AN IMPLEMENTATION OF FOURIER TRANSFORMS BASED ON DISTANCE RELAYING ALGORITHM USING EMTP MODELS

C. H. Kim, M. H. Lee, Y. C. Shin, J. B. Chae, S. W. Park, S. H. Byun

School of Electrical and Computer Engineering
Sung Kyun Kwan University
Suwon, KOREA

Abstract - **This paper presents a new implementation of EMTP MODELS for distance relay modeling, in which we simplified the procedures of system modeling and distance relaying system by using a single structure of MODELS.**

In this paper, we tried to integrate the modeling of the power system and the protective system in one program module. The purpose of this paper is to provide an systematic relaying concepts by modeling digital relaying system using MODELS functions within EMTP in a closed-loop manner. Various elements of digital protective relaying are organized to generate an systematic approach to modeling the actual hardware of digital relaying systems. Single phase ground fault is simulated and various distances and phases are considered.

Keywords - EMTP, MODELS, Digital Relaying, Fourier Transform, DC-offset, Fault Location Estimation

I. INTRODUCTION

The protective relaying system is required to detect the abnormal signals indicating the faults in transmission system, separate the faulty part of the system from the normal operation portion and hence prevent the propagation of the fault sources. The electrical energy transmission system becomes complicated, and longer in distance as power plants tend to be larger and located in a small bound due to environmental restrictions. Digital protective relaying system as a consequence for such a large system control comes to play a role instead of the traditional analog relaying system which is known for a large variance in distance estimation. It has to, therefore, estimate the region of the fault source and block the propagating effect as fast as possible[1-5].

In order to develope a new relay system to be used it needs to be tested in a miniature system or to be simulated with the faulty data obtained usually from EMTP. With a simulation method, ones actually need the two steps: obtain the simulation data for various fault cases and simulate the algorithm with the data. Combining the two separated tasks into one programming module in simulation is very much called for. Chaudhary and Phadke[6-8] developed the EMTP EPRI/DCG Version 3.0 that allows all the possible FORTRAN subroutine to be used. The MODELS from EMTP recently introduced, make it possible to control the inter-operation between the power system and protective system and to model system operations[9-12]. In this paper, we tried to integrate the modeling of the power system and the protective system in one program module. All the procedures for the simulation of a digital relaying system are in a EMTP formatted file, thus simplifying the evaluation of a new protective algorithm.

II. EMTP MODELS

MODELS is a symbolic language interpreter for the EMTP which is recently popularized for electromagnetic transient phenomenon modeling. MODELS provides the monitoring and controllability of power systems as well as some other algebraic and relational operations for programming. MODELS approaches to model the power system by describing the physical constants and/or the subsystems functionally for target systems. With some compromised functions it is also called a new TACS.

III. IMPLEMENTATION OF DISTANCE RELAYING BY MODELS

Distance relaying system implemented in a microprocessor is widely used for protecting transmission system which requires reliability in maintenance. Its fast operation and independence of the capacity of the power system are responsible for the popularity in use.

Distance relaying scheme makes use of the transient voltage and current values passed through the CT and PT for the calculation of the impedance. The distance relaying methods rely on its estimation of fault distance upon the partial values and the convergence of them, which produced much work of research in this field. Among others, the transmission line protection based on the fundamental frequency signals is widely used. We studied a new implementation for it with the point of view of fast and exact extraction of the fundamental component.

When a fault happens the transient voltage and current values are mainly composed of the high frequency and exponentially decreasing dc-offset components. For the reliable estimation of the fault distance the fundamental component needs to be extracted via various digital signal processing algorithms. In this paper we implemented the anti-aliasing low-pass filters and the dc-offset removal filter with MODELS.

A. Anti-aliasing Low-Pass Filter

In order to meet the sampling theory the sampling rate should be as two times large as the maximum frequency in the analog signal. Sometimes sampling with smaller sampling rate results the aliasing effects to the discrete time signals. The anti-aliasing filter is used to remove such aliasing effect as well as the high frequency components. For the purpose of removing the unwanted components the analog second order butterworth low-pass filter is used[14]. The specifications for the filtering is that the passband cutoff frequency is 60Hz, the stop-band cutoff frequency 360Hz, stop-band attenuation 28dB and the sampling frequency 1.8kHz (300 samples/cycle).

