A STUDY OF PROTECTION SYSTEM TO IMPROVE POWER SYSTEM RELIABLITY USING ATP (ALTERNATIVE TRANSIENT PROGRAM)

By

WOO KEAN HING

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

A STUDY OF PROTECTION SYSTEM TO IMPROVE POWER SYSTEM RELIABLITY USING ATP (ALTERNATIVE TRANSIENT PROGRAM)

by

Woo Kean Hing

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

____

Ir. Perumal Nallagownden
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2007

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Woo Kean Hing

ABSTRACT

Electric power systems are one of the largest and more complex systems man has ever built. Faults represent a threat to the operation and security of power systems if the faults are not promptly corrected. Therefore protection of the power system is very important. Protective relays are electronic or electromechanical devices that are designed to protect equipment and limit injury caused by electrical failures. Protective relays cannot prevent faults; they can only limit the damage caused by faults. This thesis investigates the importance of power systems protection and also introduces the widely used power system software, ATP (Alternative Transient Program). Using this software, power system are modeled and disturbance scenarios such as lightning overvoltages and short circuit are generated. The simulation of this scenarios provides the graphical charateristics of the power system through the use of PLOTXY function. Another major work in this project is the modeling of relays that were embeded in the system to enable clossed loop simulation whereby the relay will provide a 'feedback' to the system. The 'feedback' is a trip signal which will be sent to the circuit breaker to open or reclose. The algorithm of the relay are designed by writing specific code using the MODELS language. The relays succesfully fuctioned according to the algorithm when simulated under different disturbance scenarios and the results obtained were same as the predicted output.

ACKNOWLEDGEMENTS

The author expresses his gratitude and appreciation for Ir. Perumal Nallagownden for his supervision of this work. His advice and assistance in the preparation of this thesis are thankfully acknowledged.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

ATP	Alternative Transient Program
EMTP	The Electromagnetic Transient Program
IEEE	The Institute of Electrical and Electronics Engineers
TACS	Transient Analysis of control Systems

CHAPTER 1
INTRODUCTION

1.1 Background Study

Modern civilization makes use of large amounts of energy to generate goods and services. From the industrial plants, the providers of public services to the ordinary man, all of them need energy to satisfy and create the well being of modern society. The purpose of electric power systems is to provide energy for human use in a secure, reliable and economic manner. Electric power systems are made up of facilities and equipment that generate, transmit and distribute electrical energy. Electric power systems are one of the largest and more complex systems man has ever built.
The importance of the services that power systems offer and the high amount of investments that represent the facilities and equipments, make the normal and constant operation of power systems critical and strategic for every society. Faults and failures normally occur in power systems. Due to the great amounts of energy involved, faults represent a threat to the operation and security of power systems if the faults are not promptly corrected. Power systems need an auxiliary system that must take corrective actions on the occurrence of a fault. This auxiliary system is known as protection system.Protection systems must provide different schemes and equipments to detect and to react to each and every one of
these fault scenarios, from the most simple of them to the most complex and compelling.

Protective relays are electronic or electromechanical devices that are designed to protect equipment and limit injury caused by electrical failures. Relays are only one part of power system protection, because
protection must be designed into all aspects of power system facilities. Protective relays cannot prevent faults; they can only limit the damage caused by faults. A fault is any condition that causes abnormal operation for the power system or equipment serving the power system. Faults include but are not limited to: short- or low-impedance

circuits, open circuits, power swings, overvoltages, elevated temperature, off-nominal frequency operation, and failure to operate.

1.2 Problem Statement

A comprehensive evaluation of a protection system can be carried out using sophisticated test equipments such as digital simulators [1],[2]. Although relays testing using digital simulators is the most attractive method to test individual relays, however extended length of time are required to carry out the test and it is expensive as it involves costly amplifiers and interfacing equipments. Computer simulation of power system and protective relays on the other hand provides a good alternative to relay performance evaluation. Protection system simulation can be used a valuable preliminary step for overall relay design performance testing. This approach allows complex, coordinated relaying systems simulations and its also cost effective to test the algorithm of the relays on the modeled power network. If the initial algorithm of the relay does not perform accurately under certain fault condition, the algorithm can be redesigned and retested again until its suitable to be implemented on the real power system. One software which can be used for this purpose is the widely used power system software ATP which is suitable for power network modeling and also the modeling of relays using the MODELS function.

1.3 Objectives of the research

In this project, three(3) objectives are to be achieved which are:

i) To study the importance of power systems protection
ii) To do modelling of power network and relays using ATP (Alternative Transient Program)
iii) To do simulation to study the charateristics of the power system under diferrent disturbance scenarios.

1.4 Scope

This project involves research for information about the importance of power systems protection and also the important function of the main component of protection, which is the relay. The information and knowledge gained from this study helps in the accurate modelling of power system network using ATP (Alternative Transient Program). Understanding the basic operation of relays also helped in the designing of accurate relay algorithm that operate accordingly to certain fault and provide a feedback to the system. The other major work involved after familiarization of the ATP software during FYP 1 are to model power system network and generate disturbance scenarios such as lightning overvoltages and short circuit fault. This works involved heavy research from Internet and also understanding of the ATP User's Manual. The generated disturbance scenarios were important for simulation studies to observe the behavior of the power systems in response to the faults.

