International Journal of Innovative Computing, Information and Control
Volume **8**, Number **9**, September **2012**

ICIC International ©2012 ISSN 1349-4198
pp. 6491–6502

THE PROTECTION OF TRANSMISSION NETWORK SYSTEMS USING DISCRETE WAVELET TRANSFORMS

Atthapol Ngaopitakkul and Chaichan Pothisarn

Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang
Chalongkrung Rd. Ladkrabang, Bangkok 10520, Thailand
knatthap@kmitl.ac.th

Received May 2011; revised October 2011

Abstract. *This paper proposes a novel protective relay algorithm to protect transmission systems using Discrete Wavelet Transforms (DWT). Fault conditions are simulated using PSCAD/EMTDC in order to obtain current signals. Various cases based on Thailand electricity transmission systems are carried out to verify the validity of the proposed technique. The maximum coefficients of the positive sequence current obtained from all buses are compared in order to detect the faulty bus on a three-bus transmission network with a loop structure. The first peak time of positive sequence current obtained from the faulty bus is used as input data for travelling wave equation. The coefficient ratio between buses that the fault occurs is calculated so that the proper protective relay sequence can be selected. The result is shown that the proposed algorithm is capable of locating the fault position as well as arranging the protective relay sequence, with satisfactory accuracy results, and is suitable for all types of fault that occurs in different sections on the transmission lines.*
Keywords: Wavelet transform, Transmission system, Fault, Protective relay sequence

1. **Introduction.** Occurrence of faults can cause damage to the equipment; thus, protecting transmission line is an important task to safeguard electric power system. Generally, when a fault occurs on a transmission line, many additional transmission and sub-transmission lines are protected with distance relays. The precision protection schemes have to be developed, particularly in fault detection and fault location on the transmission lines. Several algorithms employed in fault detection and fault location have been developed for the protective relays [1-4] but these several algorithms have different solutions and techniques [5-7]. Single-ended impedance-based fault locators calculate the fault location from the apparent impedance seen looking into the line from one end. A correct fault location estimation is influenced by many factors such as influence of zero-sequence mutual effects on the components, untransposed line and charging capacitance. The two-terminal location methods are more accurate than one-terminal methods and are able to minimize or eliminate the effects of fault resistance, loading and charging current. The main drawback is that data from both ends must be terminated by the relay or other device collecting the data. Conventional method for fault location which is employed in Electricity Generating Authority of Thailand (EGAT) is Line Fault Locator (LFL) Type "c". However, LFL has a disadvantage since devices of LFL are complicated and expensive. The currently most effective technique for identifying fault location, based on a travelling wave, has been proposed in several papers in the 1980s [1-3].

During the 1990's, the development in the algorithm for detecting the faults on the transmission lines has been progressed and results in transient based techniques [8]. In order that the transient based protection can be greatly successful in operation, the application of wavelet transform (WT) is widely used. The advantage of the transform is that the band of analysis can be fine adjusted so that high frequency components and low frequency components are detected precisely. Results from the wavelet transform are shown both in time domain and frequency domain. The development of the algorithm for locating fault on the transmission line with the wavelet transform was initially proposed by F. H. Magnago et al. [9]. In the literature for fault location, most researches [9-17] have only considered the fault location for single bus and two-bus systems but not for multi-terminal. The location of the fault was normally calculated using travelling wave approach, as presented in [9]. In addition, artificial intelligence (AI) has been reported in the literature for fault location. In [16], this paper shows how diverse ANN structures can be applied to the processes of fault classification and fault location in overhead two-terminal transmission lines, with single and double circuit. Nowadays, fault diagnosis for the transmission line has been also progressed with the applications of WT and AI [18,19]. Although the accuracy of fault locations from the prediction of the WT and AI is highly satisfactory, these algorithms could not discriminate between faults on a protected circuit and those on other circuits connected to the same busbars, i.e., between forward and reverse faults. It is important to identify the fault direction and fault location on transmission lines as soon as possible to repair and maintain the power system.

In the literature for directional relay [20-25], several algorithms used in fault direction have been developed for the protective relays. In [20], this paper presented an application of a neural network ability in pattern recognition and classification to provide a solution using Elman recurrent network to detect the direction of a fault on a transmission line. G. Benmouyal el al. [21] applied three scalar products between three voltage and current phasor pairs and directionality of a fault can be determined. A. Fernandez el al. [22] presented a novel approach to fault detection, faulted phase selection and direction estimation based on artificial neural networks. A novel wavelet based directional protection scheme was presented in [23]. A directional relay algorithm for EHV transmission lines using positive sequence fault components was presented in [24]. M. M. Mansour el al. [25] presented a method based on particle swarm optimization for the coordination of directional overcurrent relays.

However, most researches have only considered the over-current relay for single bus and two-bus systems but not for multi-terminal. In fact, transmission lines are connected to each other and become a large grid connected system owing to increasing demand of electric power. During faults, it is necessary that the protection system deals with a complicated transmission network. As a result, it is important to take into account the loop structure of the transmission network for fault location and direction processes in order that the transmission line can re-interconnect with power system. A decision algorithm based on discrete wavelet transforms (DWT) is an alternative or improvement to the existing protective relaying functions. A combination of DWT and travelling wave technique is employed for the location of fault on the transmission systems. In addition, the direction of fault on a three-bus transmission network can be identified using DWT. The systems under consideration have the loop structure. The fault conditions are simulated using PSCAD/EMTDC. The current waveforms obtained from PSCAD/EMTDC are extracted to several scales with the Wavelet transform, and the coefficients of the first scale from the Wavelet Transform are investigated. In addition, the construction of the decision algorithm is detailed and implemented with various case studies based on Thailand electricity transmission systems.

