Identification of Fault Locations in Underground Distribution System using Discrete Wavelet Transform

A. Ngaopitakkul, C. Apisit, C. Pothisarn, C. Jettanasen and S. Jaikhan

Abstract—In this paper, a technique for detecting faults in underground distribution system is presented. Discrete Wavelet Transform (DWT) based on traveling wave is employed in order to detect the high frequency components and to identify fault locations in the underground distribution system. The first peak time obtained from the faulty bus is employed for calculating the distance of fault from sending end. The validity of the proposed technique is tested with various fault inception angles, fault locations and faulty phases. The result is found that the proposed technique provides satisfactory result and will be very useful in the development of power systems protection scheme.

***Index Terms*—Wavelet Transform, Travelling wave, Fault Location, Underground Cable, ATP/EMTP.**

I. Introduction

The main function of the electrical transmission and distribution systems is to transport electrical energy from the generation unit to the customers. Generally, when fault occurs on transmission lines, detecting fault is necessary for power system in order to clear fault before it increases the damage to the power system. Although the underground cable system provides higher reliability than the overhead line system, it is hard to seek out the fault location. The demand for reliable service has led to the development of technique of locating faults. During the course of recent years, the development of the fault diagnosis has been progressed with the applications of signal processing techniques and results in transient based techniques. It has been found that the wavelet transform is capable of investigating the transient signals generated in power system. The location of fault using wavelet transform was initially proposed by F. H. Magnago et al [1]. Recently, several techniques have been employed to determine the fault location in underground cable such as age cable [2], bridge technique [3], Murry loop pulse radar [3] and traveling wave [4-6] but each technique has different solutions. In addition, a technique selection is available for fault locating; it depends on several factors such as length of circuit (or cable) and type of fault (sustained or temporary), etc.

Manuscript received January 12, 2010. This work was supported in part by the faculty of engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL).

A. Ngaopitakkul, C. Apisit, C. Pothisarn and C. Jettanasen are with Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand (e-mail: knatthap@kmitl.ac.th).

S. Jaikhan is with Designs and Supervision Department, Metropolitan Electricity Authority, Bangkok 10900, Thailand (e-mail: sirarote-ong@hotmail.com).

This paper is aimed to present a technique based on a combination of Discrete Wavelet Transform and traveling wave in order to determine the fault location in the underground distribution systems. The fault conditions are simulated using ATP/EMTP and the current waveforms obtained from the simulation are extracted using the wavelet transform. The coefficients of the first scale from the wavelet transform that can detect fault are investigated. The travelling wave theory is applied to calculate the distance of fault from sending end.

II. Simulation

The ATP/EMTP [7] is employed to simulate fault signals, at a sampling rate 200 kHz. The system employed in case studies is chosen based on the underground distribution system as illustrated in Figure 1. In addition, a cross-sectional view of a cable is shown in Figure 2. To avoid complexity, the fault resistance is assumed to be 10Ω. Fault patterns in the simulations are performed with various changes of system parameters as follows:

- Fault types are under consideration, namely: single phase to ground (SLG), double-line to ground (DLG), line to line (L-L) and three-phase fault (3-P).
- Fault locations on the underground distribution system are the distance of 1, 8, 27 km measured from the sending end.
- Inception angle on a voltage waveform is varied between 0°-180° , with the increasing step of 30°. Phase A is used as a reference.