Another important work involved after that is the modeling of relays. In order to study protective relaying system performance accurately, a closed loop simulation of the system is highly desirable, therefore it is important to embed relays in the system which will provide trip signal to the circuit breaker to open or reclose. Modeling of relays needs the users to understand the MODELS language, where the algorithm of the relay is written in MODELS codes.

CHAPTER 2

LITERATURE REVIEW/THEORY

2.1 IMPORTANCE OF POWER SYSTEMS PROTECTION

2.1.1 GOALS OF PROTECTION

Maintain the Ability to Deliver Electric Power

Power systems that have evolved in the 20^{th} century consist of generation plants, transmission facilities, distribution lines, and customer loads, all connected through complex electrical networks. In the United States, electrical energy is generated and distributed by a combination of private and public utilities that operate in interconnected grids, commonly called power pools, for reliability and marketing. Elsewhere in the world, generation is tied to load through national or privatized grids. Either way, power flows according to electrical network theory.

Interconnection improves the reliability of each pool member utility because loss of generation is usually quickly made up from other utilities. However, interconnection also increases the complexity of power networks. Power pool reliability is a function of the reliability of the transmission in the individual members. Protection security and dependability is significant in determining the reliability of electrical service for both individual utilities and the interconnected power system pool.

Public Safety

Relays are designed to deenergize faulted sections as quickly as possible, based on the premise that the longer the power system operates in a faulted condition, the greater the chance that people will be harmed or equipment damaged. In some cases power system stability and government regulatory commissions set the speed requirements of extra high voltage (EHV) systems. Because of cost constraints, relays are not designed to prevent the deaths of people or animals who make direct contact with high voltage lines. Instead, designers use physical separation and insulation to prevent direct contact. Still, the faster a faulted system element can be detected, isolated, and deenergized, the lower the probability that anyone will encounter hazardous voltages.

Equipment Protection

The primary function of power system protection is to limit damage to power system apparatus. Whether the fault or abnormal condition exposes the equipment to excessive voltages or excessive currents, shorter fault times will limit the amount of stress or damage that occurs. The challenge for protective relays is to extract information from the voltage and current instrumentation that indicates that equipment is operating incorrectly. Although different faults require different fault detection algorithms, the instrumentation remains the same, namely voltages and currents.

Power System Integrity

Properly operating relay systems isolate only the portions on the network directly involved with the fault. If relays operate too quickly or fail to operate, the fault-affected area expands and some circuits are deenergized. Parts of the power system can become isolated from the rest of the network. A large mismatch between generation and load can put an islanded network in jeopardy of losing the generation control that holds frequency and voltage within acceptable limits. Without generation control, the isolated systems will eventually be tripped off by other relays. Widespread outages caused by cascading voltage or frequency excursions require many work hours to restore power, which is costly from both a labor and a lost revenue perspective.

Power Quality

The factors measured to determine the quality of power are voltage amplitude, frequency, and waveform purity. Voltage amplitude quality takes into account persistent RMS value, flicker, and intermittent dips and peaks, as well as momentary and long-term outages. Frequency changes at most a few hundredths of a hertz, unless the power system has lost generation control. Induction motors have the most sensitivity to power system frequency. Waveform purity is largely a function of harmonic content and is predominantly influenced by load.

The quality of electrical power is an issue for loads that are sensitive to momentary outages and harmonics. In the past, when loads were primarily resistive and inductive, harmonics were either inconsequential or nonexistent. Also, momentary outages had little effect on residential customers. Commercial and industrial customers compensated for momentary outages either with multiple feeds from the utility power sources or with local generation.

Today, every residential customer knows that there was an outage whether she or he was home to experience it. Outages affect home computers and the digital clocks on VCRs, microwave ovens, and other numerous appliances. Although the inconvenience may seem trivial to the relay engineer and perhaps the actual number of outages is even less than in years past, the customer may perceive that the power system is not as reliable today. Good relay selectivity is key to reducing the number of outages and faster relaying minimizes the duration of power dips.

2.2 Modelling of power systems protection

Relay models have been used for a long time by manufacturers, consultants and academics for designing new prototypes and algorithms, to check and optimize the performance of relays already installed in power systems and to train new protection personnel.

Relay manufacturers were the first to develop relay models for evaluating the performance of their designs. Those models implemented the processes by substituting the values of inputs in equations representing the relays to check if the outcomes were acceptable. The characteristics of overcurrent relays were the first to be modeled. Mathematical models [3], [4] were developed in the form of algebraic equations for representing time-current characteristics of overcurrent relays. The first transient model of a distance relay was presented in [5], where the ninth-order state space mathematical model of a mho element was developed.

Electromagnetic transient programs are computer software developments that simulate transients of multiphase networks, and their use has been popular and generally approved. When working with computer models of relay, electromagnetic transient programs are powerful tools for protection investigations and studies.