2. **Power System Simulation Using PSCAD/EMTDC.** The PSCAD/EMTDC is employed to simulate fault signals at a sampling rate of 200 kHz (corresponding to the chosen sampling time of 5 μs used in PSCAD/EMTDC). The fault types are chosen based on the Thailand's transmission system as shown in Figure 1. To avoid complexity, the fault resistance is assumed to be 10 Ω. Fault patterns in the simulations are performed with various changes of system parameters as follows:

- Fault types under consideration, namely: single phase to ground (SLG : AG, BG, CG), double-line to ground (DLG : ABG, BCG, CAG), line to line (L-L : AB, BC, CA) and three-phase fault (3-P : ABC).
- Fault locations on each transmission line are at the distance of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%, measured from the sending end.
- Inception angle on a voltage waveform is varied between 0°-330°, with the increasing step of 30°. Phase A is used as a reference.

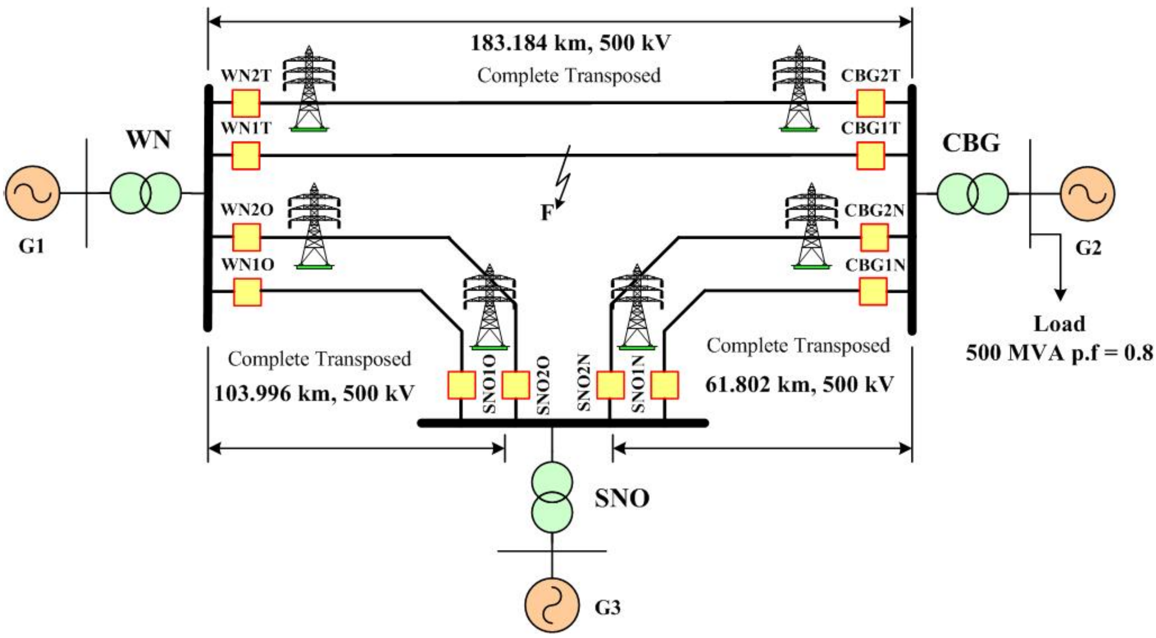

FIGURE 1. The system used in simulations studies for loop structure [26]

3. **Discrete Wavelet Transform Decision Algorithm and Results.**

3.1. **Fault detection algorithm.** The fault signals generated using PSCAD/EMTDC are interfaced to the MATLAB/Simulink for a construction of fault detection process. Fault detection [27] is processed using the positive sequence current signals. The Clark's transformation matrix is employed to calculate the positive sequence currents. The fault signals generated using PSCAD/EMTDC are extracted to several scales with the DWT in order to analyse the transient high frequency components using wavelet toolbox. The mother wavelet, daubechies4 (db4) [27-29], is employed to decompose high frequency components from the signals. After applying the DWT to the positive sequence currents, the comparison of the coefficients from each scale is considered. Coefficients obtained using DWT of signals are squared so that the abrupt change in the spectra can be clearly found. It is clearly seen that when fault occurs, the coefficients of high frequency components have a sudden change compared with those before an occurrence of the faults as illustrated in Figure 2. An example of fault current signals is shown in Figure 2. This is a fault occurring with phase A to ground fault at the 20% in length of section WN-CBG in the transmission network shown in Figure 1. When carefully considering, it is found that all coefficients obtained from the positive sequence currents at every bus have a change of more than 5 times of a normal value during the faults due to the effect of a loop structure of the transmission network. The comparison among the maximum coefficients in first scale of each bus, which can detect fault, is performed in order to detect the faulty bus.

