Power Transmission Line Fault Location based on Travelling Wave using Wavelet Transform

Khushboo Balani, Deepak Sharma

Abstract— With the fast expansion of electrical power systems, accurate and fast fault localization is important for the permanence and dependability of the power transmission system. The transmission lines contain overhead conductors which are exposed to the environment. This exposure to the harsh environmental conditions is the foremost factor for incidence of faults on the transmission lines. In this work, a travelling wave based method for fault location on power transmission line is proposed. Using Clarke's transform, the fault generated high-frequency current transients are transformed into their modal components and using the discrete wavelet transform fault features are extracted from the modal components. The differences among recorded travelling wave arrival time at the bus terminals are used to calculate the fault location. In addition, the influence of fault resistances and fault distances are also considered. The simulation of the transmission system and post fault analysis has been performed in MATLAB/SIMULINK. The simulation results confirm that the correctness of the travelling wave technique for fault location is satisfactory.

Index Terms— Fault location, Travelling waves, Transmission line, Wavelet transform.

1 Introduction

An electrical power system includes generation, transmission and distribution of electrical energy. Expansion in electrical power system has led to formation of very large and complex networks. In general, power systems operate in a steady state, but a short-term and permanent disturbance happens intermittently due to the existence of a large number of equipment's prone to faults. These faults are caused by natural disasters, human errors and equipment's aging. Faults cause dip on voltage magnitude and large magnitudes of currents to flow into the equipment that would damage if current flows were not interrupted punctually [1]. A power transmission line involves huge investment of money. Appropriate function and protection of transmission lines is requisite to diminish the impact of failures. Fault location methods are currently being developed in many different ways. Methods for locating fault on a transmission line can be separated into two basic groups: Techniques based on impedance measurement and the other using travelling wave techniques. The impedance measurement based techniques utilizes the power frequency component of voltage and current recorded at the line terminal [2-15]. Using this technique, phase voltage and current can be used from both ends or from a single transmission line terminal. The two-terminal algorithm delivers more accurate results than the one-finished algorithm.

The methods based on traveling waves are currently known as the most accurate method for locating fault in power transmission lines. Rohrig [16] first introduced travelling wave technique for fault location in transmission line. In this method, the electrical pulses generated due to fault is used for fault localization. The appearance time of these pulses at the terminals is recorded for fault localization, this method was appropriate for long homogenous lines. The downside of the travelling wave method is difficulty in locating the faults which occurs close to the bus or faults and also for the faults which occurs near zero inception angle [17]. Travelling wave methods is divided into two category; single ended methods and double ended methods. Methods proposed in [18, 19] uses a single ended algorithm for the location of the fault using the first traveling wave peak from the faulted point to the line terminals and the arrival of the same wave after reflection from the faulted point which is proportionate to the distance of fault. This algorithm is considered to be inaccurate because there is difficulty in differentiating the wavefront. Sometimes the wave peaks that are lost due to noise in the signal are hard to detect. In two ended algorithms, the fault location at each end of the transmission line is proportionate to the arrival times of the wave peaks. It was first developed by Dewe et al. [21]. Requirement of this method is need of communication channel between to end of the line to transfer each end data. Therefore, cost of this method is more because setup of communication channel is expensive. Fault location estimation accuracy of two-ended method is high as it doesn't need to recognize reflections of wave from the fault point. Wavelet transform has been applied by authors in [22] for fault location in transmission lines. The author of [23] compares the fault location obtained using Fourier transform and wavelet transform. A fault location method combining single-end and two-end method is proposed by Ping et al. in [24]. The purpose of combing both methods was to complement the result of each other. And the method proposed in [25] combines the cross-correlation technique with travelling wave method for fault location in HVDC line. The cross-correlation technique is used to detect the travelling wave peaks by matching the similarity between the first wave peak (reference signal) and a succeeding wave peak, both recorded at the same line terminal. [26] Presents method based on analysis of voltage measurements and bus impedance matrix. The travelling wave fault location technique presented in [27] is applied in hybrid multi-terminal circuit containing offshore wind farm.

