Proceeding of International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2014),Yogyakarta, Indonesia, 20-21 August 2014

Simulation of Distance Relay Operation on Fault Condition in MATLAB Software/Simulink

Abdullah Asuhaimi bin Mohd Zin
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
Skudai, Johor. +607 5535366
Email: abdullah@fke.utm.my

J.Tavalaei
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
Skudai, Johor 81310
Email: jalal.tavalaei@ieee.org

Mohd Hafiz bin Habibuddin
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
Skudai, Johor. +607-5535227
Email:mhafiz@fke.utm.my.

***Abstract*—In this paper a distance relay is simulated in the proposed transmission line protection which is combination of overhead line and significant part of underground cable. Transmission line is modeled as distributed parameter instead of lumped parameter to have more accurate analysis compare to conventional analysis. Voltage and current are sampled at relay point. But, high charging current of cable affects distance relay operation. Using appropriate filtering can reduce charging current effect on distance relay. Simulated impedance will be compared with positive sequence impedance of power system in order to evaluate simulated relay. The relay shows a good result for faults in zone 1, but high resistance faults force distance relay to mis-operation.**

I. Introduction

Power system network is one of the most expensive members of power transmission system. This system is normally protected by several relays to save apparatus against hazardous condition. Although, overcurrent relay are main responsible in protecting overhead line (OHL), underground cables (UGC) are save with differential relay. In long transmission line distance relay is used to protect OHL and find the fault location. Distance relay is normally used as the main protection and backup by overcurrent relay in transmission line. There are various studies on improving distance relay in operation, fault detection and make it adaptive on specific network. Due to simplification of power system apparatus protective units may face with mis-operation. Operation units are reported several negative effect of lumped parameter analysis instead of distributed parameter, mutual coupling of OHL, capacitive current on OHL and UGC, doubly fed transmission line and utilizing two level voltage on a same transmission line on distance relay operation. The effects are confronted distance relay with two well-known mis-operation: overreach and underreach. Several researches are done on improving distance relay algorithms [1], [2], [3], charging current effect [4], [5], [6], [7], [8], mutual coupling [2], [9], [10], [11], fault detection [12], [13], [14], [15], [16], doubly fed effect [17] and signal decomposition algorithm [18], [19], [20]. Fault resistance push distance relay to overreach; hence, fault impedance is calculated based on Bergerons equation and compensate distributed transmission line capacitance is presented in [1]. The authors claims that error ratio of impedance calculation by Bergerons method is less than lumped parameter. However, in [2], the negative effect of fault resistance is omitted by adaptive algorithm using shift vector procedure. In addition, this algorithm has compensated pre-fault power flow effect on distance relay which is done by changing relay characteristics position by simple mathematical equation. In [3], compensation of fault resistance negative effect is done by instantaneous active power measurement at sending end (relay point) which is independent of line length. OHL has significant difference in structure and characteristics with UGC. At a same voltage, accurate analysis can be done on dielectric material of UGC, sheath and bounding compared with OHL. On the other word, UGC need more space between conductors, have lower reactance higher X/R ratio on positive sequence and huge charging current compare with OHL [4]. The authors in [5], compare current differential relay used for UGC and discuss distance relay constrains on protecting UGC. The bonding methods affected zero sequence impedance measurement of UGC in fault condition. Moreover, zero sequence impedance is affected by parallel path and earth resistivity [5]. Because of UGC length bound, bounding methods are applied to overcome length defect. On the other hand, induced voltage and current on sheath wire is going to neutralize by bonding methods. Furthermore, zero sequence impedance of sheath, zero sequence impedance between conductor and sheath, and different return path at fault condition on cable are illustrated in [7]. High OHL voltage raise distributed capacitance. This undesired capacitive affect apparent impedance measurement on distance relay which cause underreach [6]. The authors suggested a mathematical formula to compensate distributed capacitance of ultra/extra high voltage transmission line by modifying zero sequence current at shunt reactor. Charging current of OHL forced distance relay to overreach or slow operation. In addition, filtering voltage and current of fault in presence of charging current is difficult. Hence, mathematical analysis of charging current is improved by adding a capacitor in the traditional analysis [8]. Mutual coupling affects distance relay operation. The most efficient method to overcome mutual coupling is explained in [9]. Quadratic characteristics of distance relay zones are modified by ANN algorithm and instantaneous power. Mutual coupling dose not effectively change the positive sequence impedance of OHL, but zero sequence suffers adequately. A mathematical analysis to suppress mutual coupling on distance relay measurement is expressed in [10] which encompass zero sequence variation by this phenomenon. Symmetrical component theorem is applied to compensate mutual coupling effect on impedance measurement based on derivation of compensated value [11]. This compensation improve intercircuit fault, too. The signal waveforms of voltage and current fed distance relay required filters to eliminate undesired harmonics and noise with different algorithm [18]. Otherwise, wavelet transform and AIs methods are used to detect, localize and classify fault feature. In this signal processing method, signal is decomposed to high scale with low frequency and low scale with high frequency [19]. Finally, self impedance and mutual impedance is calculated and analyzed mathematically [20]. Mutual coupling impedance is highly inductive and ground return path and neutral wire affect zero sequence impedance. This study has addressed a unique transmission line contain both OHL and UGC. Therefore, distance relay will be suffered by aforementioned puzzles, which push distance relay to mis-operation. This paper will cluster data and analysis in section II, results are explained in section III and then precise discussion is presented in section IV.