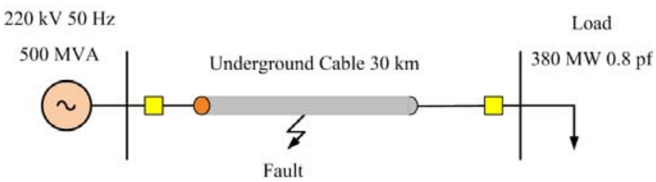


Figure 1. The system used in simulation studies

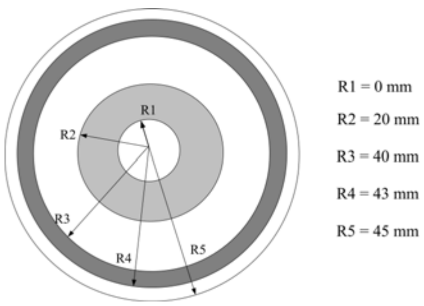
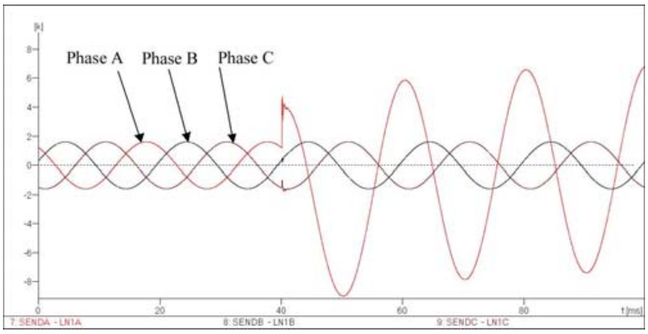


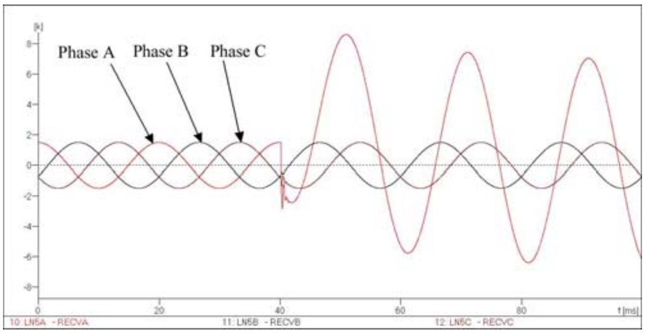
Figure 2. The configuration of cable in simulation studies

ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

The example of ATP/EMTP simulated fault signals is illustrated in Figure 3. This is a fault occurring with phase A to ground fault at 8 km measured from the sending bus as depicted in Figure 1. The fault signals generated using ATP/EMTP are interfaced to the MATLAB for the fault detection algorithm.



(a) Sending end



(b) Receiving end

Figure 3. Example of ATP/EMTP simulated fault signals for AG fault

III. Fault Detection

With several trial and error processes, the fault detection decision algorithm [7] on the basis of computer programming technique is constructed as shown in Figure 4. Fault detection using positive sequence current signal is employed. The Clark's transformation matrix is employed for calculating the positive sequence and zero sequence currents. The mother wavelet, daubechies4 (db4) [7-8], is employed to decompose high frequency components from the signals. After applying the Wavelet transform to the positive sequence currents, coefficients obtained using DWT of signals are squared. The comparison of the coefficients from each scale is under investigation. The result is clearly seen that when fault occurs, the coefficients of high frequency components have a sudden change with those before an occurrence of the faults as illustrated in Table 1 and Figure 5. This sudden change is used as an index for the occurrence of faults.