The proposed fault localization technique is based on DWT

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investigation of fault originated current travelling waves. The earlier presented methods are generally based on voltage transients and for signal processing they depends on cross correlation techniques and some other methods. The errors in previous methods are high due to low sampling rates of fault data and use of other signal processing methods. Hence, the presented method in this work proposes a two terminal travelling wave method based on DWT exploration of fault generated current transient to increase the accurateness of fault location assessment in power transmission lines.

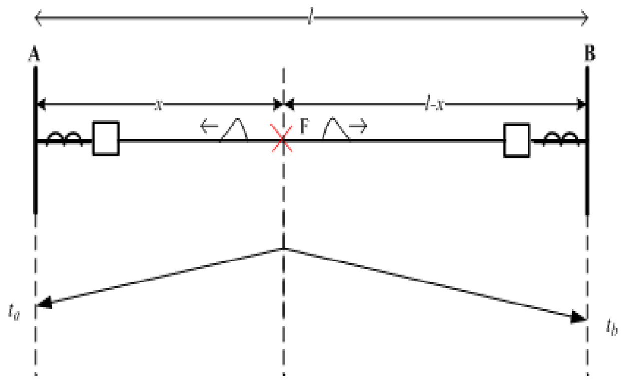

Fig. 1. Travelling wave arrival due to fault at the line terminals.

2 Proposed Fault Location Method

2.1 Two Terminal Travelling Wave Method

The fault location process is illustrated with the help of Fig. 1, where a line section is linked by bus A and bus B. In the development of the technique, it is supposed that the measurement is available at both end of each line section. The travelling wave recording devices are positioned at both ends of the lines. The captured signals are transformed into modal component and then DWT [28] decomposition is performed. If WTC² spikes are spotted by the relay then the time consistent to the arrival of the wave is logged and fault location is calculated. Fig. 2 shows flowchart of fault location estimation process. The relays at both ends can send and receive data from each other with the help of a communication channel. It is assumed that a fault occurs at point F from a distance x the bus A; the fault originated travelling waves propagates away from the fault towards the terminal A and B. At each end, the relay transfers the time measured to the relay at the other end. The difference in time recorded by the relay at each end is assumed as t_d , therefore,

$$t_d = |t_a - t_b| \quad (1)$$

Here, t_a is the time recorded by the relay at bus A (R_a), and t_b is the time recorded by the relay at bus B (R_b).

The time required by the travelling wave to travel the total length of the line segment is given by

$$t = l / v \quad (2)$$

Where, l is the length of faulted line segment and v is the velocity of travelling waves.

The fault distance from relay R_a is calculated as

$$x = \left(t_a - t_b + (l / v)\right) \times v / 2 \quad (3)$$

2.2 Processing of Fault Transients

The three phase voltages and currents signal is recorded at substation node by the simulation system. These three phase values are converted into modal components using modal transformation. For this purpose Clarke transform matrix [29] is used to obtain aerial mode and ground mode components from the transformation matrix. Then DWT is applied using db4 mother wavelet to obtain wavelet detail coefficients from the modal components. Then, the points where WTC² peaks occurs for aerial mode component are the exact wave peak positions, so that the sample number of wave peaks are the point positions of WTC². Fig. 3 shows the different steps of the proposed fault location method.

