of Proposed Technique for Variation in Fault Type: The performance of proposed technique has been verified for varying fault type. As an case, the simulation results of proposed technique in case the transmission line is subjected to AG fault at a distance of 50 % from the relaying point at FIT=0.1 seconds with R_F=R_G=5 are depicted in Figures 5-6. For all types of faults, R_F and R_G are kept at 5 , respectively; all faults are simulated at 50 % from the relay location, while FIT is selected as 0.1 second. Further, the response of the proposed technique for other types of faults with varying fault type is demonstrated in Table 2. It is clearly examined from Table 2 that the proposed technique correctly detects the faults and classifies the faulty phase accurately and variation in fault type has no significant consequence on the accuracy of the proposed technique.

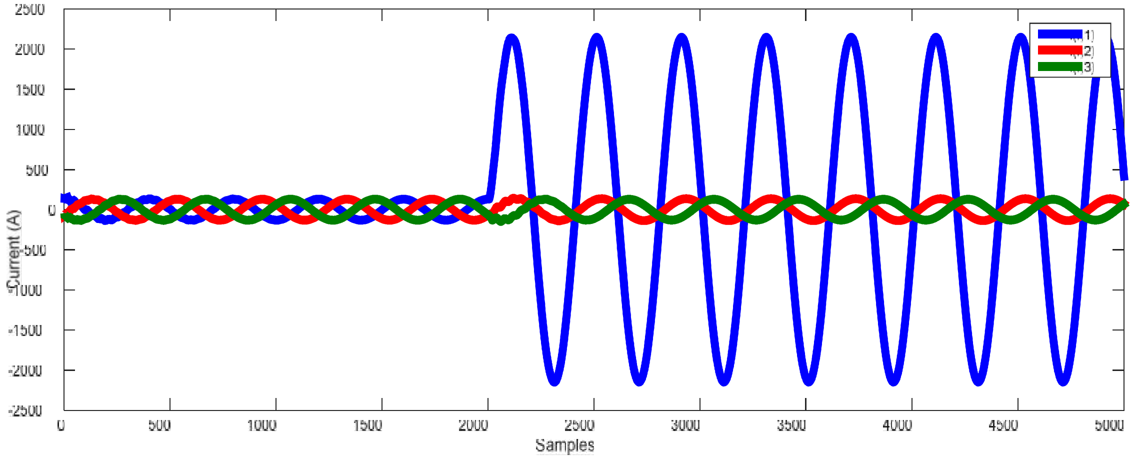

Figure 5. Three phase current during AG fault at a distance of 50 % from the relaying point at FIT=0.1 seconds with R_F=R_G=5

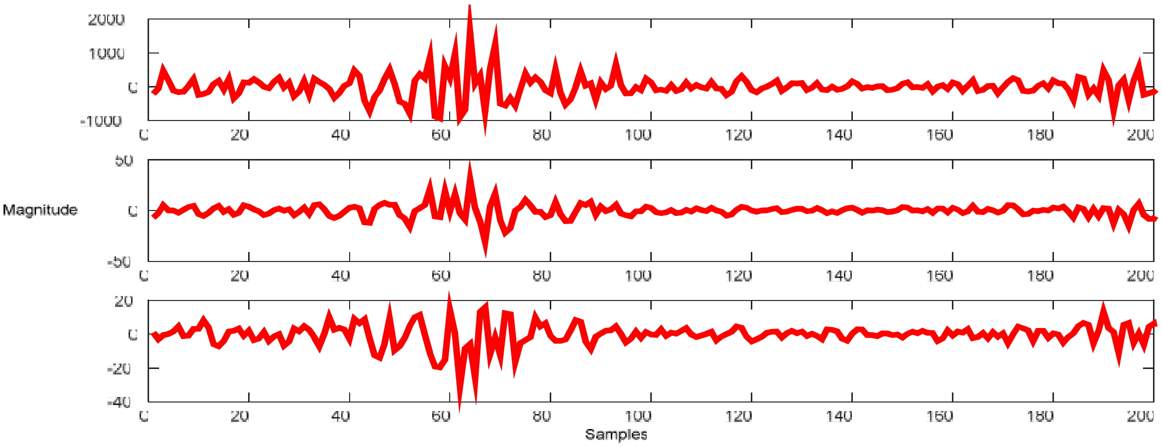

Figure 6. Walsh Hadamard coefficients of three phase current during AG fault at a distance of 50 % from the relaying point at FIT=0.1 seconds with R_F=R_G=5