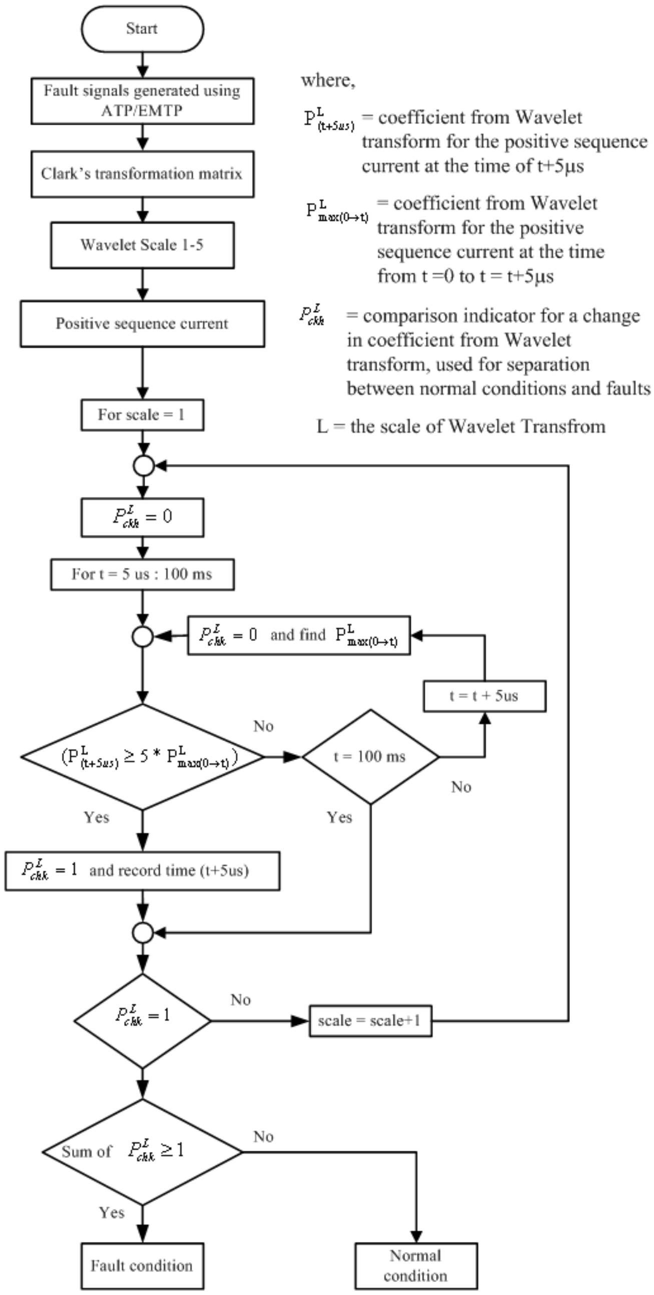


Figure 4. Flowchart for fault detection.

TABLE 1 RESULT FOR FAULT DETECTION FROM SIGNAL SHOWN IN FIGURE 3

Wavelet scale	Sending End		Receiving End		Result
	Max (pre)	Max (post)	Max (pre)	Max (post)	
1	0.00004	78,548	0.001403	135,134	Fault
2	0.01662	169,715	0.005627	160,559	Fault
3	0.44905	293,555	0.179792	185,927	Fault
4	2.89337	592,877	1.005606	322,468	Fault
5	15.1703	352,046	4.019407	660,034	Fault

ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

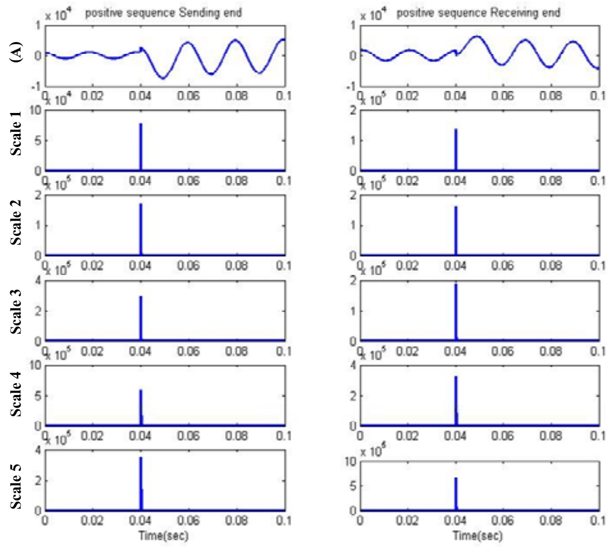


Figure 5 Wavelet transform from scale 1 to 5 for the positive sequence of current signal shown in Figure 3.

