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Transmission Line Protection Schemes Based on Discrete Wavelet Transform Using Voltage Signals

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Abstract

This research work presents an algorithm for detection and classification of transmission line faults. In the algorithm, voltage-based approach using discrete wavelet transform is introduced. Algorithm is successfully tested for different case studies such as variations in fault location on transmission line, variations in fault impedance and event of reverse power flow. The algorithm is also tested for switching transients. It is established that the proposed algorithm based on the discrete Wavelet transform and using voltage signal is effective in detection and classification of the different types of the faults on the transmission line. The study has been carried out in MATLAB/Simulink environment.

Keywords: *fault; Transmission line; voltage; wigner distribution function; wavelet transform.*

1. Introduction

Transmission line is the important element of the power system network. Power flow on the line may be interrupted by the faulty events which take place on the transmission and distribution lines. Fast detection of these faults and fault location estimation accurately is required to restore supply. Hence, efficient protection schemes are required to protect the power system network against faults like phase to ground (LG), double phase (LL), double phase to ground (LLG) and three-phases to ground (LLLG) [1]. The signal processing methods like wavelet transform (WT), Stockwell transform (ST), Gabor transform (GT), Hilbert transform (HT), neural network (NN), Fuzzy logic (FL) etc. are being widely utilized for detection and classification of faults on the network of power system [2]. Mahela et al. [3], introduced an approach using Stockwell transform for identification of faults on the transmission line in the presence of Thyristor switched capacitor (TSC). Krishnanand *et al.* [4], introduced an approach for pattern recognition using current differential relays on the power transmission line. This method is established for current differential protection of a transmission line. This is effective for identification of variety of faults, fault resistance, inception angles, and significant noise in the signal. Noori *et al.* [5], presented a novel technique for recognition of faults on the detection in transmission lines using adaptive cumulative sum approach whose structure is adaptive with the current passing through the corresponding line. In [6], authors developed an accurate real-time scheme for detection and analysis of faults on High Voltage transmission lines. A fault detection method for heat loss at a work-shop level is reported in [7]. Zahra *et al.* [8], proposed time-frequency features for identification of type of fault, fault-loop status supervision, and fault-zone detection modules in a compensated transmission line with a unified power-flow controller. An intelligent identification scheme for transient faults in transmission systems using Gabor Transform (GT) and Artificial Neural Network (ANN) is introduced by authors in [9]. Usama *et al.* [10], designed and implemented wavelet analysis supported fault detection and identification algorithm. These techniques for detection of transmission line faults are reported in literature. Gomes *et al.* [11], introduced a model for representing the phases of a transmission line.

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Detection and classification scheme are developed based on analysis of model parameters and evaluated using a set of simulated faults and a real database.

In this research paper, various transmission line faults such as line to ground (LG) fault, double line (LL) fault, double line to ground (LLG) fault and three phase fault involving ground (LLLG) have been investigated using an algorithm based on Discrete Wavelet Transform with voltage based features.

2. Proposed Power System of Transmission Line

Proposed test system comprises of transmission line connected between two buses of complex power system network. The large area utility on both ends of the transmission line is represented by generators 1 & 2 (G1 & G2). The test system of transmission line used for the study is illustrated in Figure 1. Total line length is taken as 230 km. The line is modeled in four sections each having length of 10 km (L1), 105 km (L2), 105 km (L3) and 10 km (L4) respectively. The fault is created at points F1, F2 and F3. The fault location points F1 and F3 are used to investigate the effect of fault location whereas fault location point F2 is used in all other cases. Two generators G1 and G2 are connected on both ends of transmission line with a voltage rating of 500 kV to represent the large area utility network. These generators have phase difference of 20° so that power flows from one end of transmission line to other. In general conditions power will flow from bus B1 to bus B2. Voltage and currents are measured on bus B1. The bus B1 is located on the sending end of the transmission line and bus B2 is located on the receiving end of the transmission line. The measurement of the voltage and current is carried out using the three-phase VI measurement block of Simulink.

