ATP MODELING OF ELECTROMECHANICAL DISTANCE RELAYS

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ABSTRACT

This paper presents several methods of modeling an electromechanical relay using the EMTP/ATP. The first part of this paper discusses different approaches for representing an electromechanical distance relay, using the program's MODELS capabilities. Simulation results, as well as a discussion of the advantages and disadvantages of each approach, are included. The second part of this paper presents model application to simulate the protection of an actual power network. Although the power network modeled is real, the studies are theoretical in that no validation has been performed. The main goal of this paper is to demonstrate how a complete protection system can be represented in a transients program.

Keywords: Transient Analysis, Protection Systems, Electromechanical Relays, Distance Relays.

1. INTRODUCTION

Protection systems are an important component of power systems. Their performance during transient events can be critical. Accurately representing them is very important when analyzing their operation. Protection systems consists of three major parts: instrument transformers, protective relays, and circuit breakers (Figure 1).

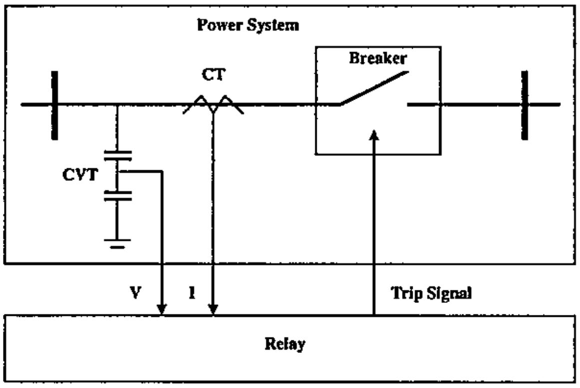


Figure 1. Components of a Protective System.

Models developed to represent current and potential transformers can be used to accurately reproduce their performance during transient conditions and analyze any performance concerns [1], [2], [3], [4]. Although several advanced circuit breaker models are available, circuit breakers are most often simulated in protection studies by ideal switches.

Analysis of relay operation is usually based on steady state analysis concepts. That is relay performance is usually determined from phasor diagrams. To predict and evaluate the performance of an electromechanical relay under transient conditions a more advanced representation is needed. This paper presents a methodology to represent electromechanical relays in an electromagnetic transients program. Little work has been performed concerning the representation of protective relays in the electromagnetic transients programs. This represents a relatively new field of study. Although little information is currently available in the literature, some interesting models have been presented in recent years [4], [5], [6], [7].

One of the first electromechanical relay models was presented in [8] in which the development and testing of a dynamic state space model of a MHO distance relay was introduced. The ATP representation of that model using the program's TACS function was detailed in [9]. Different methods can be used to represent a distance relay in ATP data files. After a short description of the dynamic model in Section 2, three different methods of representing this model using MODELS code [10] are proposed in Section 3. Simulation results are presented in Section 4. Advantages and limitations of these representations are discussed in Section 5.

Several approaches have been used to represent protection systems in transients programs [5], [11], [12]. The most accurate representations include advanced models of instrument transformers and protective relays. This paper represents the application of a distance relay model to simulate protection of an actual power system. The case study is described in Section 5. The section provides details about the representation of the power and protective components. Simulation results are presented and discussed.

2. STATE SPACE MODEL OF A DISTANCE RELAY

A diagram of a typical MHO distance relay is shown in Figure 2. The relay has two coils, a polarizing coil and an operating coil. The polarizing coil is connected to a potential transformer through a memory circuit consisting of a variable inductor and a capacitor. The operating coil is connected to a current transformer through a transactor. The electromagnetic torque is developed by the interaction of currents through the two coils. If the torque is in the correct direction and of the adequate magnitude and duration, the relay will trip. The magnitude of the impedance setting can be adjusted by a potentiometer or the taps of the transactor and autotransformer. The angle of maximum torque can be adjusted by the variable inductor.