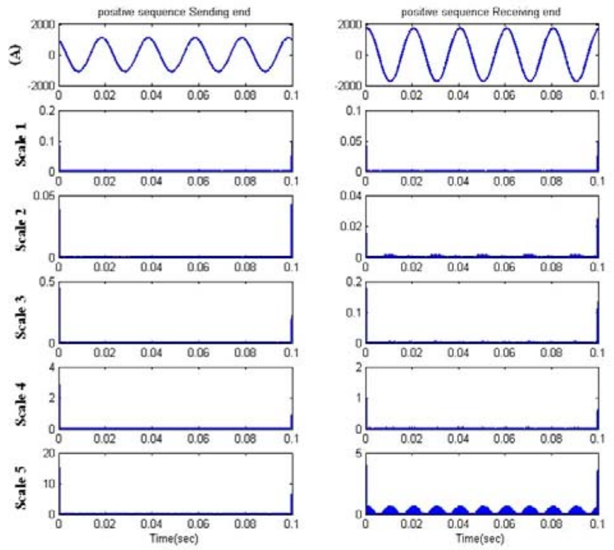


Figure 6 Wavelet transform from scale 1 to 5 for the positive sequence of current signal in normal condition.

From Figure 5, it can be seen that coefficient detail (cD1) of positive sequence current in previous fault condition has value less than coefficient detail (cD1) in post fault condition. Then it presumes that these signals are fault condition whereas the coefficient detail (cD1) in each scale of the wavelet transform does not clearly change as illustrated in Figure 6 so that the result obtained from fault detection algorithm can presume the normal condition of these signals.

As a result, fault detection algorithm is assumed that "if coefficients of any scale are changed around five times before an occurrence of the faults, there are faults occurring in underground cable and the coefficients in first scale that can detect fault is investigated as illustrated in Figure 7.

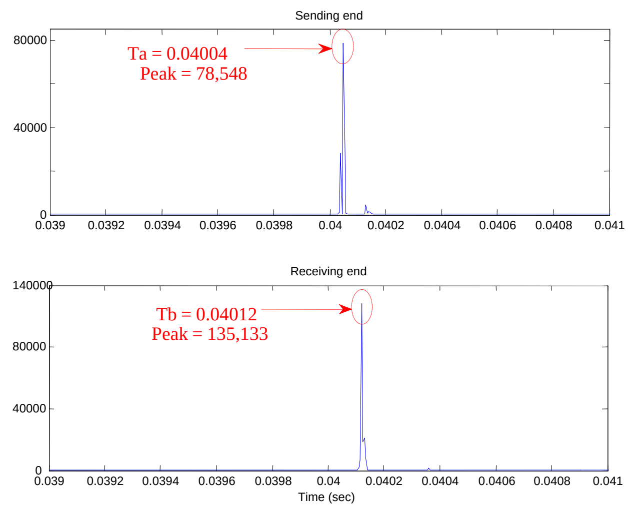


Figure 7 First peaks in the scale 1 at both ends of underground cable for the positive sequence of current signal shown in Figure 5.

IV. Decision Algorithm

Fault can occur along the length of cable. Therefore, before doing performance decision algorithm with traveling wave technique in order to locate the distance of fault, decision algorithm is necessary to understand fault behavior and the variation of coefficient detail (cD1) obtained from DWT.

Table 2 illustrates an example of phase A to ground fault when distance of fault in underground cable is varied and inception angles do not change. The result is seen that coefficients obtained from the positive sequence current decreases with increasing distance between the line end of the cable and the fault point as illustrated in Table 2. On the other hand, it is noticed that the first peak time that can detect fault obtained from the positive sequence current increases with increasing distance between the line end of the cable and the fault point as illustrate in Table 2.

Table 2 Comparison variations of coefficient detail in scale 1 for a case of phase A to ground fault at various fault location of underground cable. (Inception angle 60° and Fault occur at 40 msec)

Coefficients of high frequency components of positive sequence current		Fault location (Inception angle) (km)										
		2	4	6	8	10	15	17	19	21	25	28
Sending end	post-fault	795,263	457,476	223,968	224,534	227,191	243,048	106,021	94,928	50,987	40,964	38,385
	first peak time	40.01	40.02	40.03	40.04	40.06	40.08	40.09	40.10	40.12	40.14	40.15
Receiving end	post-fault	38,227	101,149	218,044	387,876	524,722	243,216	451,725	740,296	573,795	34,464	795,050
	first peak time	40.15	40.14	40.13	40.12	40.11	40.08	40.07	40.06	40.05	40.03	40.01

ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Table 3 Comparison variations of coefficient detail in scale 1 at various inception angles for a case of phase A to ground fault at 8 km from the sending end. (Fault occur at 40 msec)

Coefficients of high frequency components of positive sequence current		Fault location (Inception angle)											
		30	60	90	120	150	180	210	240	270	300	330	360
Sending end	post-fault	210,317	266,169	291,729	275,334	224,535	160,940	106,340	72,240	59,817	67,573	96,610	147,106
	first peak time	40.04	40.04	40.04	40.04	40.04	40.04	40.04	40.04	40.04	40.04	40.04	40.04
Receiving end	post-fault	364,245	460,796	504,740	476,010	387,876	277,750	183,390	124,585	103,243	116,846	167,264	254,809
	first peak time	40.12	40.12	40.12	40.12	40.12	40.12	40.12	40.12	40.12	40.12	40.12	40.12

Table 4 Results of single line to ground fault at different location of underground cable (Inception angle 120° and Fault occur at 40 msec)

Real location (km)	Inception angle	First peak time (msec)		Proposed Technique	
		Ta	Tb	Calculation (km)	Error (km)
3	120	40.02	40.15	3.1327	0.1327
5	120	40.03	40.14	4.9584	0.0416
8	120	40.04	40.12	7.6970	0.3030
11.5	120	40.06	40.105	10.436	1.0640
17	120	40.09	40.07	16.826	0.1740
26.5	120	40.16	40.02	27.280	0.780
28.5	120	40.16	40.01	28.693	0.193

Table 5 Results of single line to ground fault at different inception angle (Fault at 8 km of underground system and Fault occur at 40 msec)

Inception angle	Real location (km)	First peak time (msec)		Calculation
		Ta	Tb	
0	8	40.04	40.12	7.6970
30	8	40.04	40.12	7.6970
60	8	40.04	40.12	7.6970
90	8	40.04	40.12	7.6970
120	8	40.04	40.12	7.6970
150	8	40.04	40.12	7.6970
180	8	40.04	40.12	7.6970

Furthermore, when inception angles of fault is varied and fault point does not change as illustrated in Table 3. The result is seen that coefficient detail (cD1) obtained from positive sequence current has variation just the same as sine wave. On the other hand, the first peak time that can detect fault obtained from the positive sequence current do not change with increasing distance between the line end of the cable and the fault point as illustrateD in Table 3.

After the fault detection process, the first peak time in first scale that can detect fault is considered so that the distance of fault can be calculated with traveling wave equation. From Figure 7, first peak time 0.04002 and 0.04015 from the faulty buses are employed as input data for traveling wave equation as shown in Equation 1.

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

where,
d = the fault location measured from the sending end
LT = the length of the cable in which the fault is detected
t_A = the time where the fault at the sending end is detected
t_B = the time where the fault at the receiving end is detected
v = velocity of the travelling wave as calculated in Equation 2

$$v = \frac{3.8 \times 10^8}{\sqrt{\varepsilon_r \mu_r}} \, {}^{m}\!/_{s} \tag{2}$$

Where, μ_r is relative permeability of cable ($\mu_r = 1$)
ε_r is relative dielectric coefficient ($\varepsilon_r = 2.7$)

After the traveling wave has been processed, the algorithm was employed in order to calculate the distance of fault in the underground distribution system. Case studies are varied so that the algorithm capability can be verified. The system under consideration has been shown in Figure 1. Case studies are performed with various types of fault at each location on the underground cable including the variation of fault inception angles and locations at each underground cable. The comparison of the average error from the results due to the algorithm proposed in this paper is shown in Table 4-5. It can be seen that the accuracy of fault locations from the prediction of the algorithm is highly satisfactory.

