COMPUTER RELAYING FOR TRANSMISSION LINES

Ayşen Basa Arsoy, *IEEE Member*
e-mail: aysen@ieee.org
Kocaeli University, Faculty of Engineering, Department of Electrical Engineering, Izmit, Turkey

Key words: Relaying algorithms, distance relaying algorithm, faults

ABSTRACT
In this study, computer-relaying algorithms for transmission lines are discussed, and advanced computer relaying techniques are outlined. This paper also presents a distance relay algorithm and explores its functionality for various faults on a two-machine system.

I. INTRODUCTION

As digital computers were introduced in power systems, the concept of computer relaying became an interest to relay engineers. The first approach was that a single computer would perform relaying functions of all the equipment in a substation. Another approach proposed a dedicated microcomputer for each relay. These approaches were explored about 40 years ago, which initiated the steadily growing computer relaying technology [1].

As computers are being heavily utilized, the application of computer relaying is now more reasonable and acceptable. Computer based relays have self-checking features, and they are more reliable than the conventional relays. They are well integrated with the computer-based devices in substations. The feature of programmability and communication capability of the relays makes them more flexible functioned and well adopted to different scenarios.

Computer relays consist of several subsystems:
A *processor* to execute the relay program, to maintain the various timing functions, and to communicate with its peripheral equipment,
an A/D converter to convert analog voltage and current signals to digital signals,
an anti-aliasing filter to eliminate the errors produced by current and voltage transducer and A/D converters, and
a signal conditioning.

The A/D converter and anti-aliasing filter are associated with the sampling process. Sampling clocks determine the sampling instants.

In this study, the overview of the relaying algorithms for transmission lines are given, then the advanced techniques in computer relaying are discussed. And finally, a relay algorithm and its performance for various faults are presented.

II. RELAYING ALGORITHMS

Transmission lines are the major part of power systems, therefore most of the early work in computer relaying took place for their protection. Several computer-relaying techniques exist to protect transmission lines [1].

The Discrete Fourier Transformation (DFT) and least square algorithms are used in phasor calculations to estimate the fundamental frequency components of currents and voltages. Both DFT and least square algorithms are essentially impedance (distance) relay algorithms since impedance is a single frequency concept, and it is equal to the ratio of voltage to current phasors. While one cycle DFT algorithm rejects a DC offset, the least square algorithm does not. The DC offset can be removed by the use of a mimic circuit algorithm. Transient monitors are utilized to disable the relay during the pre-fault to post-fault transition. They act as a sort of a self-governing blinder that testifies to the purity of the data.

The simplest distance-relay algorithm contains six single-phase impedance equations corresponding to represent ten possible faults. A fault classification algorithm can classify the type of fault. However, it tends to be error-prone for systems having short lines with weak sources or long lines with strong sources. The use of phasor calculations allows the use of symmetrical component distance relay to detect the type of fault. The use of symmetrical component relay overcomes the uncertainty of the fault classification algorithms [2].

The differential-equation algorithms are based on a model of the system. A single-phase model of a faulted line can be written as a differential equation relating the voltage and current seen by the relay. Since voltage and current can be measured, system parameters can be estimated;

therefore, the distance to the fault is estimated. The algorithm does not suffer from the DC offset. This time domain solution is useful when the frequency of the system changes over the long period.

A performance of distance relaying algorithms is measured by looking at the relationship between the length of the data window and the estimation error. The variance of the estimate is independent of the sampling rate, and is reciprocal to the length of the data window. For example, a close-in fault can not be cleared by a one half-cycle algorithm as quickly as desired. Besides, one half-cycle algorithm can not be set as near the zone-one boundary as longer window. An adaptive scheme that adapts the length of window length to the estimated fault location should be developed.

Fault location of a transmission line is one of the most useful post-fault analysis functions. The location of the fault is determined using the information from the pre-fault and post-fault sampled data of appropriate current and voltages. Speed of the operation is not concerned anymore. Locating the fault in a distance relay can be done using a double-ended fault location and single-ended fault location algorithms. Although double-ended fault location gives more accurate results, the data from both ends may not be available. In the single ended algorithm, source impedance is assumed to be known (Takagi's Approach). The improvement made in this algorithm by Phadke [1] shows that there is no need to know source impedance to find the fault location.