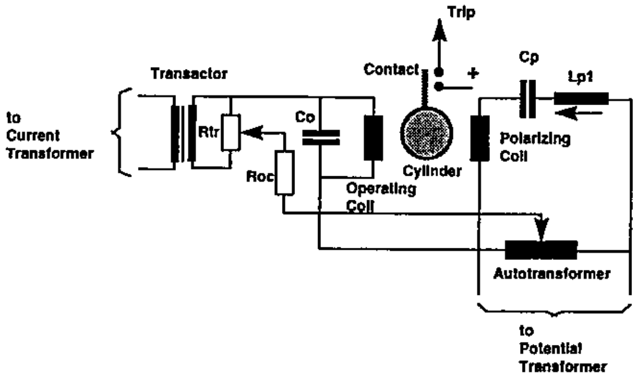


Figure 2. Schematic Diagram of a MHO Distance Relay.

A state space model can be defined from this diagram. A ninth order state space model with the following form was presented in [8].

$$\frac{d}{dt}[X] = [A][X] + [B][Y] \qquad (1)$$

$$[X] = [x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5 \quad x_6 \quad x_7 \quad x_8 \quad x_9]^T$$

$$[Y] = [y_1 \quad y_2 \quad y_3]^T$$

x_1	current through the transactor secondary
x_2	current through the operating coil
x_3	voltage across the operating coil
x_4	voltage across the memory circuit capacitor
x_5	current through the polarizing coil
x_6	max. density of induced current by the polarizing coil
x_7	max. density of induced current by the operating coil
x_8	angular displacement of the cylinder
x_9	angular velocity of the cylinder
y_1	input voltage from the PT
y_2	derivative of the input current from the CT
y_3	electromagnetic torque.

Details about matrices [A] and [B], the calculation of their elements and electromagnetic torque, are presented in [8]. It is important to note that the torque acts as an input in (1), but its value is calculated from values of some state-variables (x_2, x_5, x_6, x_7).

3. ATP REPRESENTATION

Different ATP capabilities can be used for simulating this state space relay model and several approaches can be considered. MODELS code has been used throughout this paper. A short description of each approach follows:

A) Hybrid model. The relay model is split up into two parts, and different ATP capabilities are used to represent each part in a data file: circuits of the operating and polarizing coils are represented in the BRANCH section, cylinder dynamics are represented in the MODELS section.

B) MODELS stand alone option. The state space equations of the relay are completely implemented in MODELS code. The translation of the equation set presented above into MODELS code is straightforward.

C) Type-94 component. This capability can be used in four different modes [13]. The mode used in this work is known as Thevenin type-94 and is based on the compensation method. The procedure to implement a distance relay model using the Thevenin type-94 option was proposed and detailed in [14].

4. SIMULATION RESULTS

Several test cases have been performed considering the same relay parameters and operating conditions described in [8] and [9]. For all cases, the test scheme was as depicted in Figure 3. Figures 4 and 5 show the performance of this relay model. These test cases simulated faults inside the operating characteristics of the relay.

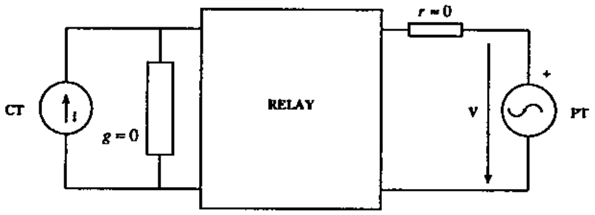


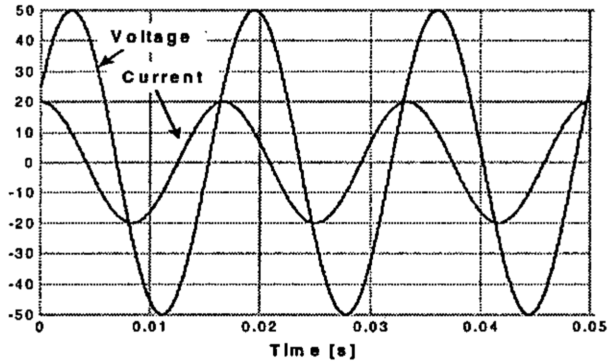
Figure 3. Scheme of the Relay Test.