The transfer function of the low-pass filter

$$H(s) = \frac{1}{s^2 + \sqrt{2}s + 1} \qquad (3\text{-}1)$$

is transform by the bilinear transformation, resulting the digital transfer function of

$$H(z) = \frac{a_0 + a_1 Z^{-1} + a_2 Z^{-2}}{1 + b_1 Z^{-1} + b_2 Z^{-2}} \qquad (3\text{-}2)$$

where, $a_0 = 0.000108058$, $a_1 = 0.000216116$

$a_2 = 0.000108058$, $b_1 = -1.9708328899$

$b_2 = 0.970815132$.

B. DC-offset Removal Filter

When the incidence breaks the abnormal components of the voltage and the current are due to the high component frequencies and the dc-offset component.

The mentioned anti-aliasing filtering removes the most of the high frequency components but not the dc-offset effect. The next step is to apply the dc-offset removal filter for the removal. We assume that the dc-offset component is of exponential form when a fault occurs:

$$x_k = \sum_{n=1}^{\infty} X_n \sin\left(\frac{2\pi nk}{N}\right) + A\exp\left(\frac{-k\Delta t}{\tau}\right) \qquad (3\text{-}3)$$

where, Δt is sampling interval,

τ is time constant,

N is samples per period.

$$y_k = x_k - x_{k-1}/\exp(\Delta t/\tau) \qquad (3\text{-}4)$$

where, Δt is sampling interval,

τ is time constant.

Applying (3-3) to (3-4) yields the following signal after the removal

$$y_k = \sum_{n=1}^{\infty} X_n a_n \sin\left(\frac{2\pi nk}{N} + \varphi_n\right) \qquad (3\text{-}5)$$

where, $a_n = \sqrt{(E_n^2 + F_n^2)}$, $\varphi_n = \tan^{-1}(F_n/E_n)$,

$E_n = 1-[1/\exp(\Delta t/\tau)]\cos(2n\pi/N)$,

$F_n = [(1/\exp(\Delta t/\tau)]\sin(2n\pi/N)$.

As can be seen (3-5) the filtering (3-4) removes the dc-offset component.

C. Digital Filter for Fundamental Frequency Component Extraction

There are three approaches used in digital transmission line protection algorithms. These approaches depend on the form of the final input signal used to make the relaying decision.

We, in this paper, used the widely accepted method which uses the fundamental frequency signal. The voltage and the current values from the extracted fundamental signals are used to calculate the impedance from the system to the point where the fault occur. There have been proposed many algorithms for the fundamental component extraction[15-16]. Fourier transform, Walsh function, Harr transform and block pulse functions are the orthogonal functions that are used for this purpose.

We used the block pulse function methods and implemented with MODELS structure.

D. Fundamental Component Signal Extraction via DFT

Assume that the N samples are obtained for each period and call the discrete time signals *x(k)*. Then the DFT of the sampled signal

$$X(n) = \sum_{k=0}^{N-1} x(k)\, W_N^{nk} \quad (n=0,\ 1,\ 2, \ldots,\ N-1) \qquad (3\text{-}6)$$

where, $W_N^{nk} = e^{-j(\frac{2\pi nk}{N})}$

The n is the order of the harmonics. The fundamental frequency signal are the one with n = 1. In (3-6), all the N samples were used in the calculation of the fundamental frequency signal, resulting full cycle DFT (FCDFT), but for faster calculation half cycle DFT (HCDFT) is sometime used.

IV. SIMULATION RESULTS AND DISCUSSION

A. Simulation Method

A set of simulation experiments were carried in order to show the validity and the simplicity of the EMTP MODELS implementation of the power system and the protective relaying system. The subsystems are largely obtaining the fault data, anti-aliasing low-pass filtering, removing of dc-offset component, and extraction of the fundamental component signal and the impedance calculation. All the subsystems are in a single EMTP file and the different experiments are carried for various fault types and fault distances.

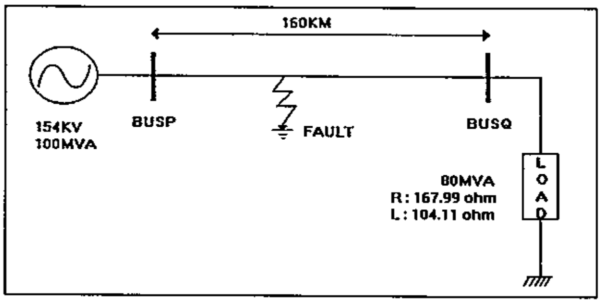


Fig. 1. Model system.