III. ADVANCED RELAYING TECNIQUES

TRAVELLING WAVES:

The theory of traveling waves has been implemented to relaying algorithms to obtain the highest possible speed of relaying. The waves set by a fault propagate towards the ends of a transmission line at approximately the speed of light. They require high-speed computation and data acquisition systems due to their high frequency contents. This technique is still in theory and not practical yet.

FREQUENCY ESTIMATION

Frequency estimation is typically used for a protection scheme against loss of synchronism, under-frequency relaying and power system stabilization [3]. Three main techniques have been developed in frequency estimation.

- Fourier Techniques
- Kalman Techniques
- Modulation Techniques

ADAPTIVE RELAYING

Adaptive relaying can be described as an adaptive change of protection systems as a response to the change in the power system. These changes in the power system may be load changes, network switching operations and faults. A hierarchy of computer relays with communication links exists in order to have the relay adapted to changing system conditions.

PHASOR MEASUREMENT

A phasor measurement unit contains a GPS receiver, a microprocessor, current and voltage transformers signal filtering and conditioning units. GPS receiving clocks provide sampling pulses to the phasor measurement units. These pulses are nominally at a multiple of the fundamental power system frequency and are phase locked with the 1 pulse-per-signal. Sampling clock synchronization would allow all the phasors to be computed on a common reference. Phasor measurement units can provide:

- phasor measurements in real time,
- high speed, high accuracy, stable and low noise,
- synchronized wide area measurements.

IV. DEVELOPED RELAY ALGORITHM

The objective of this part is to design a distance protection relay and test it for various faults on a two-machine system. The two-machine system is created and faults are simulated using an electromagnetic transient program (EMTP). The functionality of the relay is tested for three steady-state faults and two transient faults.

DESCRIPTION OF TWO-MACHINE SYSTEM

Two machines are connected with a 50km transmission line. The schematic representation of the two-machine system and possible fault locations (F1, F2, and F3) is shown in Figure 1. The designed relay (R) is located at the left generator side.

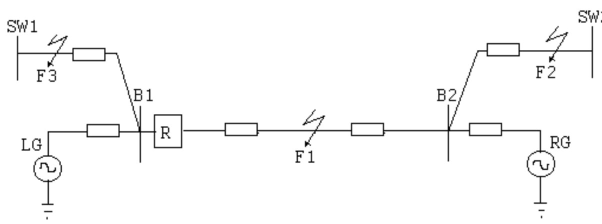


Figure 1: Simulated Two Machine System

This system has the following specified values:

- Length of Transmission Lines:

B1-F1	= 30 km
F1-B2	= 20 km
B1-SW1	= 20 km
B1-SW2	= 30 km

- Impedances of Transmission Lines

Z1=Z2	=(0.05+j1) Ω/km
Z0	=(0.05+j4)Ω/km

- Impedances of LG (Left Generator)
  Z1=Z2 = (j0.1) Ω
  Z0 = (j0.015) Ω

- Impedances of RG (Right Generator)
  Z1=Z2 = (j0.5) Ω
  Z0 = (j0.01) Ω

- Generator Voltages (rms, ϕ to ϕ): Vg = (500) kV

- Relay (R) Voltage: Vr = (500) kV

DESCRIPTION OF FAULT SIMULATION

A mutually coupled PI equivalent representation with R-L-C matrices were employed in order to model the two machine system in EMTP. Generators were modeled with the three single sources. Positive and zero sequence impedances were converted to the mutual impedances using the formulas given below.

Z11 = Z22 = (Z0+2*Z1) / 3;
Z12 = Z21 = (Z0-Z1) / 3;

In steady state, voltage at B1 where the relay is located was maintained to be 1pu (at no fault). The relay test was performed for only phase to phase faults. Three standard line control switches were used to simulate a forward in-zone fault (F1), a forward out-of-zone fault (F2) and a reverse fault (F3). These faults were considered to be steady-state faults. Two transient faults were created at F1 when phase-to phase voltage is at its maximum, and it is at zero.