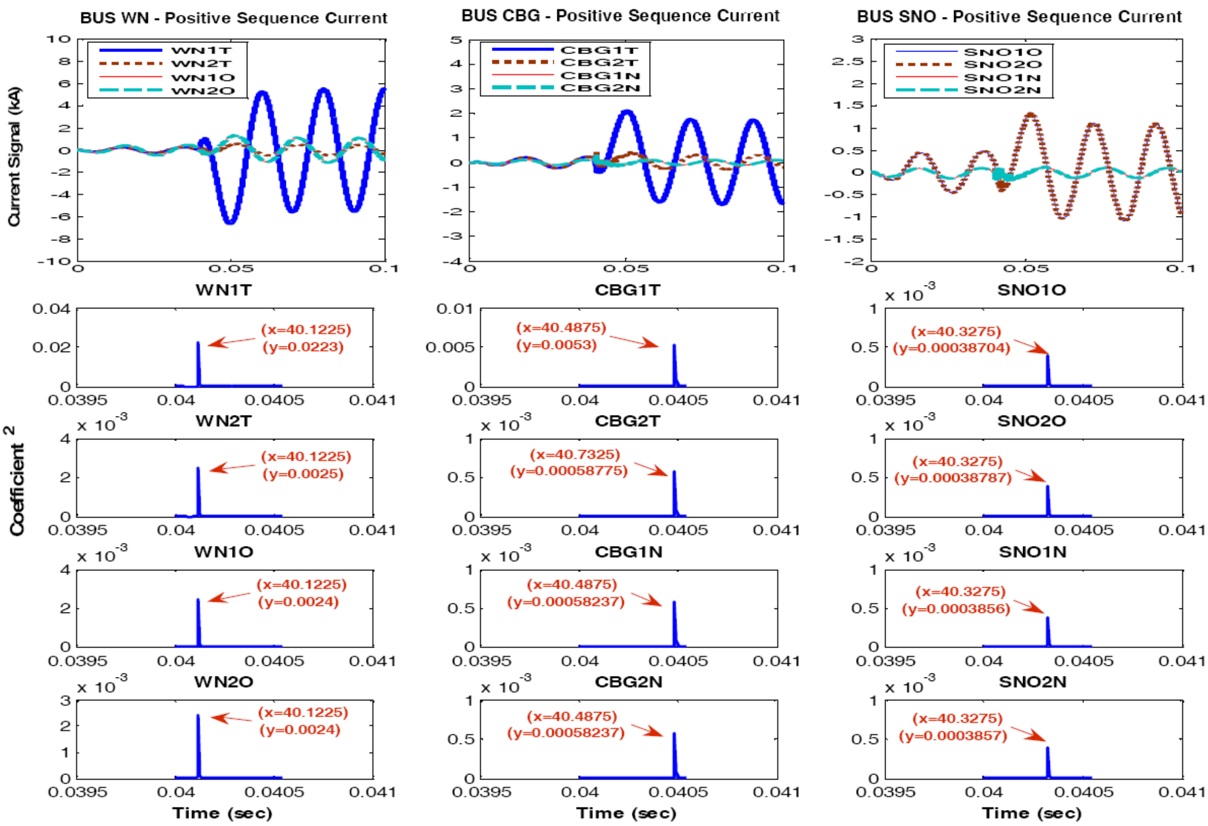

FIGURE 2. Example of wavelet transform for the positive sequence of phase A to ground fault at the transmission system (section WN-CBG)

where,

WN1T, WN2T are WN bus section WN-CBG circuit 1 and circuit 2 respectively.
WN1O, WN2O are WN bus section WN-SNO circuit 1 and circuit 2 respectively.
CBG1T, CBG2T are CBG bus section WN-CBG circuit 1 and circuit 2 respectively.
CBG1N, CBG2N are CBG bus section SNO-CBG circuit 1 and circuit 2 respectively.
SNO1O, SNO2O are SNO bus section WN-SNO circuit 1 and circuit 2 respectively.
SNO1N, SNO2N are SNO bus section SNO-CBG circuit 1 and circuit 2 respectively.

From Figure 2, it can be seen that maximum coefficients of positive currents from the faulty buses involving with a fault location (in this case, WN1T and CBG1T, with the fault location between them) are in the highest values when compared with those of other healthy buses. In case of double circuit, the maximum coefficients obtained from the same buses are also compared in order to detect the faulty line as follows:

If $WN1T^L_{(post)} > \max\left(WN2T^L_{(post)}, WN1O^L_{(post)}, WN2O^L_{(post)}\right)$
then RELAY $WN1T$ TRIP
elseif $WN2T^L_{(post)} > \max\left(WN1T^L_{(post)}, WN1O^L_{(post)}, WN2O^L_{(post)}\right)$
then RELAY $WN2T$ TRIP
elseif $WN1O^L_{(post)} > \max\left(WN1T^L_{(post)}, WN2T^L_{(post)}, WN2O^L_{(post)}\right)$

then RELAY $WN1O$ TRIP
elseif $WN2O^L_{(post)} > \max\left(WN1T^L_{(post)}, WN2T^L_{(post)}, WN1O^L_{(post)}\right)$
then RELAY $WN2O$ TRIP
end
where, L = the scale of Wavelet Transform.