5. DISCUSSION

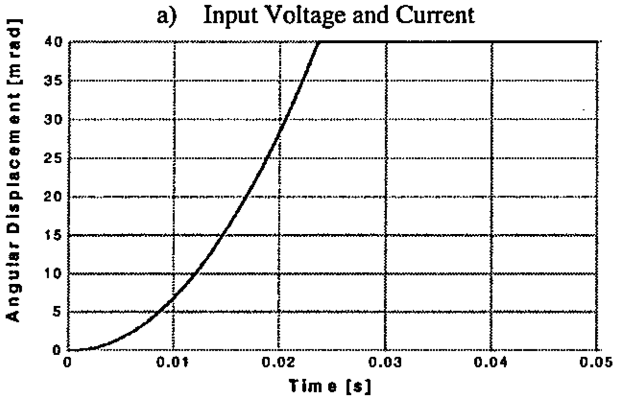
Although only one distance relay is simulated in this paper, the methodologies presented can be used to model other type of relays. A state space model will be only available if a linear behavior is assumed for the relay circuits. When nonlinearities are introduced, as in [6] and [7], the first two approaches presented in this paper can be used without any important modifications, however, the third approach based on the type-4 component, will require extra effort to represent nonlinearities in the MODELS section.

Each of these approaches has advantages and limitations.

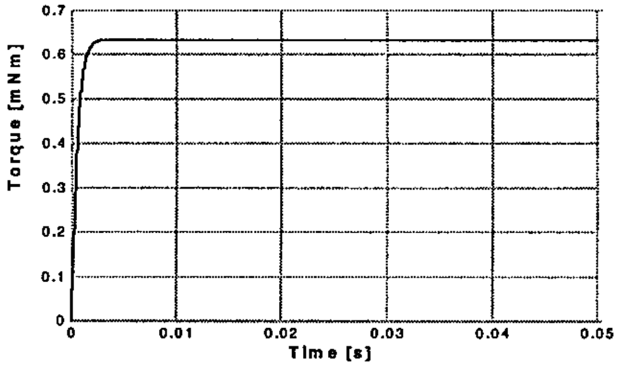
1) Using the hybrid model, the relay implementation is easier and steady state conditions in the operating and polarizing coils are automatically calculated. If more than one relay is represented in the data file, the BRANCH section of the model will be rather complex, because the circuit elements will have to be explicitly modeled for each relay.



a) Input Voltage and Current

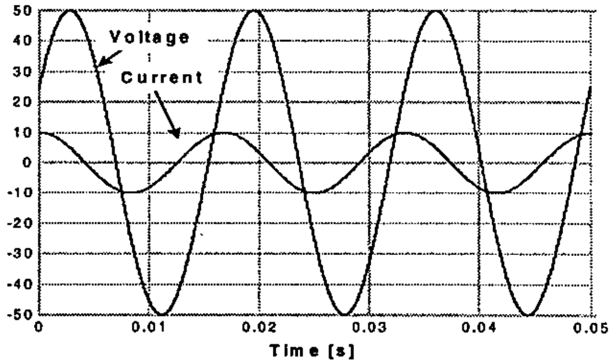


b) Angular Displacement

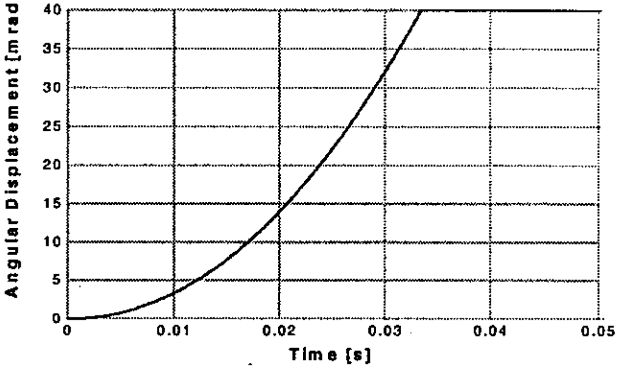


c) Electromagnetic Torque

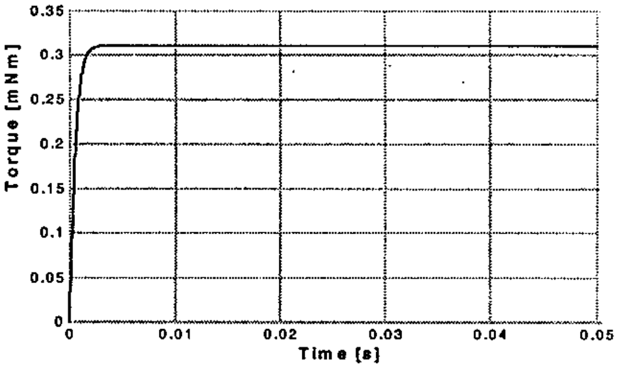
Figure 4. Relay Performance - Test Case #1.