Table 2. Test results of the proposed technique for variation in fault type

Fault Type	R_F ( )	R_G ( )	FIT (S)	F_L (km)	Walsh Hadamard Coefficients		
					Phase-A	Phase-B	Phase-C
AG	5	5	0.1	50	1.5965*10^3	30.0020	15.9438
BG	5	5	0.1	50	18.2437	1.3254*10^3	19.0865
CG	5	5	0.1	50	18.8427	19.2394	1.0656*10^3
ABG	5	5	0.1	50	1.6605*10^3	1.3126*10^3	19.2781
BCG	5	5	0.1	50	14.4548	1.9853*10^3	2.2450*10^3
ACG	5	5	0.1	50	2.7114*10^3	16.4624	2.1348*10^3
AB	5	5	0.1	50	2.0731*10^3	1.8145*10^3	17.5038
BC	5	5	0.1	50	22.3175	2.0287*10^3	2.0618*10^3
AC	5	5	0.1	50	1.2744*10^3	16.6601	893.2586
ABCG	5	5	0.1	50	2.7681*10^3	2.9001*10^3	2.0586*10^3
ABC	5	5	0.1	50	3.7881*10^3	2.9326*10^3	2.9655*10^3

4.3 Response of Proposed Technique for Variation in Fault Location: The suitability of the proposed technique has been further tested by evaluating its performance for different types of faults at different locations of transmission line. As an example, the simulation results during double line to ground BCG fault triggered at a distance of 60 % from the relay location at FIT=0.05 seconds with R_F=10 and R_G=10 are depicted in Figures 7-8. For all fault cases, R_F and R_G are kept at 10 and 10 , respectively; while FIT is selected as 0.05 second. The simulation results related to various fault scenarios with variation in locations of faults on transmission line are reported in Table 3. As can be seen in Table 3, the proposed technique detects all the types of faults correctly and identifies the faulty phase accurately. It can be observed that the DWHT-based proposed technique is robust to the variation in locations of faults.

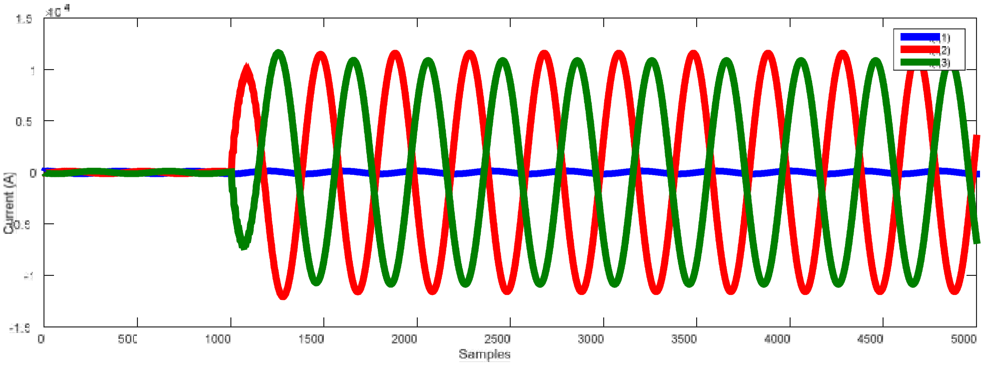

Figure 7. Three phase current during BCG fault at a distance of 60 % from the relaying point at FIT=0.05 seconds with R_F= 10 and R_G=10