The transmission system is modeled as the total length of 160Km and of 154Kv as shown in Fig.1.

The size of conductor is ACSR 477MCM 240 and the electrical constants are shown in Table 1.

Table 1. Data of line and source.

		Z_0	Z_1	Z_2
Line constants	R [Ω/km]	0.3434	0.1342	0.1342
	L [Ω/km]	1.3158	0.4765	0.4765
	C [μF/km]	0.0052	0.0090	0.0090
Source	Capacity	100 MVA		
	Power factor	0.85		
	Subtransient reactance	7.71 %		
Load capacity	80 MVA			

The simulation assumed a single line-to-ground fault which is the most often the case. A case with A-phase to ground fault is carried out for various distance and phase angles as in Table 2.

Table 2. The simulated fault type and fault condition.

Fault type	1LG: A-G	Fault dist-ance	10% (16km)	Voltage degree	0°
			20% (32km)		
			30% (48km)		30°
			40% (64km)		
			50% (80km)		45°
			60% (96km)		60°
			70% (112km)		
			80% (128km)		90°
			90% (144km)		

B. Modeling Anti-aliasing Low-pass Filter with MODELS

We examined the validity of the MODELS-implemented anti-aliasing low-pass filter. It is known that the high frequency components are found more at around the 90-degree than at around the zero-degree. For the validity of the filtering we modeled the fault data at the 90-degree for the case of A-phase to ground fault and fault distance of 50% from the system.

Fig.2 and Fig.3 show the voltage waveforms before and after the anti-aliasing low-pass filtering. The outputs of the filter shown in the Fig. 3 reveals the filter effect by removing the high frequency components. Also the phase delay and magnitude attenuation can be observed from the two figures. Here, the filter order is inversely related with the resulting time delay, or the phase delay in which the designer should consider as a trade off.

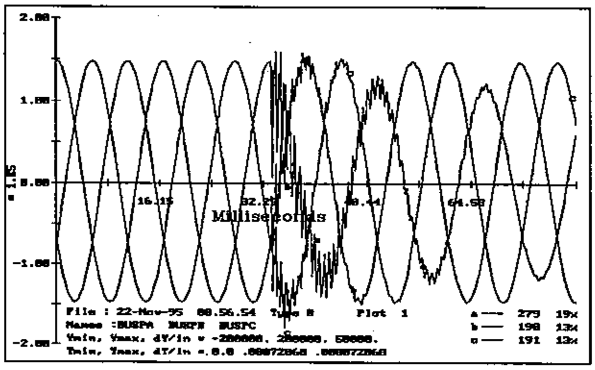


Fig. 2. Voltage waveforms when fault is occurred at fault incidence angle 90°.

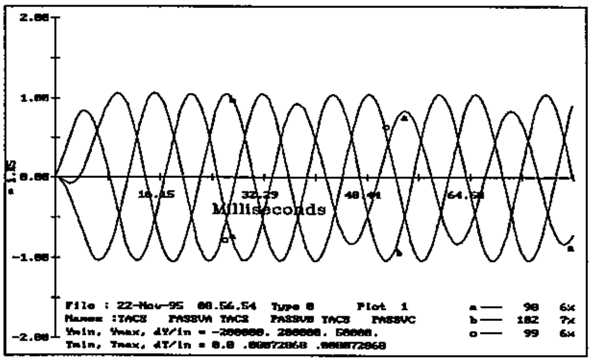


Fig. 3. Voltage waveforms after the anti-aliasing low-pass filtering.

C. Modeling Dc-offset Removal Filter with MODELS

When a fault occurs the measured voltage value consists mostly of the high component while the measured current value are affected by the exponentially decaying dc-offset component. To the contrary the case for the sensed voltage, the measured current value is more affected from the dc-offset at the zero-degree than at the 90-degree. If an algorithm using the normal component, the dc component should be removed for correct result. We rather approached to this problem by using all the three phase components and removed the dc component accordingly.

The current wavefroms distorted by the dc component at the fault incidence angle of zero, fault distances of 20% and 70% are shown in Fig. 4 and Fig. 5. Also, the outputs of the dc-offset removal filter is drawn in Fig. 4 and Fig. 5. Note the attenuation of the magnitude and phase delay of the filtered current value in the figure and especially the removal of the dc component at around the zero-degree.