II. Transmission Network Construction

The network is selected as radial network which is contains significant cable section. Three phase source with 3000 MVA short circuit level and 20 kV is generating power. To have more reliable system, X/R ratio is 9.452 [15] in 60 Hz. The generator winding are in star mode connection which neutral point is grounded. In load flow view, generator is swing generator to control voltage and frequency of network during abnormal condition. Table I portrays the generator parameters.

TABLE I
Generator Specification

Voltage (kV)	Short Circuit Capacity (MVA)	Inductance (H)		Resistance (Ω)	
		0	1	0	1
20	3000	0.48	0.35	20.73	13.96

At receiving end of transmission line a city is fed and therefore, a heavy load is connected at the point to reach precise simulation. Load specifications are 124 MVA at 0.92 lag and 63 kV. In protection and load flow analysis, load (city) is star grounded and constant impedance, respectively. The network is represented in figure 1.

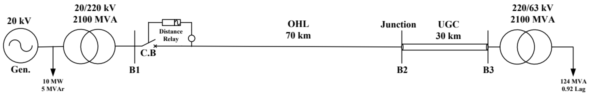

Fig. 1. Single line diagram of combined transmission line

Transmission line is connected generator to load. Transmission line is assumed to operate at 220 kV, which contains 70 km overhead line (OHL) and 30 km underground cable (UGC). Both, OHL and UGC are modeled and analyzed based on Distributed parameter instead of PI model to obtain more accurate result. Table II is represent the OHL and UGC parameters [12], [15].

TABLE II
Transmission Line Parameter

Section	R Ω/km		L mH/km		C μF/km	
	1	0.	1.	0	1.	0
OHL	0.3317	0.4817	1.326	4.595	0.008688	0.00476
UGC	0.024	0.412	0.4278	1.5338	0.2811	0.1529

It is clear that OHL resistance is higher than UGC in positive and negative sequence, but it is close for zero sequence. The positive inductance of OHL is 1.33 mH/km; but it is less than 0.5 mH/km on UGC. The discrimination is clearer for zero sequence of inductance of OHL and UGC. OHL zero sequence inductance is 4.6 mH/km, but it is 3 times less for UGC. Although, series branch (Z=R+jX) is more dominant in OHL, yet it is fluctuated for admittance (Y=G+jB) of UGC. Although, the capacitance of OHL is less than 0.01 μF/km on positive and zero sequence , but it can bounce up to 32 times more for UGC sequence. The calculation of ABCD matrix is illustrated for OHL and UGC in distributed parameter analysis as in equation 1 to 3.