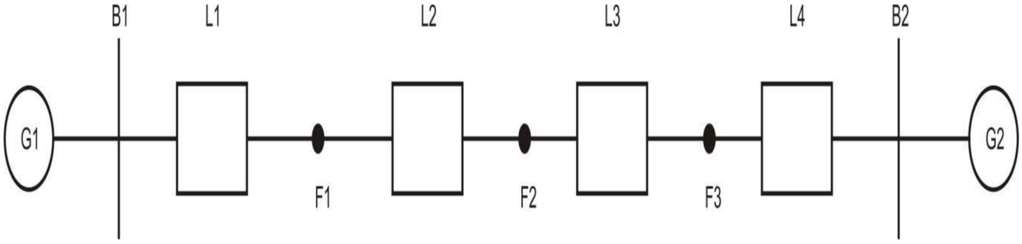

Figure 1. Single line diagram of the test system.

Technical parameters of test system such as system voltage, system frequency, transmission line positive and zero sequence resistances, transmission line positive and zero sequence inductances, transmission line positive and zero sequence capacitances, source resistance and source inductance are provided in the Table 1.

Table 1. Technical Parameters of Test System.

Particulars of parameters	**Values of parameters**
Voltage Rating of System	500 kV
Frequency	60 Hz
Source resistance (ohm)	17.77Ω
Source inductance	0.1218 H
Positive sequence resistance of line	0.01273 Ω/km
Zero sequence resistance of line	0.3864 Ω/km
Positive sequence inductance of line	0.9337e-3 H/km
Zero sequence inductance of line	4.1264e-3 H/km
Positive sequence capacitance of line	12.74e-9 F/km
Zero sequence capacitance of line	7.751e-9 F/km

3. Proposed Current Based Protection Scheme

The voltage-based transmission line protection scheme is based on the discrete wavelet transform. The voltage signal using the discrete wavelet transform with db5 as mother wavelet up to fourth level of decomposition. Absolute values of the detailed coefficient obtained at second level of decomposition are designated as discrete wavelet transform based fault index using voltage signal. This fault index is designated as DWTV index. This is used for the detection of various types of faults as well as discrimination of faulty phase from the healthy phase.

4. Discussion of Simulation Results

The simulation results related to detection and classification of power system faults using an algorithm based on Wigner distribution function and Discrete Wavelet transform is detailed in this chapter. Voltage signal is taken as key factor for the proposed investigations.

4.1. Line to Ground Fault

A line to ground (LG) fault is simulated at middle of the transmission line by grounding the phase-A of the transmission line illustrated in Figure 1. Voltage signal is recorded on bus B1 at sending end of the transmission line. Voltage signal is decomposed using the discrete Wavelet transform with a sampling frequency of 3.8 kHz up to fourth level of decomposition with db5 as mother wavelet. The detailed coefficient obtained at second level of decomposition is obtained. The absolute values of this detailed coefficient are designated as DWTV index which is also considered as fault index for the recognition of faulty events. The voltage signal of all the phases is shown in Figure 2 (a). The DWTV index corresponding to phase-A is illustrated in Figure 2 (b). Similarly, the DWTV index corresponding to phase-B is illustrated in Figure 2 (c). The DWTV index corresponding to phase-C is illustrated in Figure 2 (d). Threshold value of the proposed fault index is taken as 10 to discriminate the faulty phases from the healthy phases.

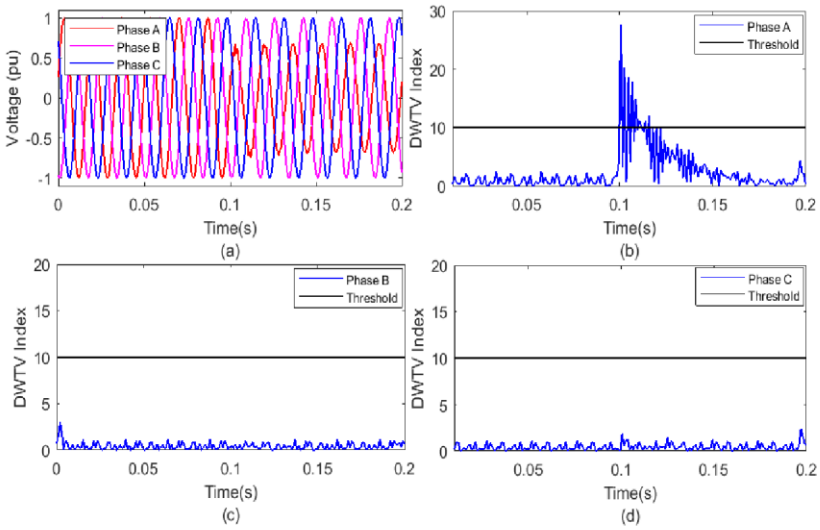

Figure 2. Detection of line to ground (LG) fault using voltage-based fault index (a) voltage waveform (b) proposed DWTV-index for phase-A (c) proposed DWTV-index for phase-B (d) proposed DWTV-index for phase-C.