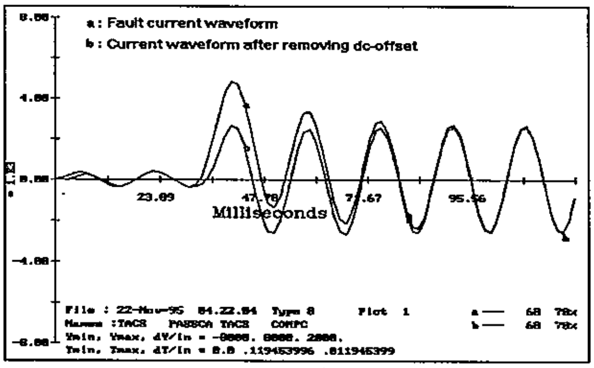


Fig. 4. Current waveforms of fault and after removing dc-offset (fault incidence angle : 0°, fault distance : 20%).

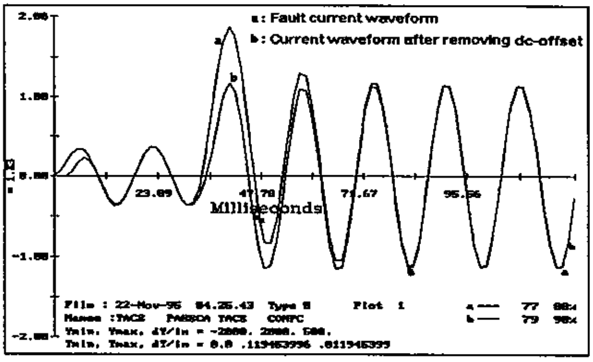


Fig. 5. Current waveforms of fault and after removing dc-offset (fault incidence angle : 0°, fault distance : 70%).

The fore-mentioned anti-aliasing low-pass and the dc-offset removal filtering are implemented in a single EMTP file and the simplicity of controlling the power systems and the protective digital relaying systems is hence ensured.

D. Results

As preprocessing stages the anti-aliasing low-pass filtering and the dc-offset removal filtering are carried to produce the voltage and the current values for the extraction of the fundamental frequency component, which in turn used for the impedance calculation. In order to confirm the impedance convergence, we experimented for each fault types and distances. The system diagram for the simulation is shown in the Fig. 6.

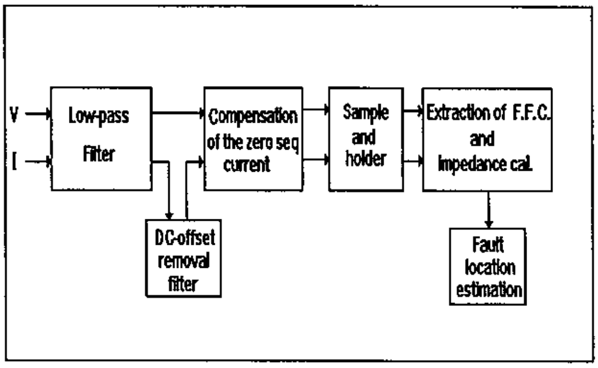
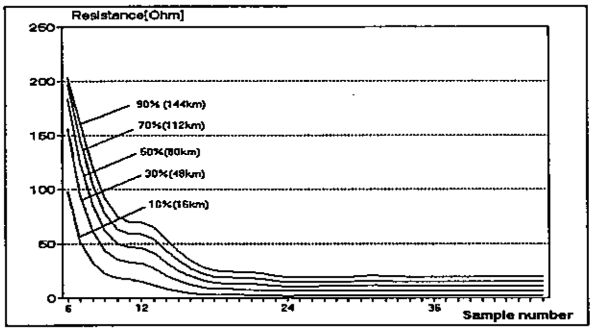
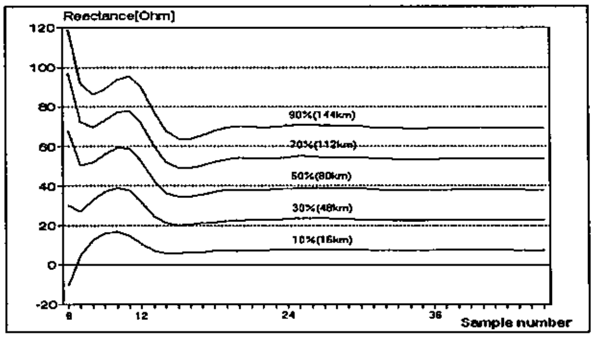


Fig. 6. Overall block diagram of simulation using MODELS.