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \times \begin{bmatrix} V_R \\ I_R \end{bmatrix} \tag{1}$$

where:

$$\begin{aligned} A &= \cosh \gamma l \\ B &= Z_c \times \cosh \gamma l \\ C &= Z_c^{-1} \times \cosh \gamma l \\ D &= \cosh \gamma l \end{aligned} \tag{2}$$

and:

$$\begin{aligned} \gamma l &= \sqrt{ZY} l \\ Z_c &= \sqrt{\tfrac{Z}{Y}} \end{aligned} \tag{3}$$

Multipication of both ABCD of OHL and UGC matrix, the transmission line matrix is:

$$ABCD_{TL}^1 = \begin{bmatrix} 0.8799\angle 5.078 & 46.0621\angle 59.117 \\ 0.0034\angle 90.153 & 0.9872\angle 0.229 \end{bmatrix} \tag{4}$$

The charging current is capacitance between high voltage line and ground. In OHL, the dielectric is air, but for cable this value is increased by dielectric material of cable. The effect of charging current can cause overreach on distance relay. Therefore, calculation of charging current for avoiding mis-operation of distance relay is necessary. Charging current is calculated by:

$$I_{charge} = \sqrt{3}\ Y \times V_{ph} \tag{5}$$

Because transmission line involved two segments and both operate at 220 kV, charging current of sequence for OHL and UGC positive sequence are expressed as:

$$\begin{cases} I_{Ch}^{OHL-1} = 0.416\ A/km/ph \\ \\ I_{Ch}^{UGC-1} = 13.46\ A/km/ph \end{cases}$$

TABLE III
TRANSFORMER SPECIFICATION

Power (MVA)	voltage (kV)	Windding Connection	R_M	L_M	R_T	R_T
			(pu)			
2100	20/220	Y/Y_g	500.01	500	0.004	0.016
2100	220/63	Y_g/Y	500.01	500	0.004	0.016

A. Transformer

Generator output voltage is 20 kV. Moreover, load demand voltage is 63 kV, but transmission line support 220 kV. Therefore, two transformers are required to install at sending end and receiving end. A step up transformer is installed at sending end to increase voltage from 20 kV to 220 kV. The primary windding is connected in star and the secondary at high voltage side is star solidly grounded. On the other hand, a 220/63 kV step down transformer is installed at receiving end to provide power for load (city). This transformer looks like other transformer has star connected winding which is solidly grounded at high voltage side. Transformer parameters in pu are represented in table III.

The R_T and L_T are summation resistance and inductance of sides of transformer, respectively. The primary and secondary value of resistance and inductance of transformer are equal in pu form. Hence;

$$R_1^{pu} = R_2^{pu} = 0.5R_T^{pu} \quad (6)$$

and

$$L_1^{pu} = L_2^{pu} = 0.5L_T^{pu} \quad (7)$$

This is need to multiple by the base value of transformers sides to convert to real value:

$$R = R^{pu} \times Z_{base} \quad (8)$$

and

$$L = L^{pu} \times Z_{base}/\omega \quad (9)$$

The main reason of grounding the apparatus is to eliminate 3^{rd} harmonics waveforms and have return current path to ground.

B. Load Flow

Usually power system is evaluated after load flow in static mode. The main scope of this analysis is to have voltage, current and frequency in range. The acceptable voltage range based on IEEE standard is the voltage cannot vary beyond $\pm$5% per unit (0.95pu$<$V$<$ 1.05pu). The standard frequencies around the world are 50 Hz and 60 Hz and the tolerable range for frequency changes for different countries due to power quality issue. Thermal limit, stability limit and voltage drop determine power limitation of transmission line. The voltage of generator is reduced to 18.65 kV (control excitation) in full load condition to keep receiving end voltage in light load condition in range. The main problem on combined transmission line is exposed at light load. Huge capacitive effect of UGC during light load condition is face at the receiving end due to Ferranti effect. In this study, receiving end voltage in full load is a bit more than 0.95 pu at bus 3. Moreover, light load condition is described by 30% of full load condition. The system is designed and managed to control the receiving end voltage close to 1.05 pu during light load. For study on protection application, the effect of load current and voltage can be neglected due to fault condition. In bus 1, the voltage is exceeding 220 kV by times of 1.007 and its angle is closed to zero. Voltage increasing of bus 2 and 3 is shown due to long cable effect, which is more than voltage on bus 1. This also shows the effect of charging current of cable and needed to be compensated for protecting plan [8]. The voltage of bus 2 is increased by 0.0011 pu to 1.0018 pu with angle of -9.56°. Moreover, the voltage of bus 3 is slightly higher than bus 2, but its angle increase to -10.24°. Changing in phase angle of two successive buses in radial network with close voltage magnitude is proved the power system work properly. Table IV represents power flow of system in full load condition.