a) Input Voltage and Current



b) Angular Displacement



c) Electromagnetic Torque

Figure 5. Relay performance - Test Case #2.

2) The MODELS stand alone representation needs some simulation time to reach steady state conditions in the relay coils prior to any relay action. The complete model, however, is represented inside a single section. In addition, only an USE statement is needed to include an additional relay. This last aspect is very important. Once a relay model has been developed using MODELS, users do not have to be concerned about developing the model again. Only implementation rules inside a data file need to be considered. In fact the rules to be learned are reduced to those related to USE and RECORD statements [10].

3) The main advantage of the type-94 approach is its usage. Once the relay model is developed, the representation inside a data file is made as with any other built-in model. In addition, this option does not introduce a time-step delay between the circuit and the relay. Drawbacks of the approach presented in this paper are obvious : ports to which the relay is connected must be decoupled and the network to which the relay is connected cannot be nonlinear. In fact, the limitations are so important that the only practical application is to test the performance of the relay model.

The main drawback of approaches B and C is that these relay models are not included at the initial steady-state calculation. This means that the secondary of the current transformer will be open circuited at t=0 unless additional branches are added to represent the operating coil. Because of this, only option A has been used in the test case.

6. CASE STUDY

Figure 6 is a diagram of the power network studied in this case. The Redmond-Harney 115 kV transmission line is an actual transmission line located in Oregon. The protection system represented in this study includes instrument transformers and electromechanical distance relays.

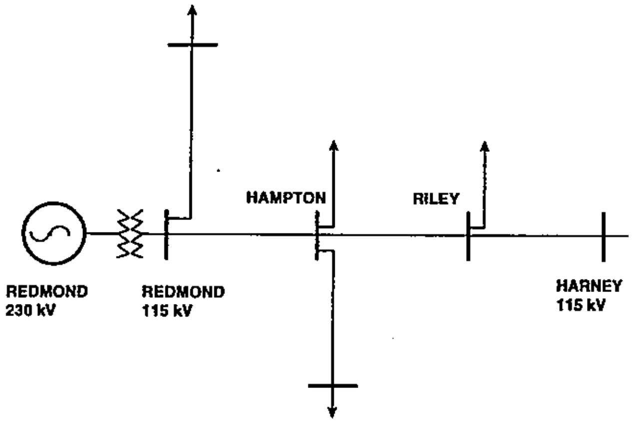


Figure 6. Diagram of Test Network.

The transmission line to be protected is represented by a frequency dependent model. The network equivalents at both ends of the line are modeled as linear lumped parameter impedances. Models used to represent instrument transformers are similar to those presented in [1], [2], [3], and [4].

Validation tests have shown that CT models can accurately reproduce the rise of the flux in the core during a fault with maximum dc offset, the behavior of the flux-current loops under transient conditions, the actual secondary current, which can differ severely form the ideal one, and the effect of remanence on the onset of saturation. The ATP capabilities used to implement this model were:

⇒ the TRANSFORMER element is used to represent ideal coupling,

⇒ the Type-96 element is used to represent the magnetizing reactance, and

⇒ one winding resistance and one leakage inductance is represented, in the secondary winding.

Capabilities used to model the CVT are similar to those used to model the CT, although the magnetization characteristics, represented inside the TRANSFORMER data does not include hysteresis, and the CVT model incorporates some stray capacitances. Sensitivity studies have shown that these capacitances can have an appreciable influence on the CVT frequency response above 1 kHz, although validation tests performed without considering stray capacitances have shown that the model can reproduce transient and ferroresonance behavior with acceptable accuracy. The subsidence transients have a major effect on CVT behavior. According to simulation results, these transients have the largest magnitude and the longest duration when a fault occurs at a primary voltage zero. Their magnitude increases with increased burden. The magnetization inductance has a negligible effect on the subsidence transients.