The Electromagnetic Transient Program (EMTP) was the first software that simulates the transient nature of power systems [6]. EMTP, which is based on the algorithm proposed by Hermann W. Dommel [7], was presented to the public domain by the Bonneville Power Administration (BPA) in the late 1960's.

To rationalize the development of the program, the EMTP Development Coordination Group (DCG) was founded in 1982. Original members of the DCG included BPA, the US Bureau of Reclamation, Western Area Power Administration (WAPA), the Canadian Electrical Association, Ontario Hydro and Hydro-Quebec. The DCG and the Electric Power Research Institute (EPRI) started the initiative of commercial sale of the EMTP in 1984. The first version of the DCG EMTP was released in 1987.

The Alternative Transient Program (ATP) is the free version of EMTP, and today it is widely used for power system simulation [8]. Complex networks and control systems can be simulated with ATP. ATP has extensive modeling capabilities and additional features such as the Transient Analysis of Control Systems (TACS) and MODELS, which enable modeling of control systems and components with non-linear characteristics, respectively. However, while having strong features for programming in simulation tasks, MODELS has limited memory allocation size for data arrays.

M. Kezunovic and Q. Chen presented in 1997 a work where the power system transients are simulated using ATP and the protective relay is modeled in MATLAB [9]. The interaction between both systems was implemented in a closed-loop employing an "interaction buffer" for communication. The approach also permitted the simulation of the relay model in other high level languages while maintaining the link. Minor modifications to the ATP program were included to establish the interaction between the power system modeled in ATP and the external relay model.

2.3 Introduction to protective relays

One of the most important equipments employed in the protection of power systems are protective relays. These are one of the most flexible, economic and well-known devices that provide reliable, fast and inexpensive protection.

Relay is defined by the IEEE as "an electric device that is designed to interpret input conditions in a prescribed manner, and; after specified conditions are met, to respond to cause contact operation or similar abrupt changes in associated electric control circuits [10]". Relays acquire signals from the power system (electrical, magnetic, heat, pressure, etc.) and process them with a designed process or algorithm. IEEE defines a protective relay as "a relay whose function is to detect defective lines or apparatus or other power conditions of an abnormal or dangerous nature and to initiate appropriate control circuit action [10]".

Protective relays have provided protection since the beginning of the electric industry, and have encountered great transformations with time as power systems have grown in size and complexity. Early protective relays were constructed using solenoids and electromagnetic actuators. Those relays were bulky and heavy devices that needed lot of space to be mounted. Because of their development and use over several decades, electromechanical relays evolved to become standard accepted devices. Even modern relays use most of the principles of operation of electromechanical relays.

Solid-state relays replaced electromechanical actuators by analog electronic elements. Even when the protection systems based on electromechanical relays had proved to be reliable, solid-state relays gained confidence of protection engineers because of their advantages of lower costs, reduced space and weight, and ease to set, maintain and operate.

The developments in digital technology led to the incorporation of microprocessors in the construction of relays. Digital and numerical relays are sophisticated, multiplepurpose equipment with the capacity to record signals during faults, monitor themselves and communicate with their peers. Numerical relays employ microprocessors especially constructed to process digital signals, which make them faster and more powerful, while preserving their economic advantages.

2.4 Investigation topics on protective relaying

The developments in relaying technology have not solved definitively all the protection issues, and, therefore, substantial investigations and research on protection and protective relaying continues [11]. The following are the most relevant topics currently being investigated in the field of protective relaying.

- Setting and adjustment of relays and interrelation of protective relays with different component of the power system, especially control elements
- Behavior of relays during different operating states of power systems (steadystate, faulted system, etc.)
- Designing of new relay algorithms, relay functions and protection schemes
- Engineering of new relay products
- Education and training of protection personal

Most of the times, it is impossible to investigate the mentioned topics on real systems due to operation, security and economical restrictions. Several approaches and resources have been developed to overcome these difficulties. These include Real Time Digital Simulators (RTDS), Real Time Playback Simulators (RTPS) and software packages for modeling protective relays.

Computer models of protective relays offer an economical and feasible alternative to investigate the performance of relays and protection systems. Computer models of relays permit investigators to observe in a very detailed way the performance of processes in each internal module of the relay.

Designing new relaying algorithms or new relaying equipment is also improved with relay modeling because relay designs are refined before prototypes are built and tested. For specific problems and conflicting scenarios, use of models open the possibility of creating new solutions when known approaches do not work satisfactorily.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Introduction

The importance of power systems protection and the functions and operations of the relaying system had been addressed in the earlier chapter.The methodoly of this project will be divided into two major steps which are the modelling of the power network and also the modelling of relays. The modeled power network are faulted to generate disturbance scenarios and simulated to observe the system behavior. Relays modeled are embedded in the system to provide neccessary action during the fault i.e sending trip signal to circuit breaker.

The modelling of relays are important in this project as it can provide a closed loop simulation or a 'feedback' to the system when the system detected a fault. Figure 3.1 shows the structure of closed loop simulation.The normal open loop simulation on the other hand will only provide the graphical transient behavior of the system. Fault such as lightning and short circuit will also be generated as analysis for disturbance scenarios and algorithm designed for the relays will act accordingly in response to the fault. Figure 3.2 shows the detail methodology of this project.