TABLE IV
LOAD FLOW

Bus (No.)	Voltage (pu)	Angle (deg.)	P_{Load} (MW)	Q_{Load} (MVAr)
B_1	1.01	-0.6	10	5
B_2	1.02	-8.4	-	-
B_3	1.02	-9.09	116.18	49.97

C. Other existed apparatus

The design radial network contains 2 circuit breaker (CB) to disconnect transmission line during faults. Moreover, in order to sectionalize the network voltage base 3 bus is used. Although, buses are operating in 220 kV, they are utilized to discriminate between different level voltages. Bus 1; determine the step up point and the OHL commence point, bus 2 shows the junction between OHL and UGC and bus 3 determine the step down level and UGC is ended. The relay and sensors are located immediately after bus 1 to protect transmission line.

III. DATA ACQUISITION

Distance relay sensors are settled at bus 1 to extract current and voltage at relay point. Bus 1 is a three phase voltage and current measurement block of MATLAB software. The output voltage and current of this block is represented in per- unit phasor mode. The three phase measurement block need to be tuned by user in base voltage and power to extract the pu values. Therefore, base values for this block are: voltage is 220 kV and power is 100 MVA. On the other hand, the base current of power system is obtained I= 262.432 A.

A. Network sequence

Converting abc to positive, negative and zero sequence (PNZ or it is also known as 1,2 and 0 or +,- and 0) mathematically is done by Fortescue matrix which is called symmetrical component. In this conversion, assume that: $a = 1\angle 120°$

For converting symmetrical component to abc, the fortescue matrix is as following:

$$V^{abc} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} V^{012} \tag{10}$$

Utilization of this transformation in any software needs several line programming. In MATLAB software, this transformation is done by Discrete 3-Phase Sequence Analyzer Block which is converting acb phasor domain to magnitude and phase of required harmonic order of symmetrical component. The fault waveform is highly distorted and contained harmonics of fault condition and fault resistance. Hence, waveform filtering before relay is fed by voltage and current is vital. This filtering is done by MATLAB Discrete Fourier block. This block is able to extract desired harmonic of input signal in polar form over a running window of one cycle of fundamental frequency.

B. Sequence Impedance

While current and voltage are transformed into sequence, calculated impedance is in sequence, too. The desire power system is operated just with positive sequence, hence negative and zero sequences are undesired. Negative and zero sequence are existed in real network because of network's inherent configuration and power system apparatus. By the way, in this research positive sequence impedance is assumed to be extracted by dividing positive voltage and positive current. The sequence voltage and current obtained in section III-A are expressed in polar coordination. Hence, the voltage magnitude needs to be divided on current magnitude and the phases difference. Finally, the resistance (real part of impedance) and reactance (imaginary part of calculated impedance) are in hands. Now, change in measured impedance reveals disturbance and in fault case impedance measurement is function of distance. So:

$$Z^{desire} = Z^1 = \frac{V^1}{I^1} \times Fault.point \quad (km) \tag{11}$$

IV. Distance Relay Impedance measurement

Extracting sequences in real network is difficult and is usually done by connecting instrument transformer in various forms. The designer hope to have network with just positive sequence, but other sequences are also available in system duoe to unbalance condition of transmission lines and winding distribution in rotating machine and transformers. Hence, using abc is more convenience compare to sequence. Installed distance relay measure voltage and current of related phase and the cumulative impedance measured by distance relay is:

$$Z_i^{Measured} = \frac{V_i}{I_i - kI^0} \tag{12}$$

for single line, but for double line is:

$$Z_{ij}^{Measured} = \frac{V_i - V_j}{I_i - I_j} \tag{13}$$

Where i and j represent abc phase and 'k' factor in equation 12 is constant factor calculated by:

$$k = \frac{Z_L^0 - Z_L^1}{Z_L^1} \tag{14}$$

V. Evaluation of Design Distance Relay

Figures 2 and 3 portray reactance of transmission line measured at relay point. Figure 3 is contains 6 subplots. The first subplot X^+ is shown positive sequence reactance of transmission line which is called desired impedance. It is imaginary part of positive sequence measured impedance Z^+. On the other hand, next subplots are related phase reactance measured by simulated distance relay at bus 1.