As mentioned above, distance relays are represented using the hybrid approach - Option A - described in Section 3.

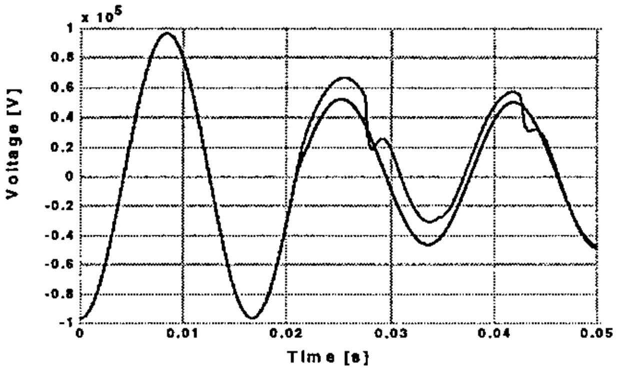
To test the distance relay model under transient conditions, several simulations were run, reproducing symmetrical and asymmetrical faults at various locations along the Redmond-Harney line. Asymmetrical faults were obtained by closing the switch at a voltage zero, while symmetrical faults were simulated by closing the switch at peak voltage. Figures 7, 8 and 9 show the simulation results of three test runs. One can observe that the closer the faults to the location of a protection device, the higher the probability of causing CT saturation. Voltages at the CVT location, after fault initiation, should be zero for the last two test cases. However, it can be seen that an oscillatory voltage appears at both sides of the potential transformer. As expected, faster relay operations are caused by faults which are closer to the relay location. In addition, it has been observed that for faults at the same location, asymmetrical faults cause faster operation.

7. CONCLUSIONS

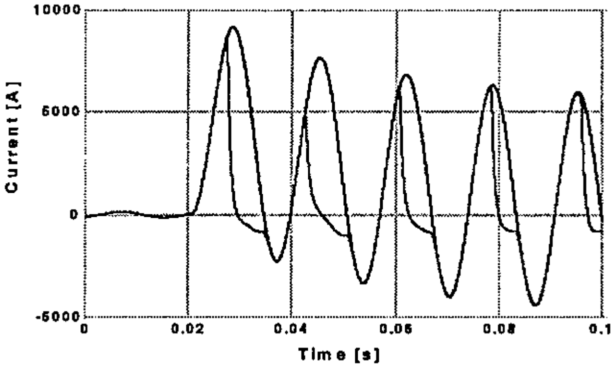
Only a dynamic model can accurately reproduce the behavior of an electromechanical relay and give a correct time-to-operate. This document has presented the application of an electromechanical distance relay model to simulate the protection of an actual power network. It has been shown how different relay behavior can be depending on the fault condition. The test network corresponds to an actual system. The studies were theoretical and no validation has been performed. However, the results are qualitatively acceptable. This paper presented the performance of a complete protection system represented in a transients program.

From the user's point of view, the relay model and its implementation have still some important limitations

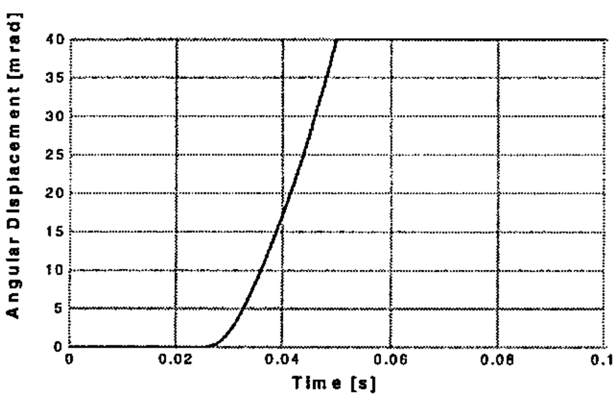
- relay settings can only be determined by trial and error, since no theoretical study has yet been performed to determine the impedance setting for a specific application
- the modeling approach used in this document - Option A - is the only one that can be used when the simulation is performed including instrument transformers, this approach may not be acceptable if more than one relay is to be represented in a single data file.