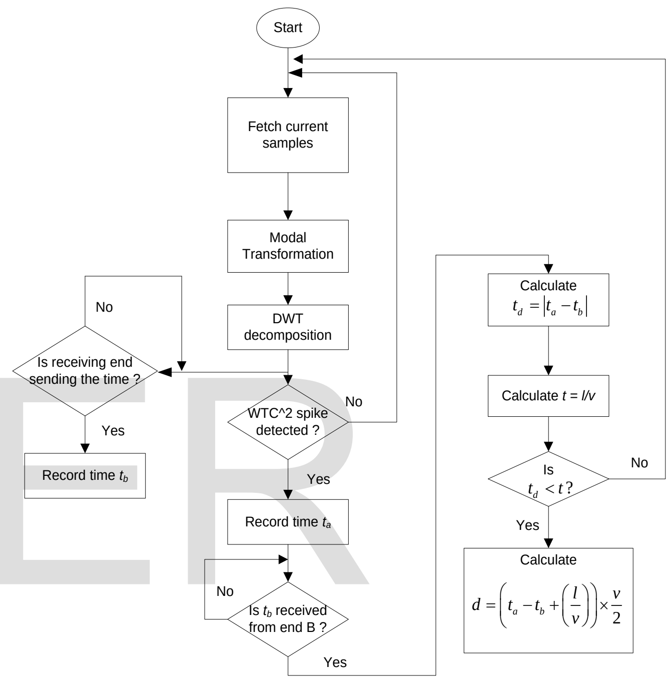

Fig. 2. Flowchart for proposed fault location method.

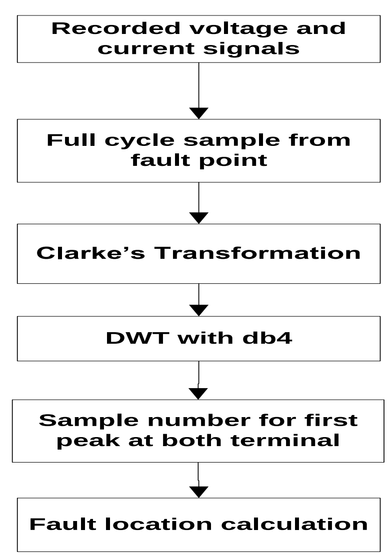

Fig. 3. Different steps of the proposed fault location method.

3 Simulation Results

The simulation work is performed on MATLAB/SIMULINK. For this work a 500 kV, 100 km length three phase transmission line model is simulated in SimPowerSystem. The speed of the travelling wave is calculated using the parameters of the system. For this work the different system parameter of the used test system is given in Appendix section. Putting the value of those parameters in we get aerial mode velocity as [30]:

$$V_1 = 2.9188 \times 10^5 \, km/s$$

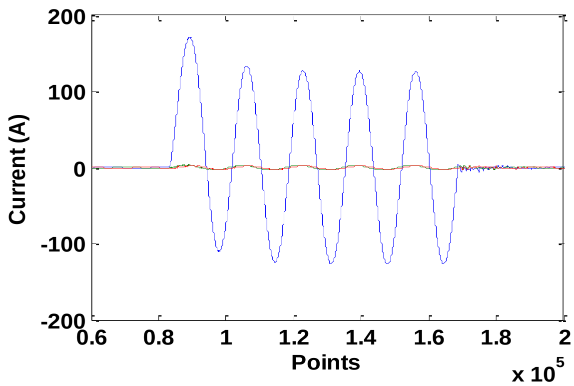

Fig. 4. Fault Current for line to ground fault.

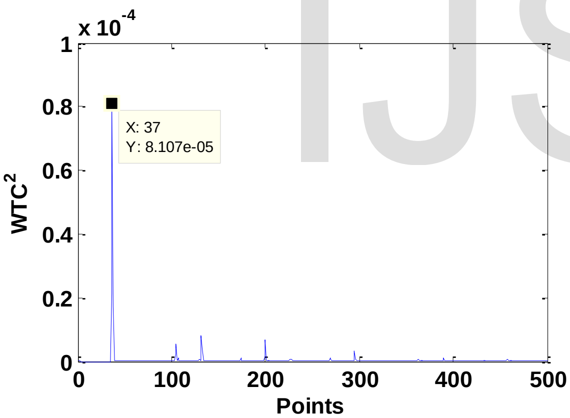

Fig. 5. WTC^2 of current transient at bus A.