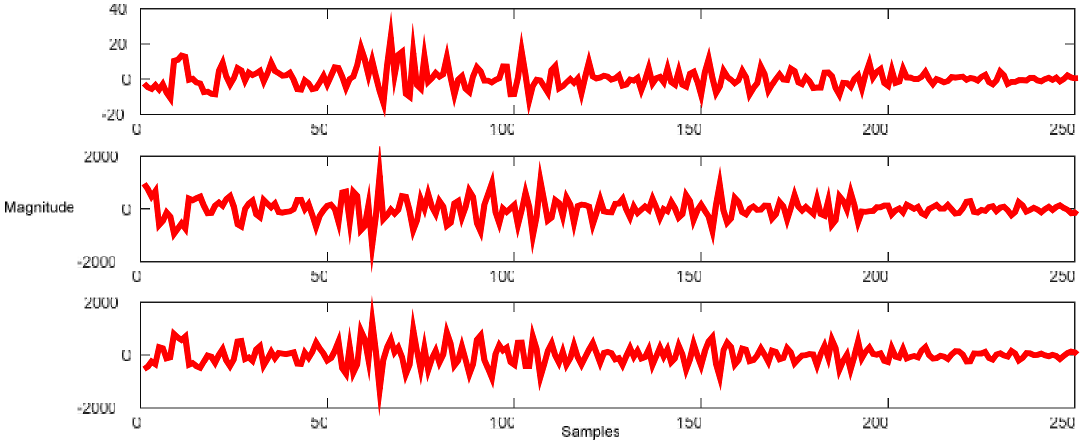

Figure 8. Walsh Hadamard coefficients of three phase current during BCG fault at a distance of 60 % from the relaying point at FIT=0.05 seconds with R_F=R_G=10

Table 3. Test results of the proposed technique for variation in fault location

Fault Type	R_F ( )	R_G ( )	FIT (S)	F_L (km)	Walsh Hadamard Coefficients		
					Phase-A	Phase-B	Phase-C
ABCG	10	10	0.05	15	5.1215*10^3	3.3775*10^3	3.5394*10^3
ABG	10	10	0.05	30	1.3484*10^3	2.0937*10^3	14.4723
BCG	10	10	0.05	60	23.8565	1.2663*10^3	1.2442*10^3
AG	10	10	0.05	90	476.5588	9.8507	15.0616
CG	10	10	0.05	100	12.4304	16.0847	602.1983

4.4 Response of Proposed Technique for Variation in Fault Resistance: It is very essential to study the impact of fault resistance variation on the precision of the proposed protection technique. To evaluate the impact of fault resistance, various types of faults with R_G= 0.001 at a distance of 50 % from the relay location at FIT=0.2 seconds have been simulated on transmission line with varying R_F and F_T. To examine the consequence of R_F variation, as an example, a three phase to ground fault ABCG is triggered on transmission line at a distance of 50 % from the relaying point at FIT=0.2 seconds with R_F=100 and R_G=0.001 . The resulting fault current waveform of three phase current which is recorded at bus-1 is depicted in Figure 9. Discrete Walsh Hadamard coefficients of three phase currents during phase ABCG fault at 50 % from relay location at FIT=0.2 seconds with R_F= 100 and R_G=0.001 are exemplified in Figure 10. Test results for various types of faults with different fault resistances are reported in Table 4. It is clearly observed from Table 4 that, for all the test cases, the faults are detected correctly and the faulty phases have been identified accurately. Thus the simulation results follow the immunity of the proposed fault detection and faulty phase identification technique to the variation in fault resistance.

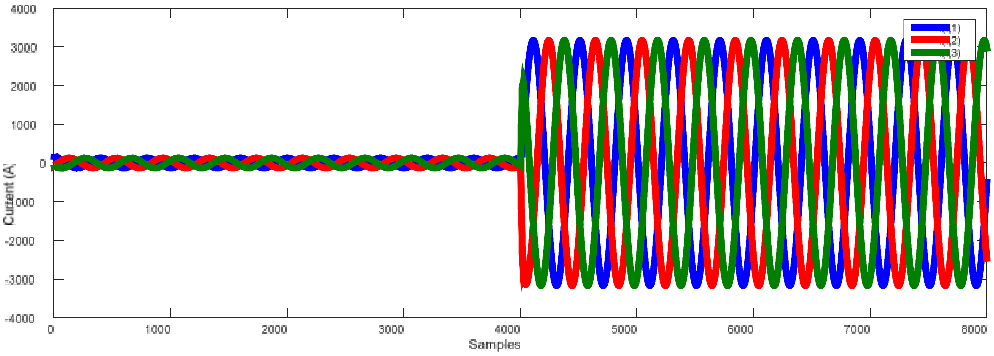

Figure 9. Three phase current during ABCG fault at a distance of 50 % from the relaying point at FIT=0.2 seconds with R_F= 100 and R_G= 0.001