3.2. **Fault location algorithm.** From Figure 2, the maximum coefficients of positive sequence currents from the WN1T and CBG1T are detected as faulty buses with the highest values when compared with those of other healthy buses. The first peak time obtained from the faulty bus [29] is used as input data for travelling wave equation as shown in Equation (1) and Figure 3. Due to the fact that WN1T(0.0223) and CBG1T(0.0053) from the faulty buses are the two highest values, the first peak time in first scale of faulty buses are used as input data for travelling wave equation as shown in Figure 3.

$$d = \frac{[LT - v \times (t_B - t_A)]}{2} \tag{1}$$

where,
d = the fault location measured from the sending end
LT = the length of the line that the fault is detected
t_A = the time that the fault at the sending end is detected
t_B = the time that the fault at the receiving end is detected
v= velocity of the travelling wave (297322 km/s)

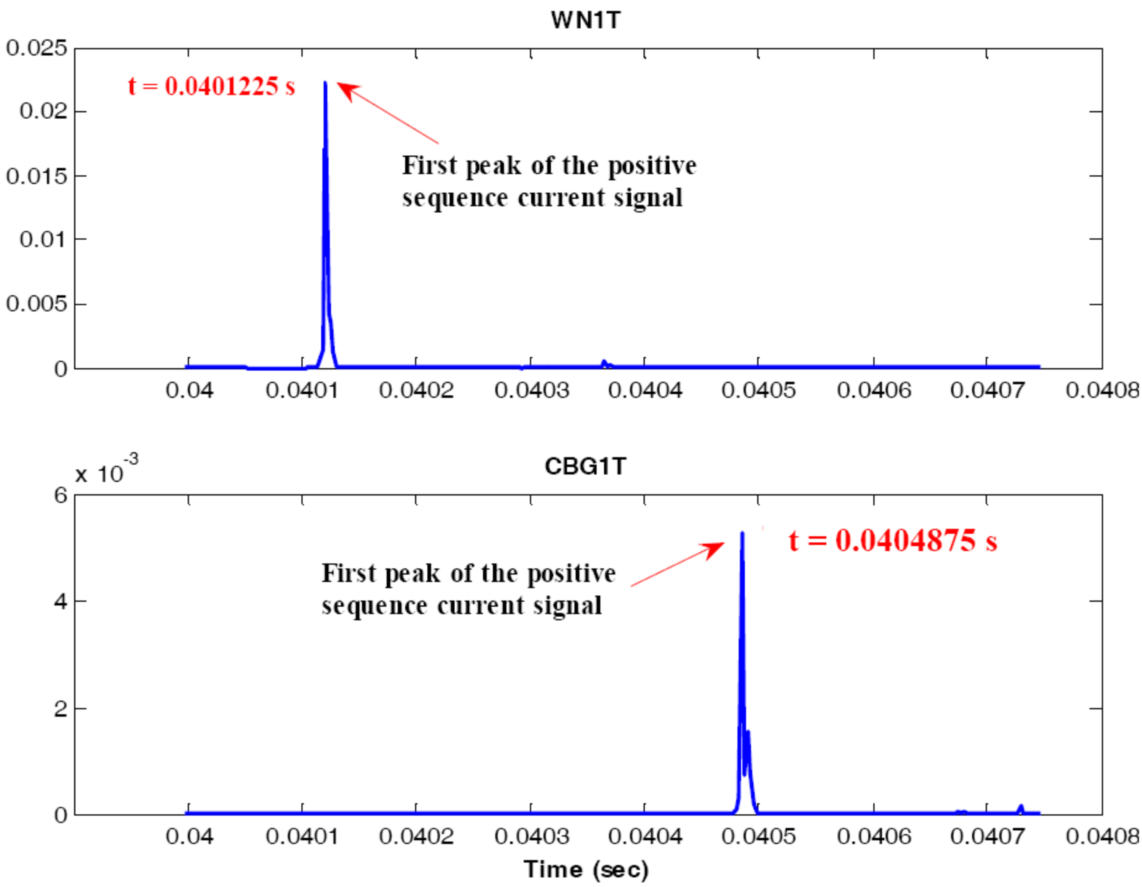

Figure 3. The first peak in the scale 1 at the faulty bus for the signal shown in Figure 2

From Figure 3, the first peak time in the scale 1 is calculated according to the travelling wave equation in order to identify the fault location. The comparison of the average error from the results due to the proposed algorithm in this paper is shown in Table 1.

3.3. **Fault direction algorithm.** The coefficient ratio between buses that the fault occurs is calculated in order that the proper protective relay sequence can be selected as shown in Equation (2). If discrimination ratio is positive, protective relay is installed at the sending end and the receiving end will be operated respectively as shown in Figure 4.

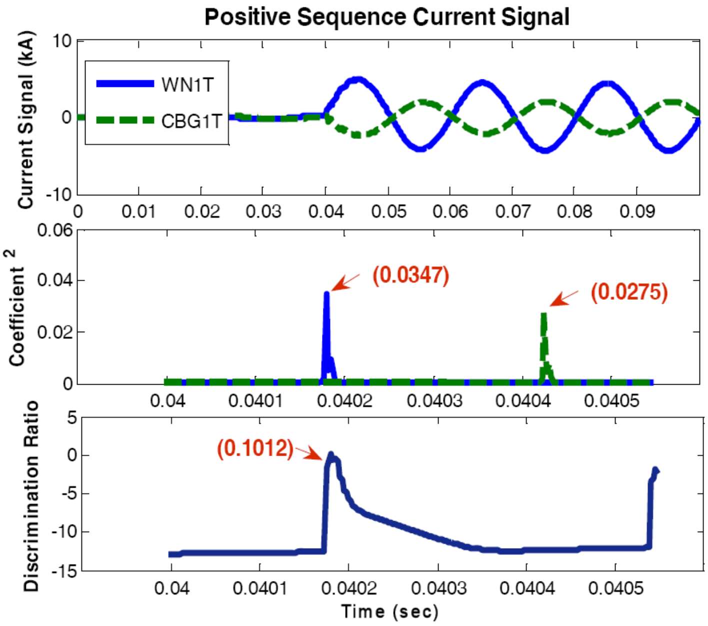

FIGURE 4. The proper protective relay sequence with phase A to ground fault at the 30% of length of section WN-CBG in the transmission network