It is observed from the Figure 2 (b) that DWTV index corresponding to phase-A has values higher than the threshold value indicating that the phase-A is faulty. This is observed from the Figure 2 (c) that DWTV index corresponding to phase-B has values lower than the threshold value indicating that the phase-B is healthy. Similarly, this is also observed from the Figure 2

(d) that DWTV index corresponding to phase-C has values lower than the threshold value indicating that the phase-C is also healthy in nature. Hence, proposed algorithm based on dicsrete wavelet transform is found to be effective in detection of the LG using the features extracted from the voltage waveform.

4.2. Double Line Fault

A double line (LL) fault is simulated at middle of the transmission line by short circuiting the phases-A & B of the transmission line illustrated in Figure 1. Voltage signal is recorded on bus B1 at sending end of the transmission line. Voltage signal is decomposed using the discrete Wavelet transform with a sampling frequency of 3.8 kHz up to fourth level of decomposition with db5 as mother wavelet. The detailed coefficient obtained at second level of decomposition is obtained. The absolute values of this detailed coefficient are designated as DWTV index which is also considered as fault index for the recognition of faulty events. The voltage signal of all the phases is shown in Figure 3 (a). The DWTV index corresponding to phase-A is illustrated in Figure 3 (b). Similarly, the DWTV index corresponding to phase-B is illustrated in Figure 3 (c). The DWTV index corresponding to phase-C is illustrated in Figure 3 (d). Threshold value of the proposed fault index is taken as 10 to discriminate the faulty phases from the healthy phases.

It is observed from the Figure 3 (b) that DWTV index corresponding to phase-A has values higher than the threshold value indicating that the phase-A is faulty. Similarly, this is observed from the Figure 3 (c) that DWTV index corresponding to phase-B has values higher than the threshold value indicating that the phase-B is faulty. This is observed from the Figure 3 (d) that DWTV index corresponding to phase-C has values lower than the threshold value indicating that the phase-C is healthy in nature. Hence, proposed algorithm based on dicsrete wavelet transform is found to be effective in detection of the LL using the features extracted from the voltage waveform.

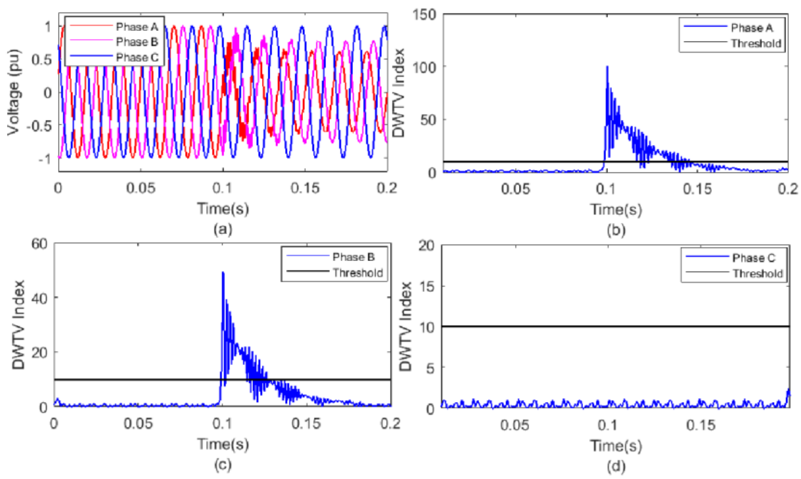

Figure 3. Detection of double line fault using voltage-based fault index (a) voltage waveform (b) proposed DWTV index for phase-A (c) proposed DWTV-index for phase-B (d) proposed DWTV-index for phase-C.