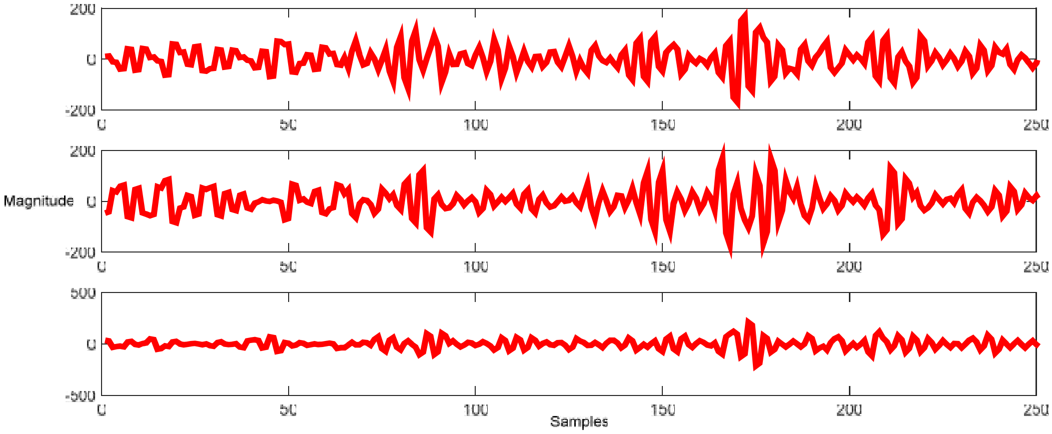

Figure 10. Walsh Hadamard coefficients of three phase current during ABCG fault at a distance of 50 % from the relaying point at FIT=0.2 seconds with R_F= 100 and R_G= 0.001

Table 4. Test results of the proposed technique for variation in fault resistance

Fault Type	**R_F ( )**	**R_G ( )**	**FIT (S)**	**F_L (km)**	**Walsh Hadamard Coefficients**		
					Phase-A	**Phase-B**	**Phase-C**
AG	1	0.001	0.2	50	1.2833*10^3	23.8268	26.1910
BG	10	0.001	0.2	50	23.5578	811.6670	15.1014
ACG	30	0.001	0.2	50	801.2852	20.4001	503.9851
ABG	60	0.001	0.2	50	403.4915	634.0735	18.0011
ABCG	100	0.001	0.2	50	168.6153	168.3640	209.2103

4.5 Response of Proposed Technique for Variation in Ground Resistance: It is very important to study the impact of ground resistance variation on the accuracy of the proposed protection technique. To evaluate the impact of ground resistance, various types of faults with R_F= 15 at a distance of 40 % from the relaying point at FIT=0.175 seconds have been simulated on transmission line with varying R_G and F_T. To analyze the effect of R_G variation, a single line to ground fault BG is triggered on transmission line at a distance of 40 % from the relay location at FIT=0.175 seconds with R_F=15 and R_G=2 . The resulting fault current waveform of three phase current recorded at bus-1 is depicted in Figure 11. Figure 12 shows DWHT coefficients. Test results for various types of faults with different ground resistances are summarized in Table 5. It is clearly observed from Table 5 that, for all the test cases, the faults are detected correctly and the faulty phases have been identified accurately. From the simulation results, it can be concluded that the proposed protection technique is insensitive to the variation in ground resistance.