Fig. 7 shows the convergences of the resistance and the reactance of the fault phase of zero for different fault distances from the half cycles after the fault instance.



(a) resistance



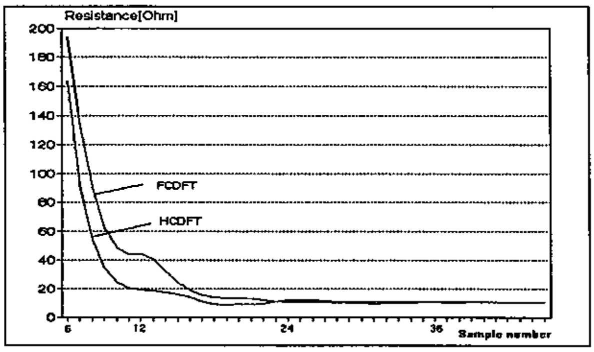
(b) reactance

Fig. 7. Convergence characteristics of impedance at fault incidence angle 0° (using FCDFT).

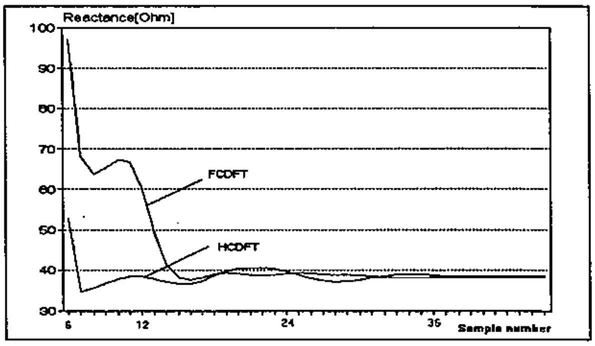
In addition, the full cycle DFT (FCDFT) and the half cycle DFT (HCDFT) are used for the fundamental frequency component extraction. The corresponding results of the resistance and the reactance convergence properties are demonstrated in Fig. 8 for the fault-degree of 45 and the fault distance 50%.

FCDFT and HCDFT each hold its merits in the fundamental frequency component extraction process. More data are used in FCDFT, thus operate slowly while in HCDFT faster computation worths it. The FCDFT trades its speed with the convergence behavior.

In order to show the stability in the impedance convergence the traces are shown in Fig. 9 for FCDFT.



(a) resistance

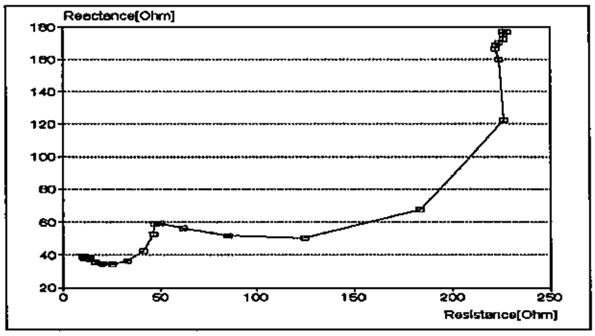


(b) reactance

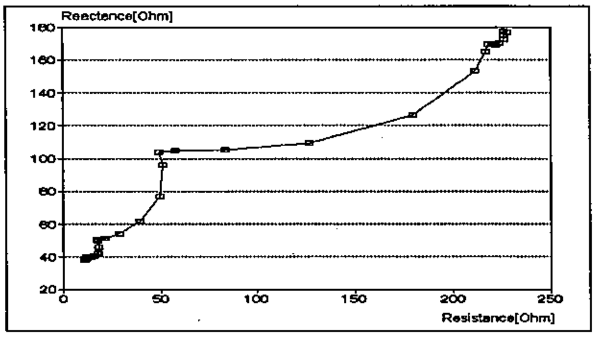
Fig. 8. Comparison of impedance convergence charac- teristics the FCDFT and HCDFT.

The horizontal axis and the vertical axis are for the reactance and the resistance in the figures. Thus, the resistance converges from the right side and the reactance from the left side. Predefined convergence areas are set for the resistance and the reactance. Protecting trip signals are issued as soon as the convergence reaches the predefined region for further necessary actions to separate the fault segment from the normal operated portion of transmission system.