4.3. Double Line to Ground Fault

A double line to ground (LLG) fault is simulated at middle of the transmission line by simultaneously grounding phases-A & B of the transmission line illustrated in Figure 1. Voltage signal is recorded on bus B1 at sending end of the transmission line. Voltage signal is decomposed using the discrete Wavelet transform with a sampling frequency of 3.8 kHz up to fourth level of decomposition with db5 as mother wavelet. The detailed coefficient at second level of decomposition is obtained. The absolute values of this detailed coefficient are designated as DWTV index which is also considered as fault index for the recognition of faulty events. The voltage signal of all the phases is shown in Figure 4 (a). The DWTV index corresponding to phase-A is illustrated in Figure 4 (b). Similarly, the DWTV index corresponding to phase-B is illustrated in Figure 4 (c). The DWTV index corresponding to phase-C is illustrated in Figure 4 (d). Threshold value of the proposed fault index is taken as 10 to discriminate the faulty phases from the healthy phases.

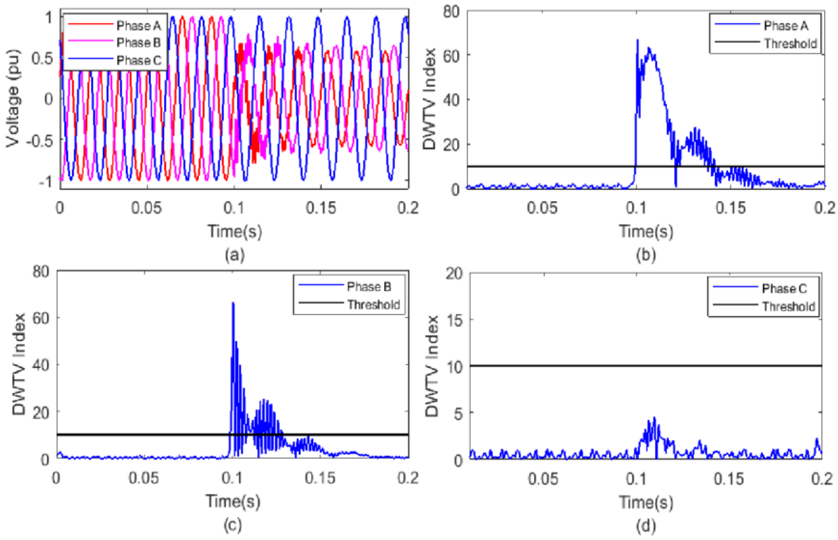

Figure 4. Detection of double line to ground (LLG) fault using voltage based fault index (a) voltage waveform (b) proposed DWTV-index for phase-A (c) proposed DWTV-index for phase-B (d) proposed DWTV-index for phase-C**.**

It is observed from the Figure 4 (b) that DWTV index corresponding to phase-A has values higher than the threshold value indicating that the phase-A is faulty. Similarly, this is observed from the Figure 4 (c) that DWTV index corresponding to phase-B has values higher than the threshold value indicating that the phase-B is faulty. This is observed from the Figure 4 (d) that DWTV index corresponding to phase-C has values lower than the threshold value indicating that the phase-C is also healthy in nature. Hence, proposed algorithm based on dicsrete wavelet transform is found to be effective in detection of the LLG using the features extracted from the voltage waveform.

4.4. Three Phase Fault Involving Ground

A three-phase fault involving the ground (LLLG) is simulated at middle of the transmission line by short circuiting all the three phases of the transmission line illustrated in Figure 4.1. Voltage signal is recorded on bus B1 at sending end of the transmission line. Voltage signal is decomposed using the discrete Wavelet transform with a sampling frequency of 3.8 kHz up to fourth level of decomposition with db5 as mother wavelet. The detailed coefficient obtained at second level of decomposition is obtained. The absolute values of this detailed coefficient are designated as DWTV index which is also considered as fault index for the recognition of faulty events. The voltage signal of all the phases is shown in Figure 5 (a). The DWTV index corresponding to phase-A is illustrated in Figure 5 (b). Similarly, the DWTV index corresponding to phase-B is illustrated in Figure 5 (c). The DWTV index corresponding to phase-C is illustrated in Figure 5 (d). Threshold value of the proposed fault index is taken as 10 to discriminate the faulty phases from the healthy phases.