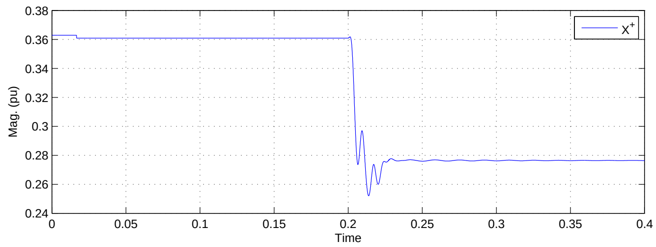

Fig. 2. Positive Sequence Reactance of Transmission Line

While the system has constant reactance in normal operation condition, measured reactance had negligible variation because of load variation. Likewise, the voltage of faulty phase decrease and current will change up to power system configuration during fault. This variation fall the reactance value down (X^+, X_a , X_{ac} ,·). Moreover, related to power system configuration and grounding the high current of faulty phase induce voltage on healthy phase which lead to increase in measured reactance X_b.

The discontinuity in first cycle in figure 3 happened by MATLAB sequence analyzer (figure 3). While the signal is decomposed, the first cycle value of desired signal need to be entered by user. This discontinuity is not effected for the remains signal from 2^{nd} cycle onward. The fault waveforms are highly distorted and contained harmonics of fault condition and resistance. Hence, a filtering on voltage and current waveform is vital. This filtering is done by using MATLAB Discrete Fourier Block. This block is able to extract desired harmonic of input signal in polar form over a running window of one cycle of fundamental frequency. However, ground faults in power system will reduce the measured reactance (on faulty phase), but it is not enough for distance relay operation. Distance relay is affected by fault resistance and fault location which can reduce fault trace on zone locus.

Distance relay operation is shown in figure 4 for different fault location . A single line to ground fault (A-G) is executed at 0 km, 40 km and 80 km of distance relay location. Moreover, the fault resistance is fixed at 10 Ω. Fault characteristics (R, X) are recorded for location between 0 km to 80 km, which are bounds of zone 1. While the