RELAY ALGORITHM AND LOGIC

The relay has been designed as a one-cycle relay using 16 points per cycle. The relay algorithm implemented in MATLAB is shown in Figure 2.

Since the input, for test purposes, comes from EMTP at a sampling rate of 160 points per cycle, an anti-aliasing filter operating at the EMTP sample rate and a decimation routine have been included in place of the anti-aliasing/input filters that would be found on an actual relay. The filter used is a standard MATLAB implementation of the finite impulse response digital filter. The cutoff was set to 420Hz. This was chosen so as to avoid any attenuation effects due to setting the cutoff too close to the 60Hz fundamental, while also making use of this filter to remove any unwanted high frequency noise. Since the original sampling rate was 9600Hz, we could have filtered at the Nyquist frequency of 4800Hz. Once this is achieved, the decimation can simply be completed by removing all but every tenth point from the output of EMTP.

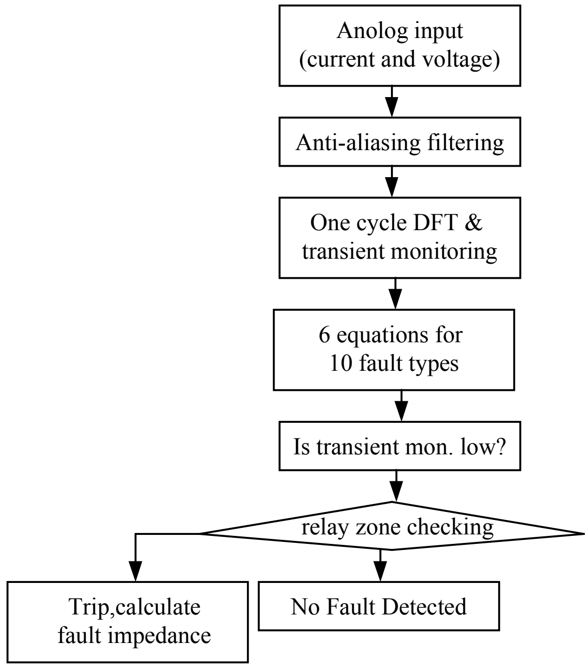


Figure 2: Relay Algorithm Implemented in MATLAB

The phasors are then computed using a standard one-cycle DFT algorithm. The use of a one cycle algorithm takes care of the DC offset problem automatically therefore the next problem to consider is computation of the transient monitor. The monitor in essence looks at the relative change in the phasor value to be sure the system is stable and that there is not an evolving fault situation prior to making a relaying decision. The monitor used calculates the percent change in a new phasor when compared to the previous phasor.

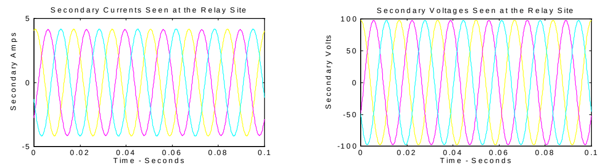
Next, the six equations describing the 10 possible faults must be computed. This algorithm does not make use of a fault detector rather it depends on the speed of the modern microprocessor to compute all equations for each window considered. Finally, the relay logic determines three things to determine whether or not to trip. The following conditions have to be met so that the relay trips:

- The relay must be out of the first cycle of its operation (16 points of startup data for the first window),
- all three transient monitors must be low (i.e. the phasor quantities are not changing), and finally,
- the impedance of the line must be within the operating characteristic of the relay.

Each new window and set of phasors are put through each of these tests, and the relay will continue to operate until it sees a fault. Then, the type of fault and the impedance are outputted to the screen.