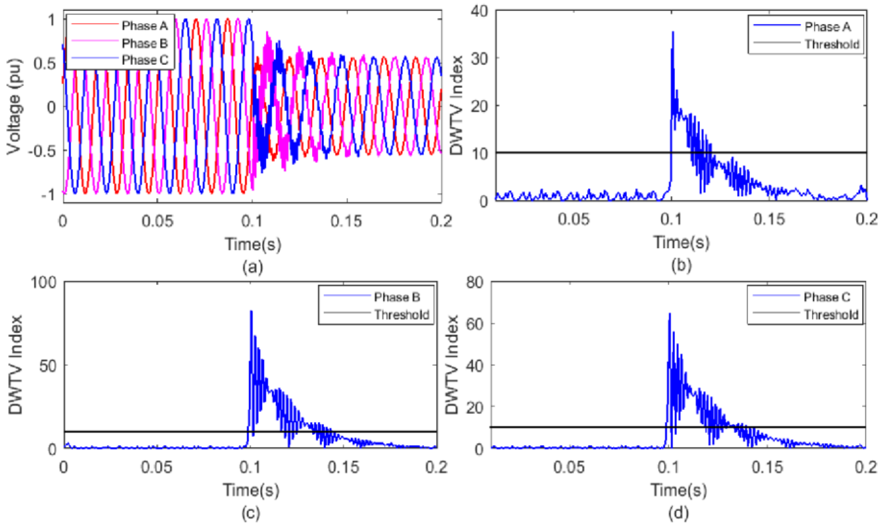

Figure 5. Detection of three phase involving ground (LLLG) fault using voltage-based fault index (a) voltage waveform (b) proposed DWTV-index for phase-A (c) proposed DWTV-index for phase-B (d) proposed DWTV index for phase-C.

It is observed from the Figure 5 (b) that DWTV index corresponding to phase-A has values higher than the threshold value indicating that the phase-A is faulty. Similarly, this is observed from the Figure 5 (c) that DWTV index corresponding to phase-B has values higher than the threshold value indicating that the phase-B is faulty. This is observed from the Figure 5 (d) that DWTV index corresponding to phase-C also has values higher than the threshold value indicating that the phase-C is also faulty in nature. Hence, proposed algorithm based on dicsrete wavelet transform is found to be effective in detection of the LLLG using the features extracted from the voltage waveform.

4.5. Effect of Variation of Fault Location

To investigate the effect of fault location on detection and classification of transmission line faults further investigations have been carried out at two extreme locations. One is taken at a distance of 10 km from sending end of the transmission line and second is taken at a distance of 220 km from sending of the line. Further, all types of faults have been investigated at these two extreme locations have been successfully identified using the proposed algorithm.

4.6. Effect of Variation of Fault Impedance

To investigate the effect of fault impedance on detection and classification of transmission line faults using proposed algorithm with voltage-based features further investigations have been carried out for fault impedances of 10 ohm and 25 ohm. All types of faults have been investigated with the 10 ohm and 25 ohm fault impedances.

4.7. Effect of Reverse Power Flow

To investigate the effect of reverse power flow on detection and classification of transmission line faults using algorithm based on voltage features further investigations have been carried out for power flowing from bus B2 to B1. Power flow has been reversed by changing the phase angles of the generators G1 and G2. Phase angle of generator G2 is set to 20° and that for the generator G1 is set equal to 0°. All types of faults have been investigated during the event of reverse power flow; however, the results of LG fault are discussed here.

A line to ground (LG) fault is simulated at middle of the transmission line by grounding the phase-A of the transmission line illustrated in Figure 1 while keeping flow of power from bus

B2 to bus B1. Voltage signal is recorded on bus B1 of the transmission line. Voltage signal is decomposed using the discrete Wavelet transform with a sampling frequency of 3.8 kHz up to fourth level of decomposition with db5 as mother wavelet. The detailed coefficient obtained at second level of decomposition is obtained. The absolute values of this detailed coefficient are designated as DWTV index which is also considered as fault index for the recognition of faulty events. The voltage signal of all the phases is shown in Figure 6 (a). The DWTV index corresponding to phase-A is illustrated in Figure 6 (b). Similarly, the DWTV index corresponding to phase-B is illustrated in Figure 6 (c). The DWTV index corresponding to phase-C is illustrated in Figure 6 (d). Threshold value of the proposed fault index is taken as 10 to discriminate the faulty phases from the healthy phases during the event of reverse power flow.