3.2 Tool required in the methodology

ATP (Alternative Transient Program) is used as the software to do the modelling of power system while the designing of relay algorithm is done by writing codes using the MODELS language.

MODELS language is a description language for general usage, associated to the interface ATPDraw, based on a group of simulation tools for representation and study of

variant systems in the time. The language MODELS (similar to PASCAL) is focused on the description of the structure of a model and in the function of their elements.
The MODELS language contain many simple and power commands that allow several different constructions of routines. Its functionality can be more explored to develop others applications.

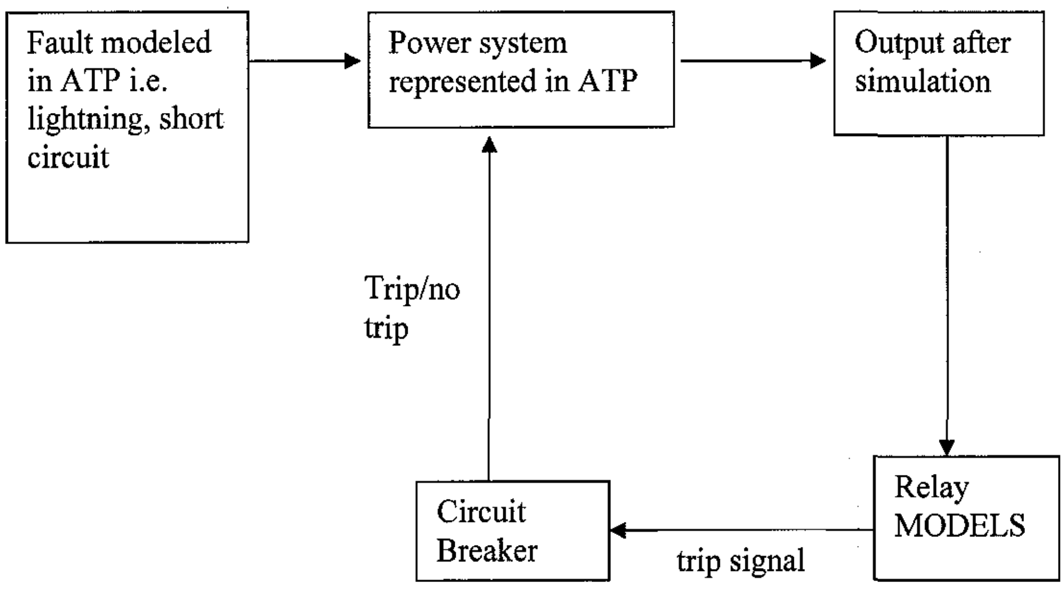

Figure 3.1: Closed loop simulation

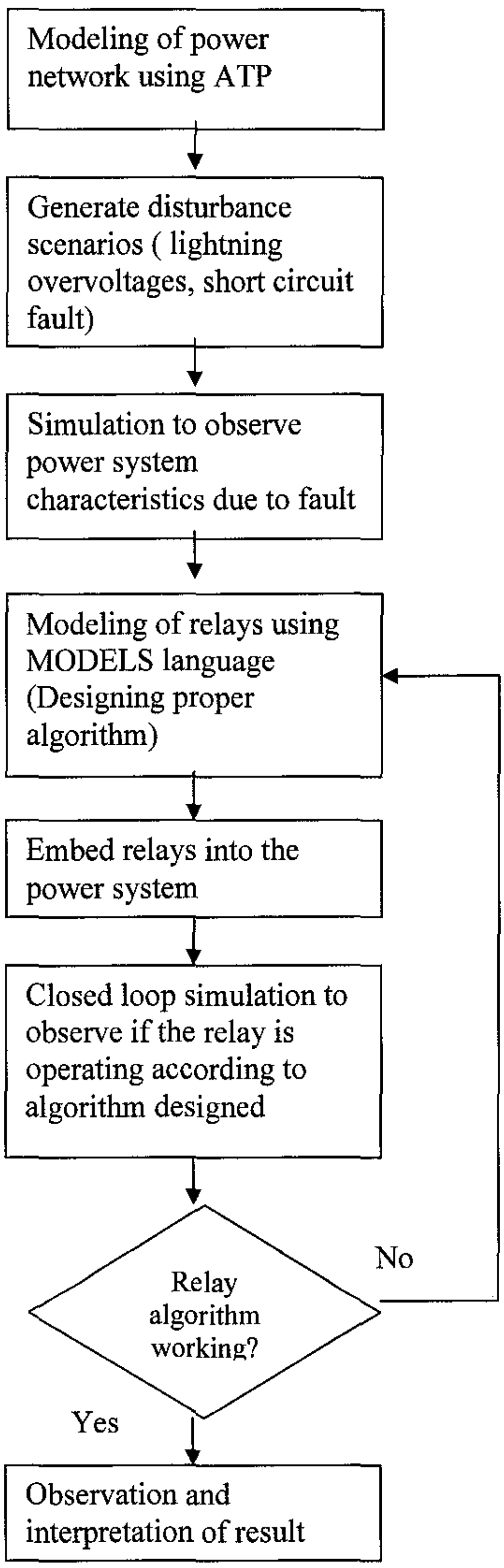

Figure 3.2 : Project Methodology

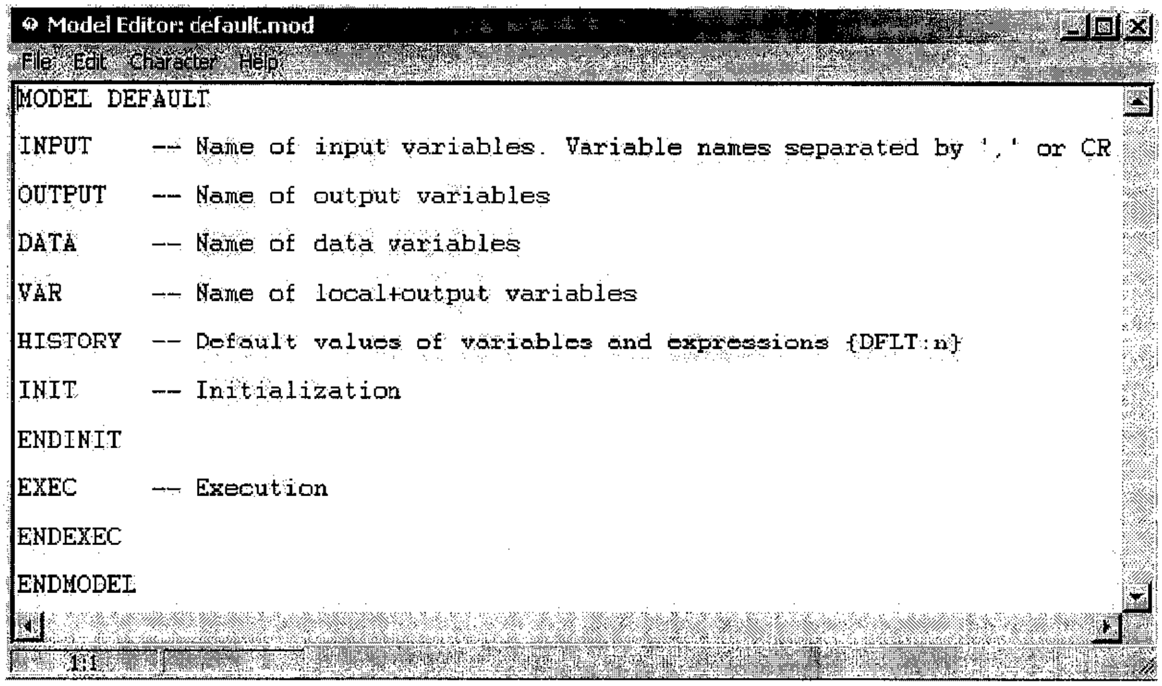

Figure 3.3: Descriptive file MODELS standard

3.3 MODELS Description

Figure 3.3 shows the default text file which is used write the MODELS code to design the algorithm of the relay.A model writen in the MODELS language includes declarations and operations procedures.

declarations:

- DATA declaration specify the name, array name and optional default value od the data parameters of the model (the externally assigned constant value holding of the element)
- VAR declaration specify the name and the array range of the variables of the model (the internally assigned variable value holding element)
- INPUT declaration specify the name, array range, and optional default value of the inputs of the model (the externally assigned variable value holding elements)
- OUTPUT declaration specify which of the models's element may be used as the output of the model.

operation procedures:

- the EXEC procedure describes the execution algorithm of the model

- the INIT procedure describes the initialization algorithm of the model

3.4 MODELS Object Composition

An object MODELS consists of a file called support file, possessing the extension .sup. Each model should have a support file with objective of being used in ATPDraw. The support file pattern for all components contains the icon, information in the types and positions of us and parameters of data. There are two options for creation of the object of a model in ATPDraw:

- Manual Operation: selecting a file support manually by main menu Object | Model | New sup-file;
- Automatic Operation: selecting a file. mod directly in the option MODELS of the menu of selection of components and leaving ATPDraw to create the file support.