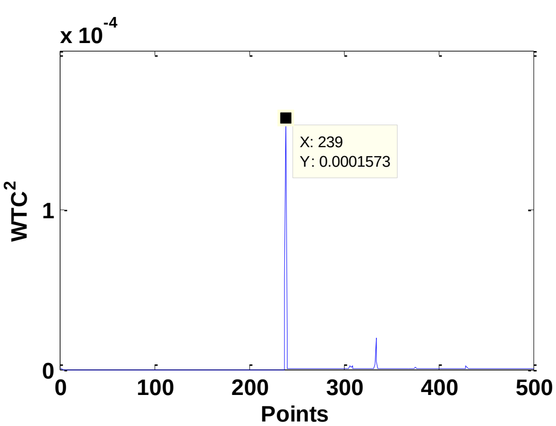

Fig. 6. WTC^2 of current transient at bus B.

A single line to ground fault is assumed at a distance of 20 km from bus A, the fault occurs at 5^{th} cycle in simulation and cleared at 10^{th} cycle. Fig. 4 shows the current waveform captured at bus A during fault. Fig. 5 and 6 shows the WTC^2 of current transients at bus A and bus B respectively. These figures shows that the first peak at the bus A and bus B occurs at P_{1A} = 37 and P_{1B} = 239 respectively. Therefore, the calculated fault location using equ (3) is:

$x = [(37-239)*1\times10^{-6} + (0.000342)]*1.4594\times10^5$

x = 20.43 km

Error in fault location is calculated as:

$\text{Error} = |20.43 - 20/20| \times 100 = 2.15\%$.

TABLE 1
FAULT LOCATION ERROR FOR LINE TO GROUND FAULT

Actual Fault location (km)	Calculated fault location (km)	Error (%)
5	5.12	2.4
10	10.10	1
15	15.24	1.6
20	20.43	2.15
25	24.84	0.64
30	30.55	1.83
35	35.26	0.74
40	40.38	0.95
45	44.37	1.4
50	50.20	0.4
55	55.35	0.64
60	60.15	0.25
65	65.35	0.54
70	70.21	0.3
75	74.67	0.44
80	80.26	0.32
85	85.15	0.17
90	89.45	0.61
95	94.85	0.15
	Average Error	0.87

Table 1 presents the estimated fault locations and the % absolute error for the obtained fault locations using the aerial mode current transients by the two terminal travelling wave based method for fault location. In this table, the calculated errors are below 2.5%, which is very low for a long transmission line and the average errors in fault position is 0.87% only. Similarly fault location for other types of fault is calculated at diverse location on the transmission line. The fault location error obtained for other type of faults is shown in Table 2.

3.1 Influence of Fault Resistances

In this section effectiveness of the proposed fault location scheme is tested against variation in fault resistance. For these purpose simulations studies are performed out for different faults at different fault resistances.

TABLE 2
FAULT LOCATION ERROR FOR OTHER TYPE OF FAULTS

Actual fault location (km)	Calculated fault location (km)			
	LL	LLG	LLL	LLLG
5	5.11	4.92	5.14	5.15
10	10.15	10.25	10.10	10.13
15	15.29	15.27	15.21	15.25
20	19.74	19.78	20.18	20.15
25	24.81	25.25	25.20	25.20
30	29.90	29.91	29.80	30.50
35	35.26	35.20	35.25	35.28
40	40.08	40.10	40.30	40.26
45	44.69	45.25	44.94	45.37
50	50.18	50.18	50.32	50.30
55	54.78	54.80	55.40	55.46
60	60.15	60.10	59.65	59.39
65	65.30	65.30	65.20	65.60
70	70.10	70.15	70.18	70.26
75	75.25	75.18	75.23	75.25
80	80.21	80.20	80.25	80.25
85	85.15	85.25	85.19	85.38
90	89.85	89.90	89.88	89.84
95	94.78	94.75	94.85	94.80
Avg. Error (%)	0.64	0.65	0.67	0.86