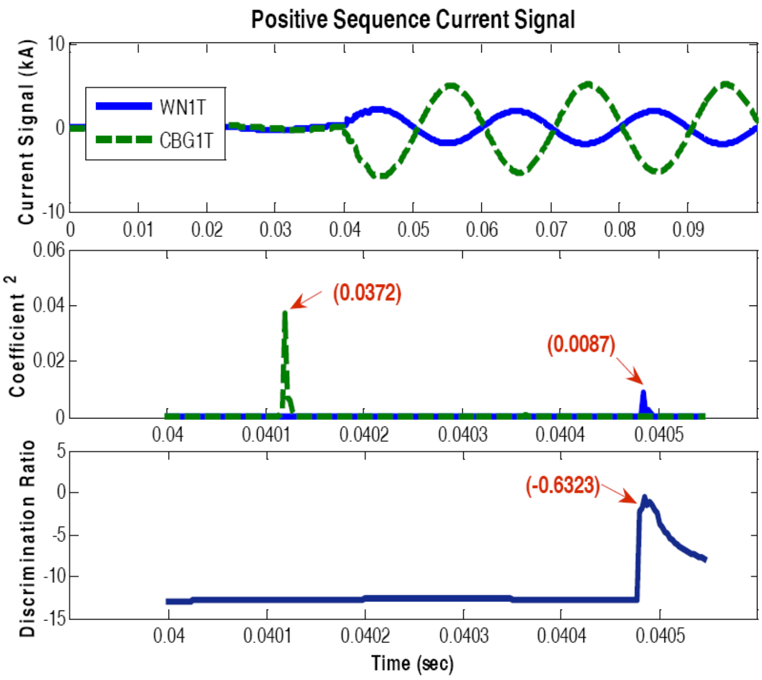

FIGURE 5. The proper protective relay sequence with phase A to ground fault at the 80% of length of section WN-CBG in the transmission network

This is a fault occurring with phase A to ground fault at the 30% of the length of section WN-CBG in the transmission network. If discrimination ratio is negative, protective relay is installed at the receiving end and the sending end will be operated respectively as shown in Figure 5. This is a fault occurring with phase A to ground fault at the 80% of the length of section WN-CBG in the transmission network. From Figures 4 and 5, it is found that the proposed method is able to detect the faulty bus and the proper protective relay sequence.

$$\text{Discrimination Ratio} = \log\left(I_{ef}/I_{er}\right) \tag{2}$$

where,
I_{ef} = Coefficients obtained from the sending end
I_{er} = Coefficients obtained from the receiving end

3.4. **Result.** After the decision algorithm is processed, case studies are varied so that the algorithm capability can be verified. Various case studies were performed with various types of faults at each location on the transmission network including the variation of fault inception angles and locations at each transmission lines. The total number of the case studies was 7128. The results obtained from the algorithm proposed in this paper are shown in Table 1 and Table 2. It is shown that the proposed algorithms is able to detect the faulty bus with the accuracy of 100%, identify fault location with the average error of 0.4639 km as presented in Table 1, and identify the proper protective relay sequence with the average accuracy of 99.90% as presented in Table 2. The results obtained from the proposed algorithm in this paper are shown in Tables 3-8 and in Figures 6 and 7.

TABLE 1. Results of the fault location

Section	**Maximum error (km)**	**Minimum error (km)**	**Average error (km)**
WN-CBG	1.1064	0.0000	0.7104
WN-SNO	0.4833	0.0000	0.2712
SNO-CBG	0.7563	0.0000	0.4103
Average	1.1064	0.0000	0.4639

TABLE 2. Accuracy of fault detection and the proper protective relay sequence from the proposed algorithm

Section	**Types of faults**	**Number of case studies**	**Fault detection**	**Direction of fault**	**Proper protective relay sequence**
WN-CBG	SLG	648	100%	100%	100%
	DLG	648	100%	100%	98.77%
	L-L	648	100%	100%	100%
	ABC	432	100%	100%	100%
WN-SNO	SLG	648	100%	100%	100%
	DLG	648	100%	100%	100%
	L-L	648	100%	100%	100%
	ABC	432	100%	100%	100%
SNO-CBG	SLG	648	100%	100%	100%
	DLG	648	100%	100%	100%
	L-L	648	100%	100%	100%
	ABC	432	100%	100%	100%
Average		7128	100%	100%	99.90%

Table 3. Results of phase A to ground fault at the 20% of length of section WN-CBG in the transmission network for various inception angles

Real location (km)	Inception angle	Maximum Coefficients		Identify Direction of Relay		
		Sending end	Receiving end	Discrimination	First Trip	Second Trip
36.6 (WN-CBG)	0	0.001	0.000239	0.620821	WN1T	CBG1T
	60	0.038	0.0089	0.630394	WN1T	CBG1T
	150	0.0223	0.0053	0.624029	WN1T	CBG1T
	270	0.0592	0.014	0.626194	WN1T	CBG1T