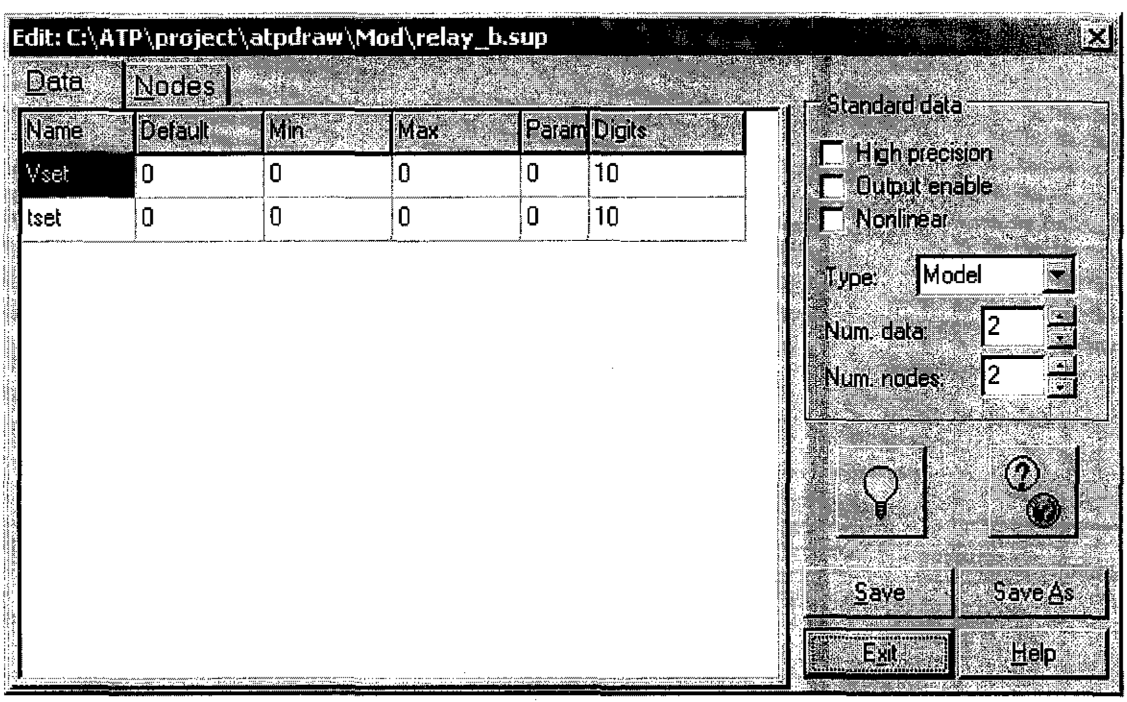

Figure 3.4 : Windows edition of the support file MODELS

3.5 Type of Relay used and its algorithm

In this project, the type of relay chosen is the voltage magnitude relay. The algorithm designed for the operation of this relay is to basically measure voltage at certain point of the network and preventing the voltage from exceeding the threshold set by the relay. Disturbance scenarios such as lightning overvoltage and short circuit will be generated to test the performance of the relay. If the measured voltage exceeded the threshold, the the relay will send a signal to the circuit breaker to open or reclose.

CHAPTER 4

RESULTS & DISCUSSION

Three scenarios were generated where power network modeled were given short circuit and lightning fault. Relays were used to control the circuit breakers to activate and clear the fault. The result are tabulated using the PLOTXY function.

4.1 Scenario 1: Lightning overvoltages

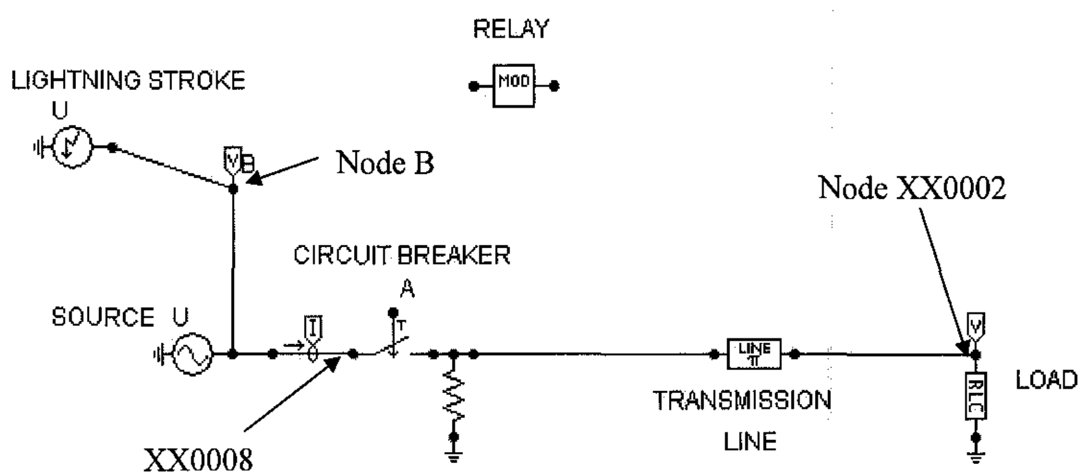

Figure 4.1: Power network with lightning overvoltage fault

Figure 4.1 above shows a power network which was modeled using a 500KV source. A circuit breaker was placed before the transmission line. As shown, a lightning stroke with 6 Megavolt was placed on the line to create an over voltage fault. Voltage and current probe were placed on the circuit to observe the transient in the system operating voltage. A magnitude relay is modeled to control the circuit breaker. Appendix A shows the algorithm of the relay written in MODELS code. The relay measure the voltage input at node XX0008. When the measured voltage at the input exceeded the voltage threshold of the relay settings, the output of relay which is TRIP will send a signal "0" to the the circuit breaker which means opening the circuit to break the connection.