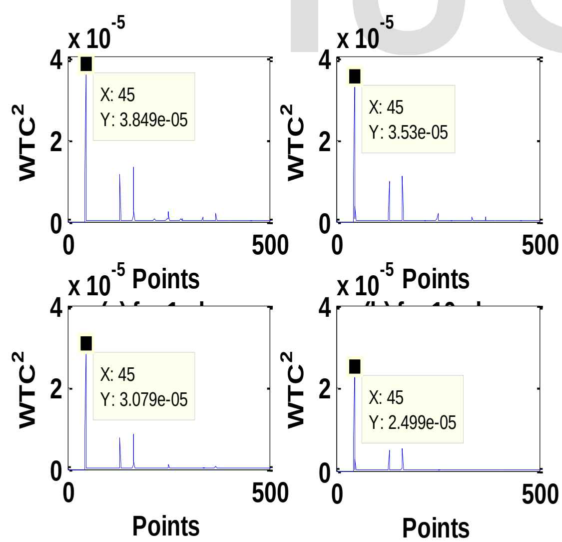

Fig. 7. WTC^2 for different fault resistances.

Fig. 7 shows simulations result for phase A to ground fault case in which simulation is carried out at a distance of 25 km from bus A for different fault resistances. In this figure simulation is shown for fault resistance of 1Ω, 10Ω, 25Ω and 50Ω respectively. As can be observed from the figures, change in fault resistance changes only magnitude of the WTC^2 and the point of peak occurrence remains same. Therefore, as the proposed method use only time information of the WTC^2 peak, the fault location accuracy remains unaffected by the change in fault resistance. Same result are obtained for other type of faults as well.

3.1 Effect of Fault distance

In this section the proposed two-terminal travelling wave method is tested with different transmission line lengths. For this purpose length of transmission line is increased to 200 km and 300 km respectively and several simulations are performed for LG fault cases. Obtained results are shown in Table 3 and Table 4 for 200 km and 300 km respectively. From the obtained results for 200 km line it is observed that the fault location method gives fairly precise results.

TABLE 3
FAULT LOCATION ESTIMATION FOR 200 KM LINE

Fault location (km)	Calculated fault location (km)	Error (%)
5	4.90	2
10	10.15	1.5
15	15.29	1.93
95	95.65	0.36
100	99.62	0.38
105	105.45	0.52
155	154.64	0.23
175	174.86	0.08
195	195.40	0.20

TABLE 4
FAULT LOCATION ESTIMATION FOR 300 KM LINE

Fault location (km)	Calculated fault location (km)	Error (%)
5	4.91	1.8
10	10.10	1
15	15.27	1.8
95	95.68	0.71
100	99.60	0.4
105	105.45	0.52
155	154.60	0.72
175	174.85	0.08
195	195.30	0.15
235	234.65	0.14
265	265.78	0.29
295	294.47	0.17

Similar to the 200 km line Table 5.7 shows fault location error for 300 km line, results from this table also approves the fault location estimation correctness of the presented method.

4 Conclusion

A fault location method which is based on travelling wave theory and applies discrete wavelet transform for the processing of fault data is presented in this paper for application in power transmission lines. The fault location is calculated using arrival time difference of first wave peaks at the respective terminal and using the aerial mode propagation velocity. For this purpose the modal components are obtained using modal transformation matrix and signal processing is done usingdb4 mother wavelet on the aerial mode components. The WTC² of these detail coefficients are used to decide the peak of the arriving travelling wave peak at the line terminals. In addition, the evaluation study presents that the two terminal travelling wave fault location method is applicable to all fault types under various fault resistances, and different transmission line lengths. In future the proposed fault location algorithm can be expanded to multi-terminal transmission lines with different type of terminal structure. The influence of different fault inception angles, influence of noise and signal processing techniques can also be analyzed. Also, implementation of the proposed work on some real system or some experimental works can also be tried out to verify the proposed two-terminal travelling wave based fault location method for power transmission line.