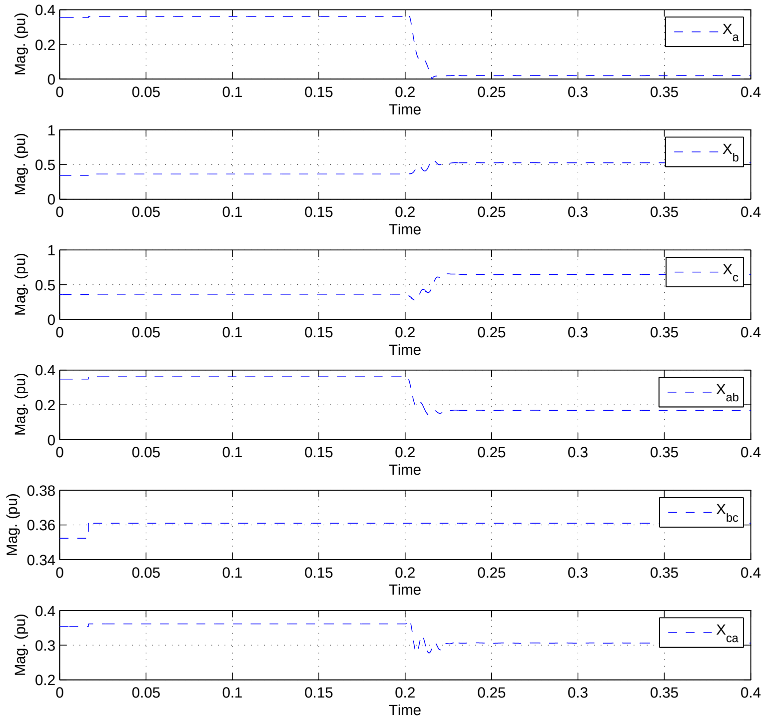

Fig. 3. Phase and Line Sequence Reactance of Transmission Line

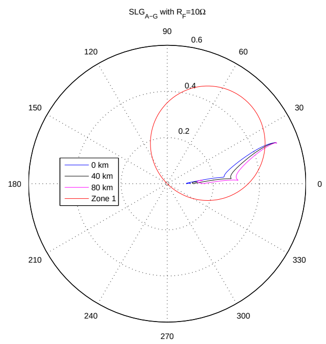

Fig. 4. Trace of SLG Fault on Transmission Line

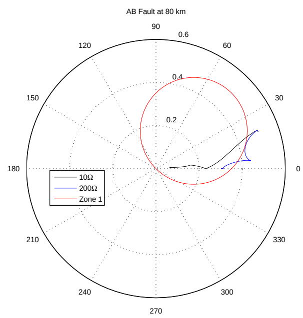

Fig. 5. Double line to Ground fault at 80 km

fault is located at plotted locus and time of fault trace is covered by zone 1 of distance relay, relay can protect the line. The locus of zone 1 is settled at 80% of transmission line impedance. Changing in fault location will push the fault trace out of locus of distance relay zone 1. When the fault is going far away of relay location, impedance and admittance of transmission line is increased. The fault trace of 0 km is more tendencies to middle of zone 1 locus compared to 80 km.

This is clear that worst case scenario occurred close to end of zone 1 with high resistance. This resistance can push fault trace out of zone 1 before scheduled time for tripping. In figure 5 high resistance fault is compared with low resistance. Fault is happened at 80 km, for a line to line to ground fault (AB-G). Although the simulated distance relay can come up with low resistance (10 Ω), the trace time on high resistance (200 Ω) is quite short to be tripped by distance relay zone 1. By the way, distance relay is going to have mis- operation on these faults. The locus of zone 1, fault trace 10 Ω fault resistance and 200 Ω fault resistance are shown in figure 5.

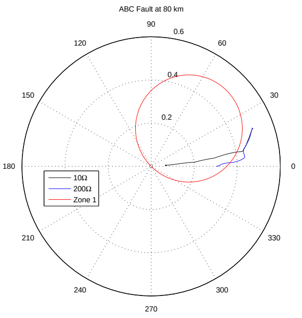

Fig. 6. Three phase to Ground fault at 80 km

Normally, the severest fault is used to evaluate power system operation and response during fault. Three phase fault is applied at 80 km (end of zone 1). The fault with 10 Ω fault resistance is easily detected, but the relay is blind to quench high resistance fault. This is because of short fault trace in zone 1 and keeps out of origin of coordination.

VI. Conclusion

In this study a distance relay is simulated in Simulink/ MATLAB software, and impedance measurement during fault is shown. Then, simulated relay is applied on transmission line with significant part of UGC. Transmission line is modeled as distributed parameter to increase fault analysis accuracy and distance relay operation. This transmission line has affected distance relay operation due to huge charging current. Although, charging current is suppressed by filtering, but the distance relay is still affected by high fault resistance close to reach point of zone 1.

Positive sequence impedance of power system is extracted as reference impedance during fault for evaluating the results of simulation.

Acknowledgment

The authors would like to thank Universiti Teknologi Malaysia (UTM) for effective supports and management under grant vote 03H45.

Moreover, I would also like to thank Malaysian Ministry of Education (MOE) for cooperation and financial support for doing this work.

References

[1] Z. Xu, S. Huang, L. Ran, J. F. Liu, Y. L. Qin, Q. Yang, and J. He, "A distance protection relay for a 1000-kv uhv transmission line," *Power Delivery, IEEE Transactions on*, vol. 23, no. 4, pp. 1795–1804, Oct 2008.

[2] M. Bozek and J. Izykowski, "Adaptive distance protection of double-circuit lines based on differential equation fault loop model," in *Universities Power Engineering Conference, 2008. UPEC 2008. 43rd International*, Sept 2008, pp. 1–5.

[3] M. Eissa, "Ground distance relay compensation based on fault resistance calculation," *Power Delivery, IEEE Transactions on*, vol. 21, no. 4, pp. 1830–1835, Oct 2006.