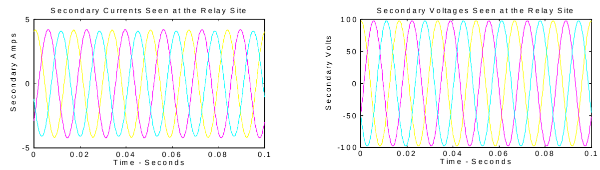
FAULTS AND RELAY RESPONSE

The faults simulated in EMTP are shown from Figure 3 to Figure 7. There were five compulsory cases to be tested all using a B-C fault. These included one steady state reverse fault, one steady state forward fault outside of the zone of protection, one steady state forward fault inside of the zone of protection, and two transient cases of having minimum B-C voltage (max DC offset) annd having maximum B-C voltage (min DC offset). In each figure, three-phase current and voltages seen at the relay location are depicted for each fault.



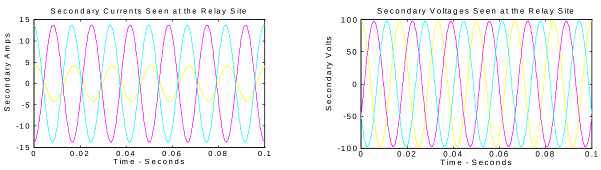
Current Voltage

Figure 3: Steady State Reverse Fault



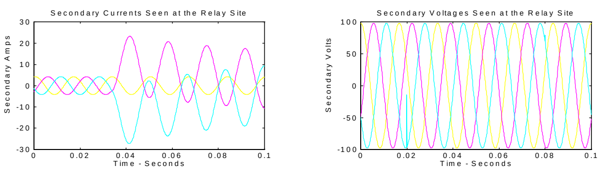
Current Voltage

Figure 4: Steady State Forward Fault (Outside of Zone)



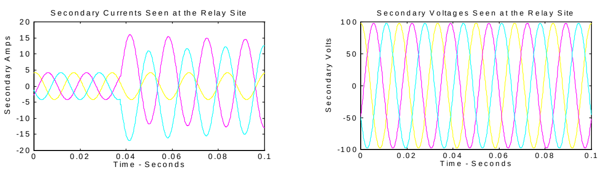
Current Voltage

Figure 5: Steady State Forward Fault (Inside of Zone)



Current Voltage

Figure 6: Transient Fault at minimum B-C Voltage



Current Voltage

Figure 7: Transient Fault at maximum B-C Voltage

The performance of the relay has been tested for these 5 compulsory faults. The response of the relay is given in Table I for each case (corresponding figures)

Table I: Relay Responses to Various Faults

Cases	Relay Response
Fig 3.	No Fault Detected
Fig 4.	No Fault Detected
Fig 5.	B to C Phase Trip, Faultimp=0.3579+7.2107i
Fig 6.	B to C Phase Trip, Faultimp=2.158+6.3227i
Fig 7.	B to C Phase Trip, Faultimp=3.2761+9.9802

As can be seen from Table I, the relay functioned correctly for all tested cases. Since the relay was designed for only Zone 1 protection, it operated when the fault is inside of its protection zone, and calculated the fault impedance.

V. CONCLUSION

This paper reviewed the relaying algorithms for transmission lines, and discussed advanced relaying techniques. A relaying algorithm was developed, and it was tested for various faults. The designed relay can be improved by including other zone protections, fault locations, and can be tested for other system configurations. Furthermore, new techniques can be employed in this algorithm.

REFERENCES

1. A.G. Phadke and J.S. Thorp, “Computer Relaying for Power Systems,” (Book), Research Studies Press, John Wiley & Sons, 1988.
2. A.G. Phadke, M. Ibrahim, T. Hlibka, “Fundamental Basis for Distance Relaying with Symmetrical Components,” IEEE Transactions on PAS, Vol. PAS 96, No. 2, March 1977.
3. M. Akke, “Frequency Estimation by Demodulation of Two Complex Signals,” IEEE Transactions on PWRD, 1996.

BIOGRAPHY

Ayşen Basa Arsoy received her B.Sc, MS., and Ph.D. degrees in Electrical Engineering from Istanbul Technical University-1992, University of Missouri-Rolla-1996, and Virginia Tech-2000, respectively. Her research interests lie in applications of computer methods, energy storage and power electronics for power systems.