V. Conclusion

This paper proposes a technique for locating the distance of fault occurring in underground cable using combination of discrete wavelet transform and traveling wave. Positive sequence current signals are used in fault detection algorithm. It is found that this algorithm can detect fault with the accuracy of 100% using scale 1 only. Various case studies have been carried out including the variation of fault

ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

inception angles and fault types. The results are shown that the proposed algorithm can identify the fault location with the average error of 0.385 km as shown in Table 4. As a result, the application of the discrete wavelet transform (DWT) based on traveling wave is a good choice in power system. The further work will be focused on the development of such a technique for using in loop circuits.

ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge financial support for this research by the faculty of engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand.

REFERENCES

[1] H Fernando, Magnago and Ali Abur, "Fault Location Using Wavelets ", IEEE Transactions on Power Delivery, pp. 1475-1480, October 1998.

[2] El Sayed Tag El Din, Mahmoud Gilany, Mohamed Mamdouh Abdel Aziz and Doaa khalil Ibrahim "A wavelet base fault location technique for aged power cables" in IEEE Power Engineering Society, Vol.3, pp.2485-2491, 12-16 June 2005.

[3] E.C. Bascom and D.W. Von Dollen, "Computerized underground cable fault location expertise," in IEEE Power Engineering Society Transmission and Distribution Conference, pp. 376–382, 10–15April 1994,.

[4] S. Potivejkul, P. Kerdonfag, S. Jamnian, and V. Kinnares, "Design of lowvoltage cable fault detector," in *Proc. IEEE Power Engineer. Society.Winter Meeting*, Jan. 2000, vol. 1, pp. 724–729.

[5] C. M. Wiggins, D. E. Thomas, T. M. Salas, F. S. Nickel, and H.-W. Ng, "A novel concept for underground cable fault location," IEEE Transaction. Power Delivery, Vol. 9, No. 1, pp. 591–597, Jan. 1994.

[6] M.-S. Choi, D.-S. Lee, and X. Yang, "A line to ground fault location algorithm for underground cable system," KIEE International Transactions on Power Engineering, Vol. 54, pp. 267–273, Jun. 2005.

[7] A. Ngaopitakkul and C. Pothisarn, "Discrete Wavelet Transform and Back-propagation Neural Networks algorithm for fault location on Single-circuit transmission line," *In Proceedings of 2004 International Conference on Robotics and Biomimetics (ROBIO2008),* Thailand, February 2009, pp. 365-371.

[8] P. Chiradeja and A. Ngaopitakkul, "Identification of Fault Types for Single Circuit Transmission Line using Discrete Wavelet Transforms and Artificial Neural Networks," The International Multi-Conference of Engineers and Computer Scientists 2009 (IMECS2009), Hongkong, China, pp. 1520 – 1525, 18-20 March 2009.

BIOGRAPHIES

Atthapol Ngaopitakkul is currently a lecture at the school of electrical engineering, King Mongkut's Institute of Technology Laddrabang, Bangkok, Thailand. His research interests are on transmission systems and Protection Relay.

Choawat Apisit graduated with B.Eng in electrical engineering from King Mongkut's Institute of Technology Laddrabang, Bangkok, Thailand in 2009. He is currently a M.Eng. candidate at the school of electrical engineering, King Mongkut's Institute of Technology Ladkrabang. His research interests are in power system analysis.

Chaichan Pothisarn graduated with B.Eng in electrical engineering from Prince of Songkla University, Songkhla, Thailand in 1994 and M.Eng in electrical engineering from King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand in 2003. He is currently a lecturer in Electrical Engineering Department at KMITL. His research interests are in power systems analysis and renewable energy.

Chaiyan Jettanasen received his B.Eng. and M.Eng. from Institut National des Sciences Appliquées (INSA) de Lyon in 2005 and Ph.D. from Ecole Centrale de Lyon, France in 2008. His research interest is EMC in power electronic systems. He is currently a lecturer in Electrical Engineering Department at KMITL.

Sirarote Jaikhan graduated with B.Eng and M.Eng in electrical engineering from King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand in 2004 and 2009 respectively. He is currently an electrical engineering level 4 of Designs and Supervision Department, Metropolitan Electricity Authority (MEA), Bangkok, Thailand.

ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)