REFERENCES

[1] M. M. Saha. Jan Izykowski and E. Rosolowski, Fault Location on Power Networks, Springer, 2010.

[2] M.T. Sant, Y.G. Paithankar, "Online digital fault locator for overhead transmission line," Nov, 1979.

[3] T. Takagi, Y. Yamakoshi, J. Baba, K. Uemura, and T. Sakaguchi, "A New Algorithm of an Accurate Fault Location for EHV/UHV Transmission Lines: Part I- Fourier Transformation Method," IEEE Transactions on Power Apparatus and Systems, vol. PAS-100, no. 3, pp. 1316–1323, March 1981.

[4] T. Takagi, Y. Yamakoshi, J. Baba, K. Uemuraand, and T. Sakaguchi, "A New Algorithm of an Accurate Fault Location for EHV/UHV Transmission Lines: Part Il- Laplace Transform Method," IEEE Transactions on Power Apparatus and Systems, vol. PAS-101, no. 3, pp. 564–573, March 1982.

[5] Erikson, L., Saha,M.M and Rockfeller, "An accurate fault locator with compensation for apparent reactance in the fault resistance resulting from remote end infeed", IEEE Trans., PAS-104, 1985, pp. 424435.

[6] M.S Sachdev, R.Agarwal, " A Technique for estimating transmission line fault locations from digital impedance relay measurements",1998.

[7] D. Novosel, D. G. Hart, E. Udren, and J. Garitty, "Unsynchronized Two- Terminal Fault Location Estimation," IEEE Transactions on Power Delivery, vol. 11, no. 1, pp. 130–137, January 1996.

[8] A. A. Girgis, D. G. Hart, and W. L. Peterson, "A New Fault Location Technique For Two-and Three-Terminal Lines," IEEE Transactions on Power Delivery, vol. 7, no. 1, pp. 98–107, January 1992.

[9] Joe-Air Jiang, Jun-Zhe Yang, Ying-Hong Lin, Chih-Wen Liu," An Adaptive PMU Based Fault Detection/Location Technique for Transmission Lines", 2000.

[10] Chi-Shan Yu, Chih-Wen Liu, Member, IEEE, Sun-Li Yu, and Joe-Air Jiang, "A New PMU-Based Fault Location Algorithm for Series Compensated Lines", January, 2002.

[11] Waikar, D.L., Elangovan, S., and Liew, A.C.: 'Fault impedance estimation algorithm for digital distance relaying', IEEE Trans., July 1994, PWRD-9, (3), pp. 1375-1383.

[12] Girgis, A.A., and Makram, E.B., "Application of adaptive Kalman filtering in fault classification, distance protection, and fault location using microprocessors", IEEE Trans., February 1982, PWRS-3, (l), pp. 301-309.

[13] Erikson, L., Saha,M.M and Rockfeller, "An accurate fault locator with compensation for apparent reactance in the fault resistance resulting from remote end infeed", IEEE Trans., PAS-104, 1985, pp. 424435.

[14] Lawrence, D.J., and Waser, D.L, "Transmission line fault location using digital fault recorder", IEEE Trans., 1988, PWRD-3, (2). pp. 496-502.

[15] V. Cook,"Fundamental aspects of fault location algorithms used in distance protection", IEE Proc. C, 1986, 133, (6), pp. 359-368.

[16] J. Rohrig, "Location of faulty places by measuring with cathode ray oscillographs", Elektrotech Zeits, 8, 241-242 (1931).