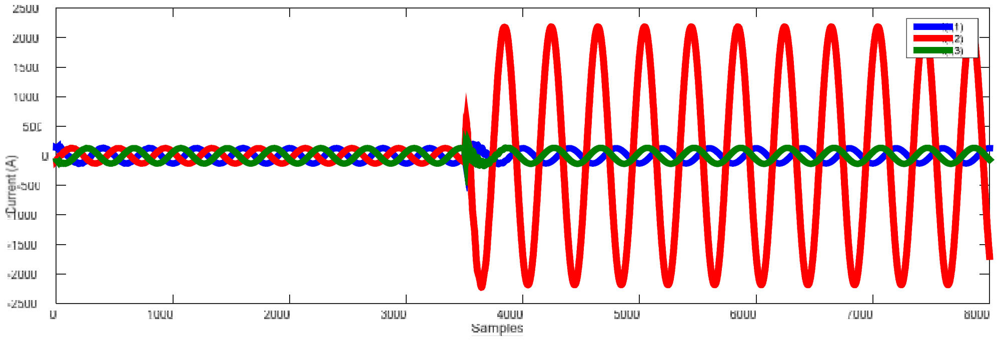

Figure 11. Three phase current during BG fault at a distance of 40 % from the relaying point at FIT=0.175 seconds with R_F=15 and R_G=2

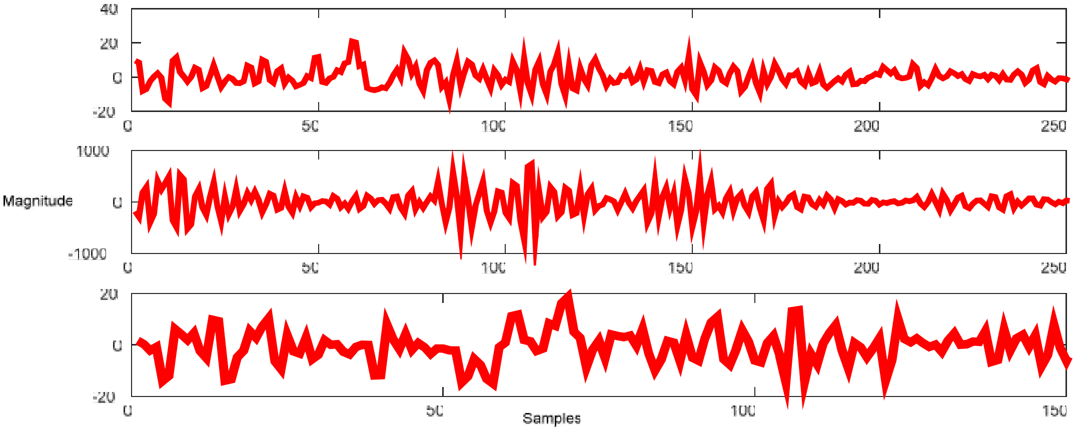

Figure 12. Walsh Hadamard coefficients of three phase current during BG fault at a distance of 40 % from the relaying point at FIT=0.175 seconds with R_F=15 and R_G=2

Table 5. Test results of the proposed technique for variation in ground resistance

Fault Type	R_F ( )	R_G ( )	FIT (S)	F_L (km)	Walsh Hadamard Coefficients		
					Phase-A	**Phase-B**	**Phase-C**
BG	15	2	0.175	40	20.8280	739.9101	18.5561
ABG	15	15	0.175	40	2.6367*10^3	2.6453*10^3	20.4988
ABCG	15	35	0.175	40	1.3708*10^3	3.0398*10^3	3.1358*10^3
BCG	15	70	0.175	40	13.7842	1.2748*10^3	1.1795*10^3
CG	15	150	0.175	40	15.7559	16.9052	170.4078

4.6 Response of Proposed Technique for Variation in Fault Inception Time: The response of the proposed protection technique has been analyzed for variation in fault inception time. In order to evaluate the response of the proposed technique, as an example, a double line to ground fault ABG at a distance of 70 % from the relay location at FIT=0.1 seconds with R_F=R_G=10 , is examined, and the simulation results are exemplified in Figures 13-14. The R_F and R_G are kept constant 10 for all fault cases, and the fault location is set at 70 % from the relaying point. Table 6 reports the performance of proposed technique for various fault cases with FIT variation. As observed from Table 6, the faults are correctly detected and the faulty phases are identified perfectly. Thus, the proposed DWHT-based protection technique is robust to the variation in fault inception time.