4.1.1 Result for Scenario 1 simulation

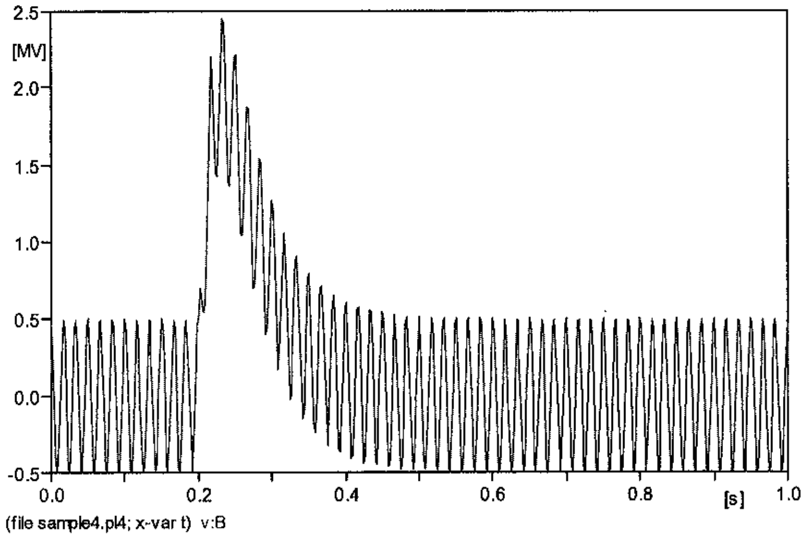

Figure 4.2 : Voltage transient measured at node B

<u>Discussion</u>

The network was simulated (Refer Appendix C for the ATP file) and result were generated in the PLOTXY. The above graph shows that the power network was initially operating normally at steady state. A lightning stroke was injected to the system at time 0.2 seconds and there is observed that there is a surge of voltage and the lightning was set to end at 0.8 seconds. And after that the system will return to its normal operating state.

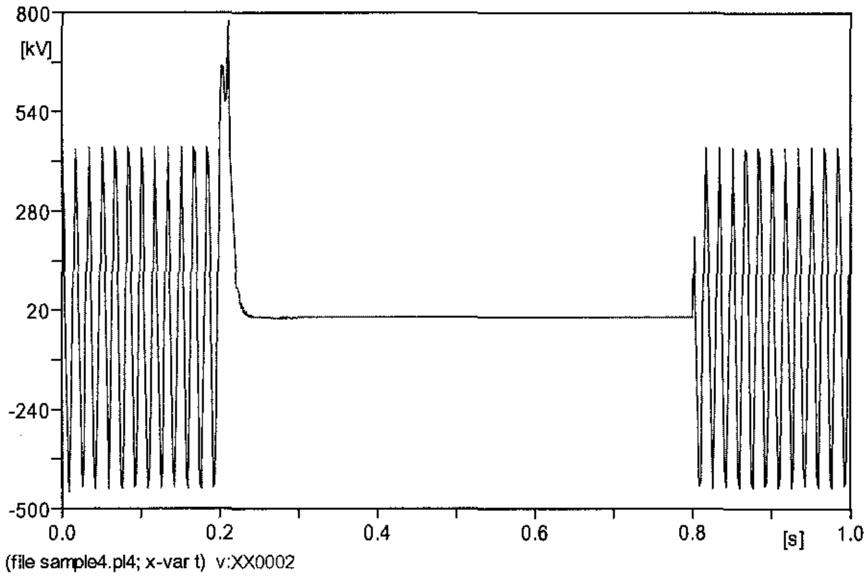

Figure 4.3 : Voltage measured at node XX0002

Figure above show exactly how the relay modeled in this simulation perform according to its algortihm. The system was initially operating in steady state. The lightning stroke at time 0.2 seconds caused the voltage to surge. The threshold set in this relay is 790KV whereby voltage exceeding this threshold is unacceptable by the system and the relay immediately send a trip signal (trip:=0) to the circuit breaker an open the connection as observed from Figure 4.3 as the measured voltage is zero. After the lightning stroke ended at 0.8 seconds which means that the fault is cleared, the relay again send signal (trip:=1) to the circuit breaker to reclose the connection and the system again resume its normal operating condition.