[17] T. Kawady and J. Stenzel. "Investigation of practical problems for digital fault location algorithms based on EMTP simulation", Asia-Pacific Transmission and Distribution Conference and Exhibition, 2002, Vol. 1, pp.118-123.

[18] T. Kawady and J. Stenzel. "Investigation of practical problems for digital fault location algorithms based on EMTP simulation", Asia-Pacific Transmission and Distribution Conference and Exhibition, 2002, Vol. 1, pp.118-123.

[19] M. Ando, E. Schweitzer, R. Baker, "Development and Field-Data Evaluation of Single-End Fault Locator for Two-Thermal HVDC Transmission Lines," Part I: Data Collection System and Field Data, IEEE Transactions on Power Apparatus and Systems, PAS-104, 3524-3530 (1985).

[20] M. Ando, E. Schweitzer, R. Baker, "Development and Field-Data Evaluation of Single-End Fault Locator for Two-Terminal HVDC Transmission Lines, "Part 2: Algorithm and Evaluation, IEEE Transactions on Power Apparatus and Systems, PAS-104, 3531-3537 (1985).

[21] M. Dewe, S. Sankar, J. Arrillaga, "The Application of Satellite Time References to HVDC Fault Location", IEEE Transactions on Power Delivery, 8, 1295-1302 (1993).

[22] F. H. Magnago, A. Abur, "Fault location using wavelets ," IEEE Transactions on Power Delivery, 13, 1475-1480 (1998).

[23] D. C. Robertson, 0. I. Camps, J. S. Mayer, and W. B. Gish, "Wavelets and Electromagnetic Power System Transients", IEEE Transactions on Power Delivery, Vol.11, No.2, pp. 1050-1058, April 1996.

[24] C. Ping, X. Bingyin, L. Jing, A Traveling Wave Based Fault Locating System for HVDC Transmission Lines, in International Conference on Power System Technology, 1-4 (2006).

[25] K. Young-Jin, K. Sang-Hee, L. Dong-Gyu, K. Hyung-Kyu, Fault Location Algorithm Based on Cross Correlation Method for HVDC Cable Lines, in IET 9th International Conference on Developments in Power System Protection, 360-364 (2008).

[26] Y. Liao, "Fault location for single-circuit line based on bus impedance matrix utilizing voltage measurements," IEEE Transactions on Power Delivery, vol. 23, no. 2, pp. 609-617, April 2008.

[27] R. J. Hamidi, H.Livani, "Travelling-wave based fault-location algorithm for hybrid multiterminal circuits," IEEE Transection on Power Delivery, Vol., 32, NO. 1, FEBRUARY 2017.

[28] Oink Chaari, Michel Meunier, and Francoise Brouaye. Wavelets: a new tool for the resonant grounded power distribution systems relaying. IEEE Transactions on Power Delivery, 11(3):1301–1308, 1996.

[29] E. Clarke (1943) Circuit analysis of AC power systems: symmetrical and related components. Wiley, New York.

[30] Y. Ge, The New Type Rely Protection and Fault Location Theory, Xi An: Xi'An JiaoTong University, 2007, pp. 184-187.

APPENDIX

Transmission line parameters
Total line length = 100 km
System frequency = 60 Hz
Source A voltage = 500 kV

Source B voltage = 500 kV
System base power = 100 MVA
Source A positive sequence impedance = 17.177 + j45.5285 ohm
Source B positive sequence impedance = 15.31 + j45.9245 ohm
Source A zero sequence impedance = 2.5904 + 14.7328 ohm
Source B zero sequence impedance = 0.7229 + j15.1288 ohm
Positive sequence resistance of line = 0.15573 ohm/km
Positive sequence inductance of line = 9.7066 * 10-4 H/km
Positive sequence capacitance of line = 1.2093 * 10-8 F/km
Zero sequence resistance of line = 0.3765062 ohm/km
Zero sequence inductance of line = 0.003 H/km
Zero sequence capacitance of line = 7.4949 * 10-9 F/km