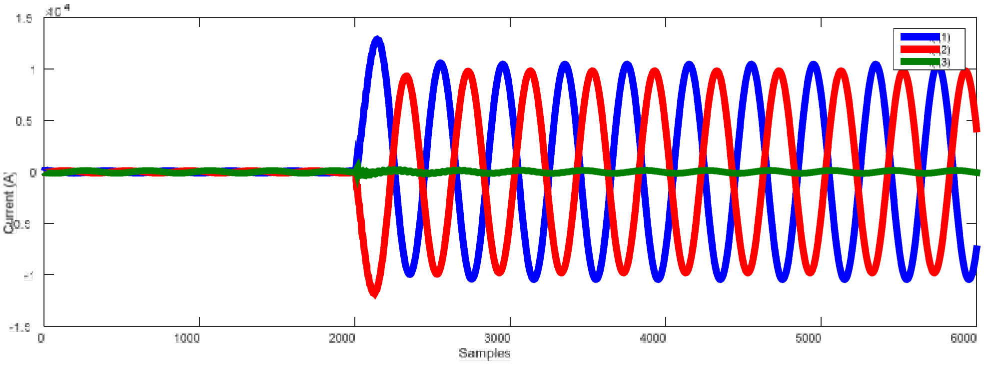

Figure 13. Three phase current during ABG fault at a distance of 70 % from the relaying point at FIT=0.1 seconds with R_F= 10 and R_G=10

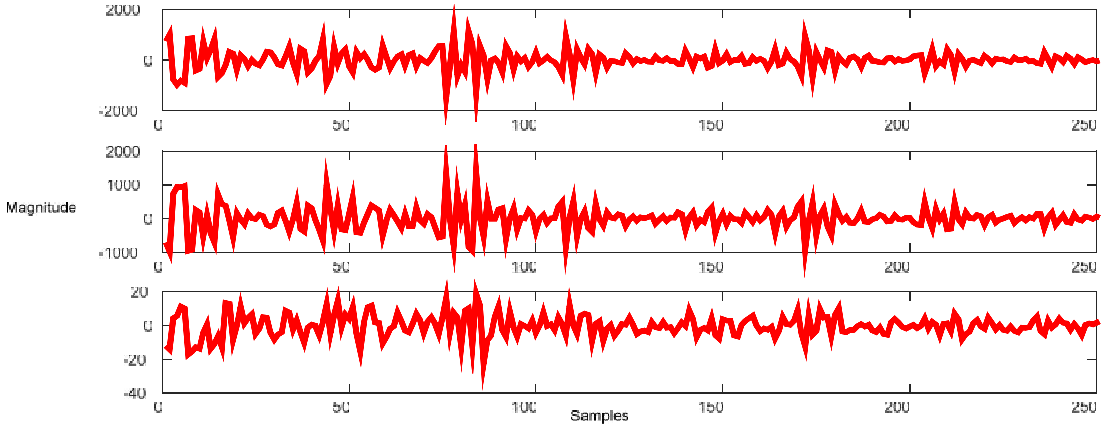

Figure 14. Walsh Hadamard coefficients of three phase current during ABG fault at a distance of 70 % from the relaying point at FIT=0.1 seconds with R_F=R_G=10

Table 6. Test results of the proposed technique for variation in fault inception time

Fault Type	**R_F ( )**	**R_G ( )**	**FIT (S)**	**F_L (km)**	**Walsh Hadamard Coefficients**		
					Phase-A	**Phase-B**	**Phase-C**
ABG	10	10	0.1	70	1.1418*10^3	1.3658*10^3	18.6230
BCG	10	10	0.245	70	32.6574	1.1461*10^3	1.1554*10^3
ABCG	10	10	0.185	70	2.1293*10^3	1.7897*10^3	1.3978*10^3
AG	10	10	0.275	70	572.0140	20.0302	16.3316
CG	10	10	0.15	70	22.0039	23.0903	635.8136

5. Conclusion

Discrete Walsh Hadamard transform-based protection technique is proposed which detects the fault and identifies the faulty phase. The fault information is captured using characteristics based on Walsh Hadamard coefficients of current signals acquired by DWHT. The three phase current signals measured at the relaying point i.e., at bus-1 only, are used for calculating the DWHT coefficients. The proposed protection technique has been authenticated with numerous types of fault cases with variation in fault type, fault location, fault resistance, ground resistance and fault inception time. Test results exhibit that the proposed protection scheme effectively detects the fault and identify the faulty phase. 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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Biographical notes

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