Table 4. Results of fault location at the 20% of length of section WN-CBG in the transmission network for various inception angles

Real location (km)	Inception angle	First peak time (ms)		Location (km)	
		t_A	t_B	Calculation	Error
36.6 (WN-CBG)	0	40.1225	40.4875	37.7	1.1
	60	40.1225	40.4875	37.7	1.1
	150	40.1225	40.4875	37.7	1.1
	270	40.1225	40.4875	37.7	1.1

Table 5. Results of phase A to ground fault at section WN-CBG for various lengths of the transmission network (inception angle is 150)

Real location (km)	Inception angle	Maximum Coefficients		Identify Direction of Relay		
		Sending end	Receiving end	Discrimination	First Trip	Second Trip
36.6 (WN-CBG)	150	0.0223	0.0053	0.624029	WN1T	CBG1T
54.9 (WN-CBG)	150	0.0207	0.0164	0.101126497	WN1T	CBG1T
73.2 (WN-CBG)	150	0.0047	0.0039	0.081033251	WN1T	CBG1T
91.5 (WN-CBG)	150	0.0007585	0.0007615	–0.001737135	CBG1T	WN1T
109.8 (WN-CBG)	150	0.0039	0.0048	–0.09017663	CBG1T	WN1T

Table 6. Results of fault location at section WN-CBG for various lengths of the transmission network (inception angle is 150)

Real location (km)	Inception angle	First peak time (ms)		Location (km)	
		t_A	t_B	Calculation	Error
36.6 (WN-CBG)	150	40.1225	40.4875	37.7	1.1
54.9 (WN-CBG)	150	40.1825	40.4275	55.39	0.49
73.2 (WN-CBG)	150	40.2475	40.3675	73.81	0.61
91.5 (WN-CBG)	150	40.3075	40.3075	91.5	0
109.8 (WN-CBG)	150	40.3675	40.2475	109.19	0.61

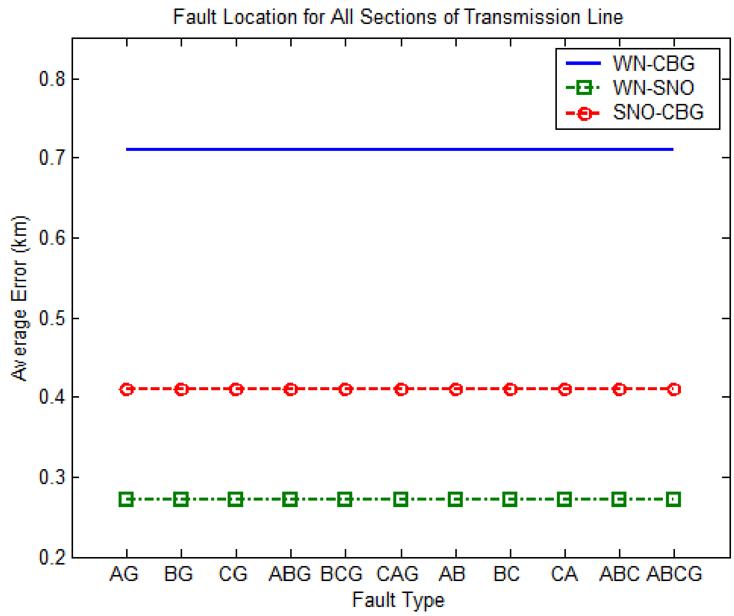

FIGURE 6. Comparison of average error for fault locations with various types of faults