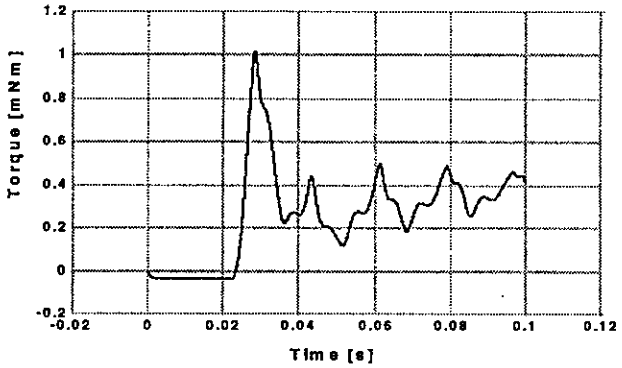
a) CVT Primary and Secondary Voltages



b) CT Primary and Secondary Currents

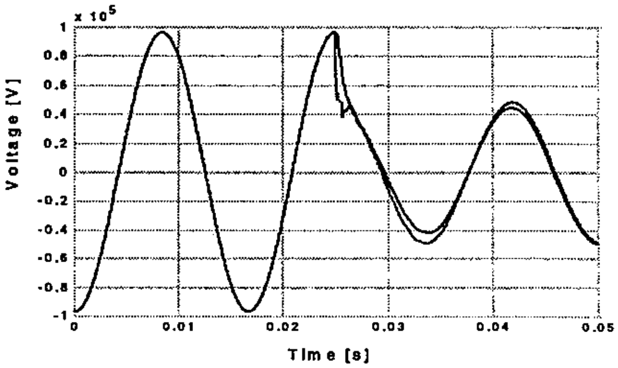


c) Relay Angular Displacement

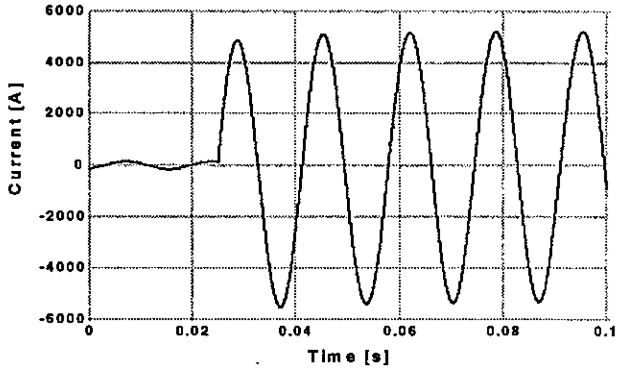


d) Relay Electromagnetic Torque

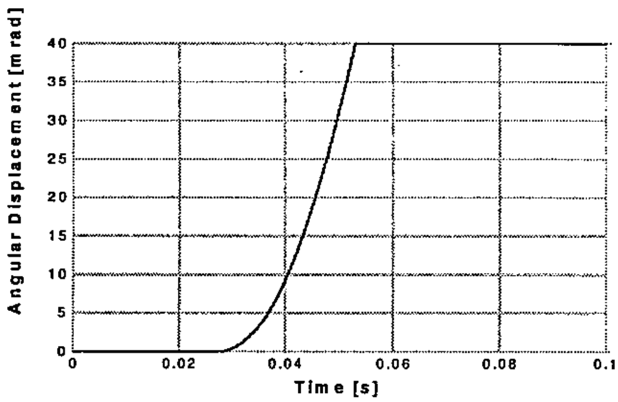
Figure 7. Asymmetrical Fault 10 km from Redmond.