It is observed from the Figure 6 (b) that DWTV index corresponding to phase-A has values higher than the threshold value indicating that the phase-A is faulty. This is observed from the Figure 6 (c) that DWTV index corresponding to phase-B has values lower than the threshold value indicating that the phase-B is healthy. Similarly, this is also observed from the Figure 6 (d) that DWTV index corresponding to phase-C has values lower than the threshold value indicating that the phase-C is also healthy in nature. Hence, proposed algorithm based on dicsrete wavelet transform is found to be effective in detection of the LG simulated at middle of the transmission line during the event of reverse power flow using the features extracted from the voltage waveform.

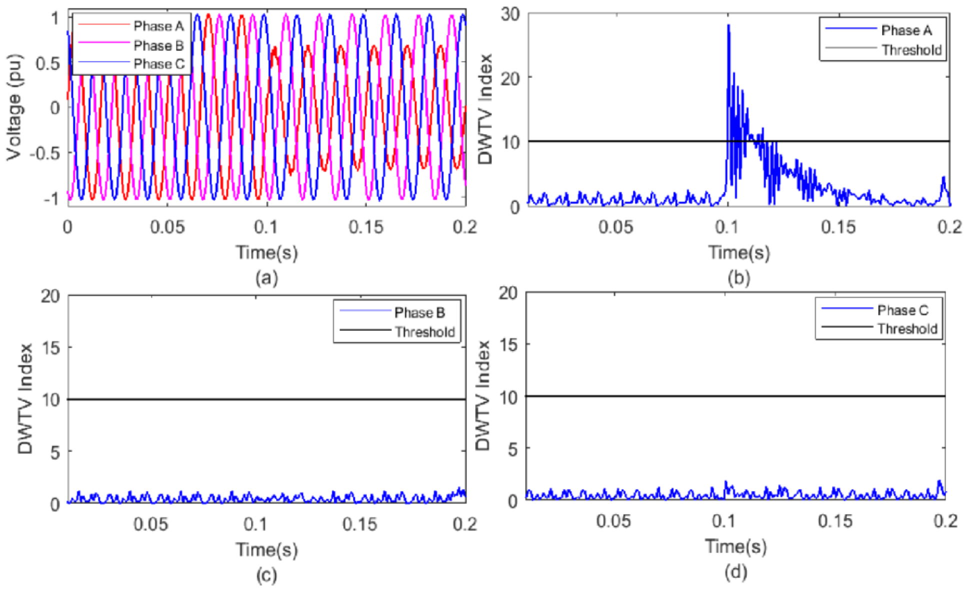

Figure 6. Effect of reverse power flow on detection of line to ground fault using voltage based fault index (a) voltage waveform (b) proposed DWTV-index for phase-A (c) proposed DWTV-index for phase-B (d) proposed DWTV index for phase-C**.**

4.8. Effect of Switching Transients

In the power system network, there are different types of operational events such as switching of capacitor banks and inductive load, these operational events also generate the transient components. The algorithm should be so much robust that these switching transients should not generate false signal to trip the line. Hence, performance of the proposed algorithm based on voltage features is also tested for operational events such as switching of capacitor banks and inductive load. It is observed that value of the fault index is lower than the threshold value during the events of switching of the capacitive and inductive loads.

4.9. Classification of Faults

The power system faults may be classified based on the number of faulty phases. The peak values of voltage-based fault index calculated on the bus B1 of the test system are provided in Table 2. It is observed that for LG fault, the values of fault index are high corresponding to one phase only whereas for the during the LLLG fault the values of the fault index corresponding to all phases are high. However, for the LL and LLG faults the fault index has high values for two phases only. Further, based on values of fault index corresponding to the faulty phase, various types of faults can be classified. During the event of LL fault the values of fault index is maximum for phase-A having value greater than 90 whereas the value is less than 30 during the event of LG fault. For the LLG fault the values of fault index lies between 50 and 90 whereas for the LLLG fault the values of fault index lies between 30 and 50.

Table 2. Peak Values of Proposed Voltage Based Fault Index.