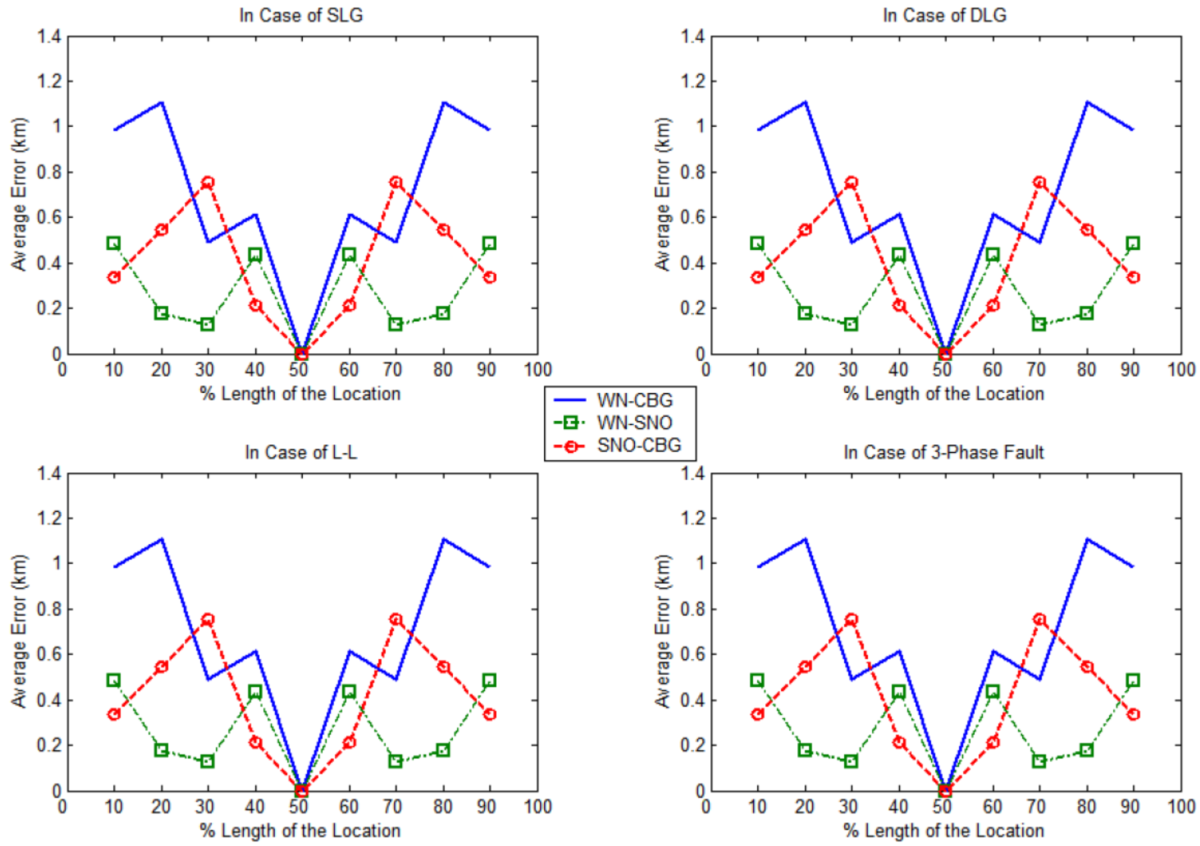

FIGURE 7. Comparison of average error for fault locations with various lengths of the transmission lines that fault occurs

Table 7. Results of phase A to ground fault at the 20% of length of section for various sections in the transmission network (inception angle is 150)

Real location (km)	Inception angle	Maximum Coefficients		Identify Direction of Relay		
		Sending end	Receiving end	Discrimination	First Trip	Second Trip
36.6 (WN-CBG)	150	0.0223	0.0053	0.624029	WN1T	CBG1T
12.4 (WN-SNO)	150	0.0029	0.0016	0.258278015	WN1O	SNO1O
20.8 (SNO-CBG)	150	0.0274	0.0142	0.285462218	SNO1N	CBG1N

Table 8. Results of fault location at the 20% of length of section for various sections in the transmission network (inception angle is 150)

Real location (km)	Inception angle	First peak time (ms)		Location (km)	
		t_A	t_B	Calculation	Error
36.6 (WN-CBG)	150	40.1225	40.4875	37.7	1.1
12.4 (WN-SNO)	150	40.0425	40.1675	12.57	0.17
20.8 (SNO-CBG)	150	40.068	40.276	21.345	0.545

From Tables 3-8 and Figures 6 and 7, it is shown that when the case studies are tested with various fault inception angles and different fault locations on a three-bus transmission network with a loop structure, the accuracy of the algorithm is highly satisfactory.

4. **Conclusions.** This paper is aimed to present an algorithm based on a discrete wavelet transform (DWT) for identifying the direction of fault on a three-bus transmission network with a loop structure. In addition, a combination of DWT and travelling wave technique in order to identify the fault location on the transmission systems is also presented in this paper. The DWT has been employed to decompose high frequency components from fault signals. The maximum coefficients of the positive sequence current obtained from all buses are compared in order to detect the faulty bus on a three-bus transmission network with a loop structure. The coefficient ratio between buses that the fault occurs is calculated so that the proper protective relay sequence can be selected. The travelling wave theory is applied in order to calculate the location of fault. The first peak times obtained from the faulty bus are used as input data for travelling wave equation. Various case studies including the variation of fault inception angles, fault types and fault locations have been carried out. The results show that the proposed algorithm is able to detect the faulty bus with the accuracy of 100%, identify fault location with the average error of 0.4639 km as shown in Table 1, and identify the proper protective relay sequence with the average accuracy of 99.90% as shown in Table 2. Thus, this technique is feasible in the development of a modern protection scheme for electrical power transmission network systems.

Acknowledgment. This work is partially supported by the King Mongkut's Institute of Technology Ladkrabang Research fund. The authors would like to thank for this financial support. The authors would like also to gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

REFERENCES

[1] P. A. Crossley and P. G. McLaren, Distance protection based on travelling waves, *IEEE Trans. on Power Apparatus and Systems*, vol.102, no.9, pp.2581-2589, 1983.

[2] P. G. McLaren and S. Rajendra, Travelling wave techniques applied to the protection of teed circuits: Principle of travelling wave techniques, *IEEE Trans. on Power Apparatus and Systems*, vol.104, no.12, pp.3544-3550, 1985.

[3] A. O. Ibe and B. J. Cory, A travelling wave based fault locator for two- and three-terminal networks, *IEEE Trans. on Power Delivery*, vol.1, no.2, pp.283-288, 1986.

[4] M. B. Dewe, S. Sankar and J. Arrillaga, The application of satellite time references to HVDC fault location, *IEEE Trans. on Power Delivery*, vol.8, no.3, pp.1295-1302, 1993.

[5] G. Song, J. Suonan, Q. Xu, P. Chen and Y. Ge, Parallel transmission lines fault location algorithm based on differential component net, *IEEE Trans. on Power Delivery*, vol.20, no.4, pp.2396-2406, 2005.

[6] L. L. Lai, E. Vaseekar, H. Subasinghe and N. Rajkumar, Wavelet transform and neural networks for fault location of a teed – Network, *IEEE Power System Technology*, pp.807-811, 2000.