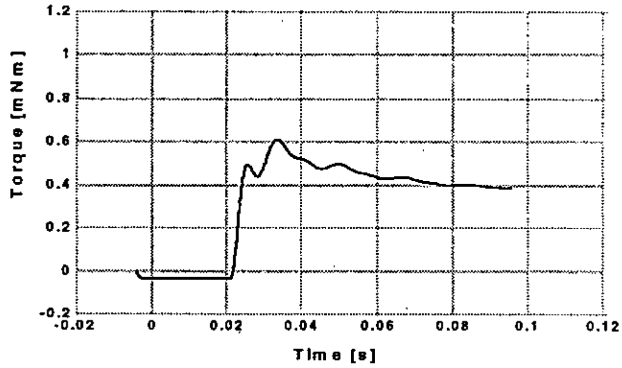
a) CVT Primary and Secondary Voltages



b) CT Primary and Secondary Currents

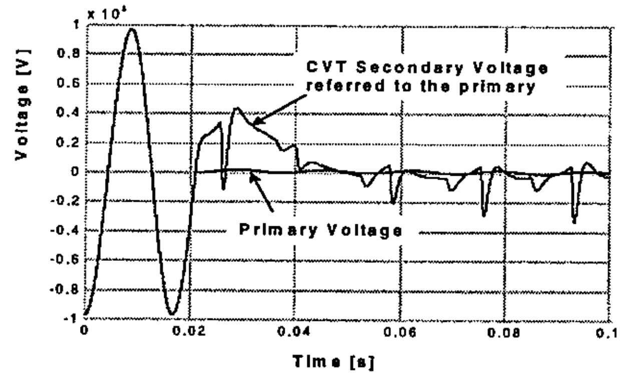


c) Relay Angular Displacement

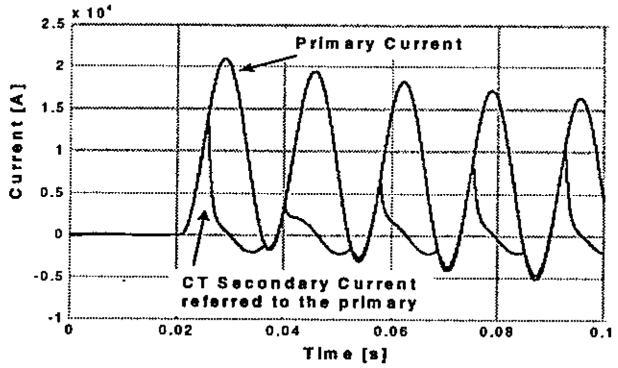


d) Relay Electromagnetic Torque

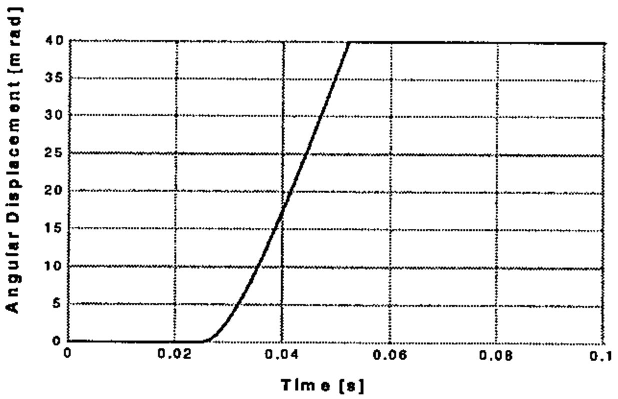
Figure 8. Symmetrical Fault 10 km from Redmond.



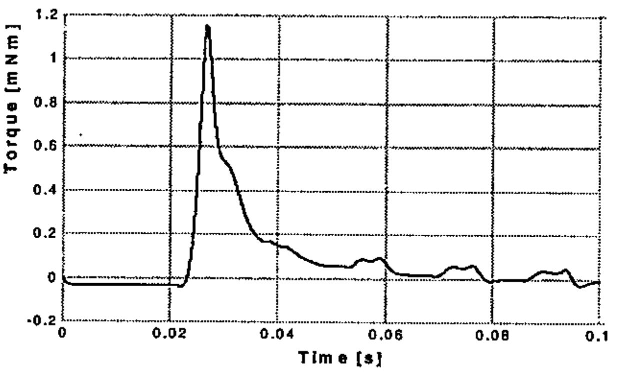
a) CVT Primary and Secondary Voltages



b) CT Primary and Secondary Currents



c) Relay Angular Displacement



d) Relay Electromagnetic Torque

Figure 9. Asymmetrical Fault at Redmond.

8. REFERENCES

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