Type of Fault	Proposed Fault Index		
	Phase-A	Phase-B	Phase-C
LG	28	1	1
LL	100	50	1
LLG	65	65	5
LLLG	35	80	65

5. Conclusions

This research work presents an algorithm based on voltage features for detection and classification of power system faults. Algorithm based on Discrete Wavelet transform is detailed in this paper. Voltage signal is taken as key factor for the proposed investigations. Voltage signal is recorded on sending end of the transmission line. Voltage signal is decomposed using the discrete Wavelet transform with a sampling frequency of 3.8 kHz up to fourth level of decomposition with db5 as mother wavelet. The detailed coefficient at second level of decomposition is designated as DWTV index which is taken as fault index. The investigated faults include the line to ground (LG) fault, double line (LL) fault, double line fault involving ground (LLG) and three phase faults involving ground (LLLG). Results related to various types of faults based on voltage-based fault index are presented and explained in detail in this thesis. It is concluded that proposed algorithm based on discrete wavelet transform using voltage signals is found to be effective in the detection and classification of various types of faults on the transmission line. The algorithm is successfully tested for the different fault locations on the transmission line, different values of the fault impedances and during the event of reverse power flow. The algorithm is also tested for the switching events such as switching of capacitor banks and inductive loads. It is concluded that the algorithm does not generate the tripping signal in the switching events. The tripping signal is generated during the faulty events only. Performance of the algorithm is also compared with the algorithm reported in literature to show the effectiveness of the proposed algorithm. The algorithm is successfully tested on a transmission line of line length 230 km in MATLAB/Simulink environment.

References

[1] Rashmi Sharma, Om Prakash Mahela and Sunil Agarwal, Detection of Power System Faults in Distribution System Using Stockwell Transform, 2018 IEEE International Students' Conference on Electrical, Electronics and Computer Science, 24-25 Feb. 2018, Bhopal, India.

[2] Ch. Durga Prasad and N. Srinivasu, Fault Detection in Transmission Lines using Instantaneous Power with ED based Fault Index, Proceedia Technology, vol 21, pp. 132-138, 2015.

[3] Om Prakash Mahela, Gulhasan Ahmad and Sheesh Ram Ola, Detection of Transmission Line Faults in the Presence of Thyristor Switched Capacitor Using Stockwell Transform, 2018 IEEE International Students' Conference on Electrical, Electronics and Computer Science, 24-25 Feb. 2018, Bhopal, India.

[4] K. R. Krishnanand, P. K. Dash and M. H. Naeem, Electrical Power and Energy Systems Detection, classification, and location of faults in power transmission lines, International Journal of Electrical Power and Energy Systems, vol 67, pp. 76-86, 2015.

[5] M. R. Noori and S. M. Shahrtash, Combined Fault Detector and Faulted Phase Selector for Transmission Lines Based on Adaptive Cumulative Sum Method, IEEE Transactions on Power Delivery, vol. 28(3), pp. 1779-1787, 2013.

[6] S. Zarbita, A. Lachouri and H. Boukadoum, A new approach of fast fault detection in HV-B transmission lines based on Detail Spectrum Energy analysis using oscillographic data, International Journal of Electrical Power and Energy Systems, vol 73, pp. 568-575, 2015.

[7] Jianhua Guo and Haidong Yang, A fault detection method for heat loss in a tyre vulcanization workshop using a dynamic energy consumption model and predictive baselines, Applied Thermal Engineering, vol 90, pp. 711-721, 2015.

[8] Zahra Moravej, Mohammad Pazoki and Mojtaba Khederzadeh, New Pattern-Recognition Method for Fault Analysis in Transmission Line with UPFC, IEEE Transactions on Power Delivery, vol. 30(3), 2015.

[9] Tamer A. Kawady, Nagy I. Elkalashy, Ayman E. Ibrahim and Abdel-Maksoud I. Taalab, Arcing fault identification using combined Gabor Transform-neural network for transmission lines, International Journal of Electrical Power and Energy Systems, vol 61, pp. 248-258, 2014.

[10] Yasir Usama, Xiaomin Lu, Hasib Imam, Chitradeep Sen and Narayan C. Kar, Design and implementation of a wavelet analysis-based shunt fault detection and identification module for transmission lines application, IET Generation, Transmission & Distribution, vol 8(3), pp. 431-441, 2014.

[11] André de Souza Gomes, Marcelo Azevedo Costa, Thomaz Giovani Akar de Faria and Walmir Matos Caminhas, Detection and Classification of Faults in Power Transmission Lines Using Functional Analysis and Computational Intelligence, IEEE Transactions on Power Delivery, vol 28(3), pp. 1402-1413, 2013.

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