[7] Y.-H. Lin, C.-W. Liu and C.-S. Yu, A new fault locator for three-terminal transmission lines-using two-terminal synchronized voltage and current phasors, *IEEE Trans. on Power Delivery*, vol.17, no.2, pp.452-459, 2002.

[8] Z. Q. Bo, F. Jiang, Z. Chen, X. Z. Dong, G. Weller and M. A. Redfern, Transient based protection for power transmission systems, *IEEE Power Engineering Society Winter Meeting*, vol.3, pp.1832-1837, 2000.

[9] H. Fernando, Magnago and A. Abur, Fault location using wavelets, *IEEE Trans. on Power Delivery*, vol.13, no.4, pp.1475-1480, 1998.

[10] P. Makming, S. Bunjongjit, A. Kunakorn, S. Jiriwibhakorn and M. Kando, Fault diagnosis in transmission lines using wavelet transform analysis, *IEEE/PES Transmission and Distribution Conference and Exhibition 2002, Asia Pacific, 2002*, vol.3, pp.2246-2250, 2002.

[11] J. A. Jiang, C.-S. Chen and C.-W. Liu, A new protection scheme for fault detection, direction discrimination, classification, and location in transmission line, *IEEE Transactions on Power Delivery*, vol.18, no.1, pp.34-42, 2003.

[12] H. Ha, B. Zhang and Z. Lv, A novel principle of single-ended fault location technique for EHV transmission lines, *IEEE Trans. on Power Delivery*, vol.18, no.4, pp.1147-1151, 2003.

[13] T. Kawady and J. Stenzel, A practical fault location approach for double circuit transmission lines using single end data, *IEEE Trans. on Power Delivery*, vol.18, no.4, pp.1166-1173, 2003.

[14] J. Izykowski, E. Rosolowski and M. M. Saha, Locating faults in parallel transmission lines under availability of complete measurements at one end, *IEE Proc. of on Generation, Transmission and Distribution*, vol.151, no.2, pp.268-273, 2004.

[15] S. M. Brahma and A. A. Girgis, Fault location on a transmission line using synchronized voltage measurements, *IEEE Trans. on Power Delivery*, vol.19, no.4, pp.1619-1622, 2004.

[16] J. Gracia, A. J. Mazon and I. Zamora, Best ANN structures for fault location in single-and double-circuit transmission lines, *IEEE Trans. on Power Delivery*, vol.20, no.4, pp.2389-2395, 2005.

[17] S. P. Valsan and K. S. Swarup, Wavelet transform based digital protection for transmission lines, *Electrical Power and Energy Systems*, vol.31, pp.379-388, 2009.

[18] C. Fan, K. Li, W. Chan, W. Yu and Z. Zhang, Application of wavelet fuzzy neural network in locating single line to ground fault (SLG) in distribution lines, *International Journal of Electrical Power & Energy Systems*, vol.29, no.6, pp.497-503, 2007.

[19] M. J. Reddy and D. K. Mohanta, A wavelet-fuzzy combined approach for classification and location of transmission line faults, *Electrical Power and Energy Systems*, vol.29, pp.669-678, 2007.

[20] M. Sanaye-Pasand and O. P. Malik, High speed transmission system directional protection using an elman network, *IEEE Trans. on Power Delivery*, vol.13, no.4, pp.1040-1045, 1998.

[21] G. Benmouyal and J. Mahseredjian, A combined directional and faulted phase selector element based on incremental quantities, *IEEE Trans. on Power Delivery*, vol.16, pp.478-484, 2001.

[22] A. Fernandez and N. Ghonaim, A novel approach using a FIRANN for fault detection and direction estimation for high voltage transmission lines, *IEEE Trans. on Power Delivery*, vol.17, no.4, pp.894-900, 2002.

[23] C. Wei, O. P. Malik, X. Yin, D. Chen and Z. Zhang, Study of wavelet based ultra high speed directional transmission line protection, *IEEE Trans. on Power Delivery*, vol.18, no.4, pp.1134-1139, 2003.

[24] H. Gao and P. A. Crossley, Design and evaluation of a directional algorithm for transmission line protection based on positive sequence fault components, *IEE Proc. of Generation, Transmission and Distribution*, vol.153, no.6, pp.711-7185, 2006.
[25] M. M. Mansour, S. F. Mekhamer and N. E. S. El-Kharbawe, A modified particle swarm optimizer for the coordination of directional overcurrent relays, *IEEE Trans. on Power Delivery*, vol.22, no.3, pp.1400-1410, 2007.
[26] *Switching and Transmission Line Diagram*, Electricity Generation Authorisation Thailand (EGAT).
[27] A. Ngaopitakkul and C. Jettanasen, Combination of discrete wavelet transform and probabilistic neural network algorithm for detecting fault location on transmission system, *International Journal of Innovative Computing, Information and Control*, vol.7, no.4, pp.1861-1874, 2011.
[28] N. S. D. Brito, B. A. Souza and F. A. C. Pires, Daubechies wavelets in quality of electrical power, *Proc. of IEEE International Conference on Harmonics and Quality of Power*, pp.511-515, 1998.
[29] P. Chiradeja and C. Pothisarn, Identification of the fault location for three-terminal transmission lines using discrete wavelet transform, *Proc. of IEEE International Conference on Transmission and Distribution (T&D Asia 2009)*, pp.1-4, 2009.