[4] B. Kasztenny, I. Voloh, and J. Hubertus, "Applying distance protection to cable circuits," in *Protective Relay Engineers, 2004 57th Annual Conference for*, Mar 2004, pp. 46–69.

[5] J. Vargas, A. Guzman, and J. Robles, "Underground submarine cable protection using a negative sequence directional comparison scheme," in *Schweitzer Engineering Laboratories*, 1999, pp. 1–22.

[6] B. Su, J. Wang, Y. Yang, W. Gong, and Y. Xu, "Setting considerations of distance relay for uhv/ehv long transmission lines," in *Power Engineering Society General Meeting, 2007. IEEE*, June 2007, pp. 1–7.

[7] D. Tziouvaras, "Protection of high-voltage ac cables," in *Power Systems Conference: Advanced Metering, Protection, Control, Communication, and Distributed Resources, 2006. PS '06*, March 2006, pp. 316–328.

[8] T. Kase, Y. Kurosawa, and H. Amo, "Charging current compensation for distance protection," in *Power Engineering Society General Meeting, 2005. IEEE*, June 2005, pp. 2683–2688 Vol. 3.

[9] J. Upendar, C. Gupta, and G. Singh, "Comprehensive adaptive distance relaying scheme for parallel transmission lines," *Power Delivery, IEEE Transactions on*, vol. 26, no. 2, pp. 1039–1052, April 2011.

[10] Y. Hu, D. Novosel, M. Saha, and V. Leitloff, "An adaptive scheme for parallel-line distance protection," *Power Delivery, IEEE Transactions on*, vol. 17, no. 1, pp. 105–110, Jan 2002.

[11] V. Makwana and B. Bhalja, "A new adaptive distance relaying scheme for mutually coupled series-compensated parallel transmission lines during intercircuit faults," *Power Delivery, IEEE Transactions on*, vol. 26, no. 4, pp. 2726–2734, Oct 2011.

[12] E. S. T. E. Din, M. M. A. Aziz, D. khalil Ibrahim, and M. Gilany, "Fault location scheme for combined overhead line with underground power cable," *Electric Power Systems Research*, vol. 76, no. 11, pp. 928 – 935, 2006. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0378779605002683

[13] C. Jung, K. Kim, J. Lee, and B. Klockl, "Wavelet and neuro-fuzzy based fault location for combined transmission systems," *International Journal of Electrical Power and Energy Systems*, vol. 29, no. 6, pp. 445 – 454, 2007.

[14] E. Ngu and K. Ramar, "A combined impedance and traveling wave based fault location method for multi-terminal transmission lines," *International Journal of Electrical Power and Energy Systems*, vol. 33, no. 10, pp. 1767 – 1775, 2011. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0142061511002018

[15] T. Kase, Y. Kurosawa, and H. Amo, "Charging current compensation for distance protection," in *Power Engineering Society General Meeting, 2005. IEEE*, June 2005, pp. 2683–2688 Vol. 3.

[16] J. Sadeh and H. Afradi, "A new and accurate fault location algorithm for combined transmission lines using adaptive network-based fuzzy inference system," *Electric Power Systems Research*, vol. 79, no. 11, pp. 1538 – 1545, 2009. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0378779609001412

[17] V. Makwana and B. Bhalja, "New digital distance relaying scheme for phase faults on doubly fed transmission lines," *Generation, Transmission Distribution, IET*, vol. 6, no. 3, pp. 265–273, March 2012.

[18] H. Khorashadi-Zadeh and H. Daneshi, "Evaluation and performance comparisons of digital distance protection algorithms," in *Industry Applications Conference, 2004. 39th IAS Annual Meeting. Conference Record of the 2004 IEEE*, vol. 4, Oct 2004, pp. 2463–2468.

[19] P. S. Bhowmik, P. Purkait, and K. Bhattacharyya, "Proposal for a distance relaying scheme based on wavelet assisted neural network," in *Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE*, July 2008, pp. 1–7.

[20] J. Horak, "Zero sequence impedance of overhead transmission lines," in *Protective Relay Engineers, 2006. 59th Annual Conference for*, April 2006, pp. 11 pp.–.