The fault instances for both simulations are of 50% distance. The fault degrees of 0 and 90 are shown in each figure of the FCDFT's.



(a) fault incidence angle 0°



(b) fault incidence angle 90°

Fig. 9. Impedance trajectory using FCDFT (fault distance : 50%).

V. CONCLUSIONS

Using EMTP MODELS, we presented a simulation algorithm for power systems and digital protective relaying algorithms in a single file format, which helps to reduce the tasks in modeling and accompanying modeling algorithms. It is evident that the electric system and the protective systems should not be considered separately when an digital protective relaying algorithm is to be considered and is hence important to consider the modelings simultaneously.

We conclude from the experiment obtained for this study that the concurrent modeling of the power system and the protective relaying system for transmission lines is desired for more efficient relaying algorithm development and improvement as well as for the evaluation of the existing algorithms.

For further research we would like to improve the speed of the computation which may be obtained via using a high level language such as C and interfacing with EMTP routines.

VI. REFERENCES

[1] Arun G. Phadke, James S. Thorp, *Computer Relaying for Power Systems*, Johns Wiley & Sons inc., pp.112-162, 1993.

[2] Barry J Mann, I. F. Morrison, "Digital Calculation of Impedance for Transmission Line Protection", *IEEE Trans. on PAS*, Vol. PAS-90, No. 1, Jan/Feb, pp270-279, 1971.

[3] Adly A. Girgis, Christopher M. Fallon, "Fault Location Techniques for Radial and Loop Transmission Systems using Digital Fault Recorded Data", *IEEE Trans. on Power Delivery*, Vol. 7, No. 4, pp.1936-1945, October 1992.

[4] T. S. Sidhu, H. Singh, M. S. Sachdev, "Design, Implementation and Testing of An Artificial Neural Network Based Fault Direction Discriminator for protecting Transmission Lines", *IEEE Trans. on Power Delivery*, vol. 10, No. 2, pp 697-706, April 1995.

[5] O. P. Malik, G. S. Hope, "A Laboratory Investigation of A Digital Protection Technique for Parallel Transmission Lines", *IEEE Trans. on Power Delivery*, vol. 10, No. 1, pp. 187-193, January 1995.

[6] Arvind K. S. Chaudhary, Arun G. Phadke, "Protection System Representation in the Electromagnetic Transients Program", *IEEE Trans. on Power Delivery*, Vol. 9, No. 2, pp. 700-711, April 1994.

[7] Robert E. Wilson, Jerry M. Nordstrom, "EMTP Transient Modeling of a Distance Relay and a Comparison with EMTP Laboratory Testing", *IEEE Trans. on Power Delivery*, Vol. 8, No. 3, pp.984-992, July 1993.

[8] J. N. Peterson, R. W. Wall, "Interactive Relay Controlled Power System Modeling", *IEEE Trans on Power Delivery*, Vol. 6, No. 1, pp.96-102, January 1991.

[9] B. Don Russel, Carl L. Benner, "Arcing Fault Detection for Distribution Feeders", *IEEE Trans. on Power Delivery*, vol. 10, No. 2, pp676-683, April 1995.

[10] Laurent Dube, *MODELS RULE BOOK (New Version)*, April 1996.

[11] Chul-Hwan Kim, "An Efficient Use of EMTP Using MODELS", *The Electrical works*, Vol. 12, No. 2, pp.22-30, 1995.

[12] Juan A. Martinez, "Educational Use of EMTP MODELS for the Study of Rotating Machine Transient", *IEEE Trans. on Power Systems*, Vol. 8, No. 4, pp.1392-1399, November 1993.

[13] J. A. Martinez Velasco, G.A. Capolino, *TACS and MODELS: Drive Simulation Languages in a General Purpose Program.*

[14] Emmanuel C. Ifeachor, Barrie W. Jervis, *Digital Signal Processing*, Addison-Wesley Publishing Company, pp.374-398, 1993.

[15] D. G. Mclaren, G. W. Swift, "A New Directional Element for Numerical distance Relays", *IEEE Trans. on Power Delivery*, vol. 10, No. 2, pp666-675, April 1995.

[16] Chul-Hwan Kim, "A study on the fault Identification of underground Cable using Neural Networks", *International conference on Energy Management and Power Delivery*, pp.571-576, IEEE Singapore sec., Nov. 1995.