4.2 Scenario 2 : Short Circuit Test

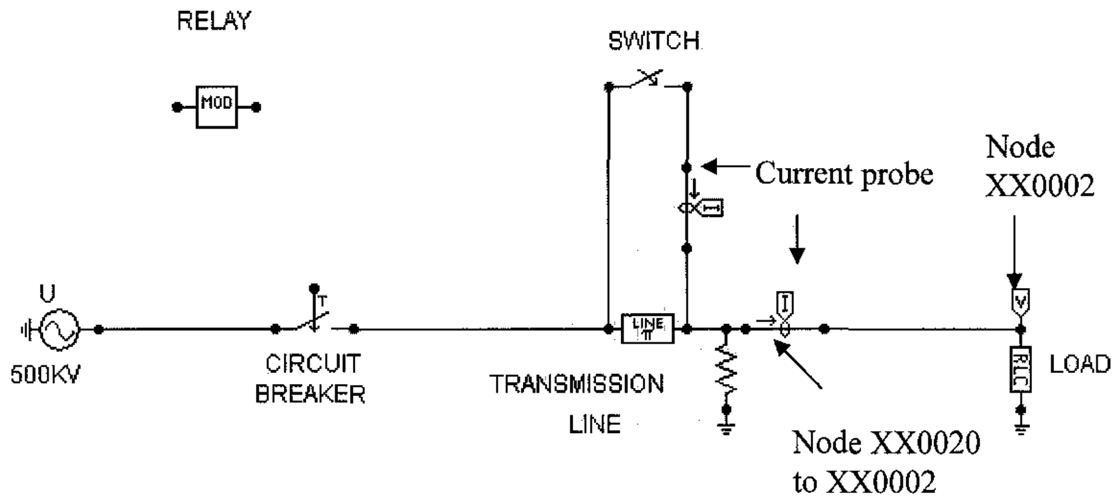

Figure 4.4 : Short Circuit test

In this scenario, a short circuit test was performed on the power network. A switch is placed at the transmission line to which was set to close at time 0.04 seconds providing a short circuit fault to the line. A current probe is placed after the switch to observe the rise in current after the switch is closed. The same relay (refer to Appendix A for the algorithm of the relay) is used in this case where the relay will send a trip signal to the circuit breaker when the measured voltage at node has exceeded the voltage settings by the relay. The scenario was simulated and the ATP file is shown in Appendix D.

4.2.1 Result for Scenario 2 simulation

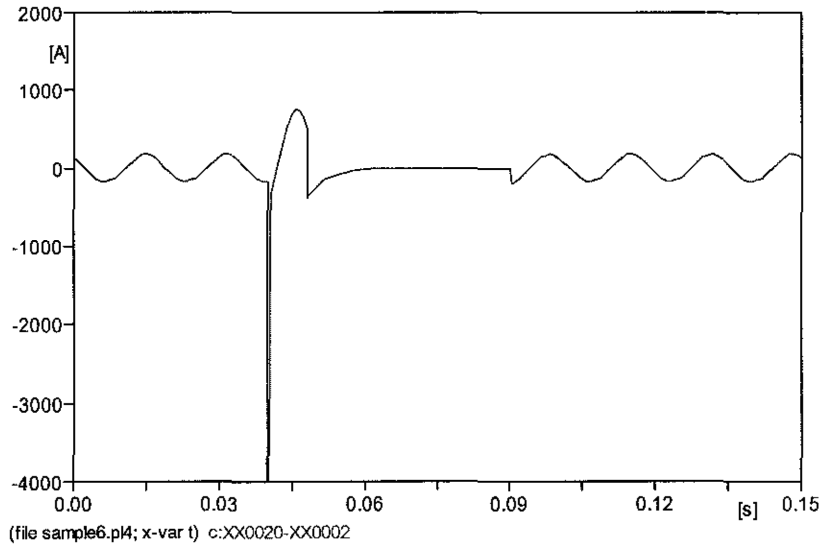

Figure 4.5: Current measured form node XX0020 to XX0002

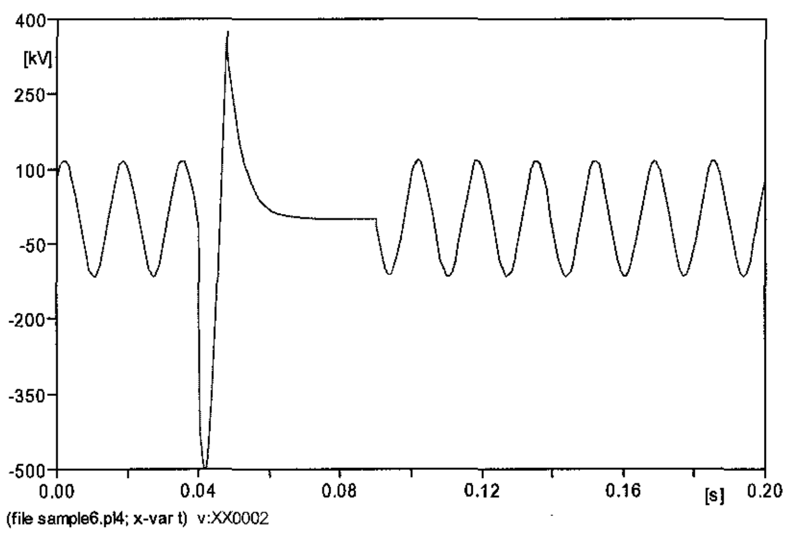

Figure 4.6 : Voltage measured at node XX0002

Based on the Figure 4.5 above, when the switch closed at time 0.04 seconds, it is observed that there is a huge transient and an increase in current and Figure 4.6 shows the voltage measured at the load also shows the rise of voltage due to the increase of current. The voltage threshold set to the relay in this case is 375KV and when the voltage rise exceeded the relay setting, the relay immediately send a trip signal (trip:=0) to the circuit breaker and break the system connection which can observed from both Figure 4.5 and Figure 4.6 as both current and voltage values dropped to zero. The short circuit fault was set to end at time 0.09 seconds and the relay send signal to the circuit breaker to reclose the line when the fault is cleared.

4.3 Scenario 3: Relay controlling multiple circuit breaker.

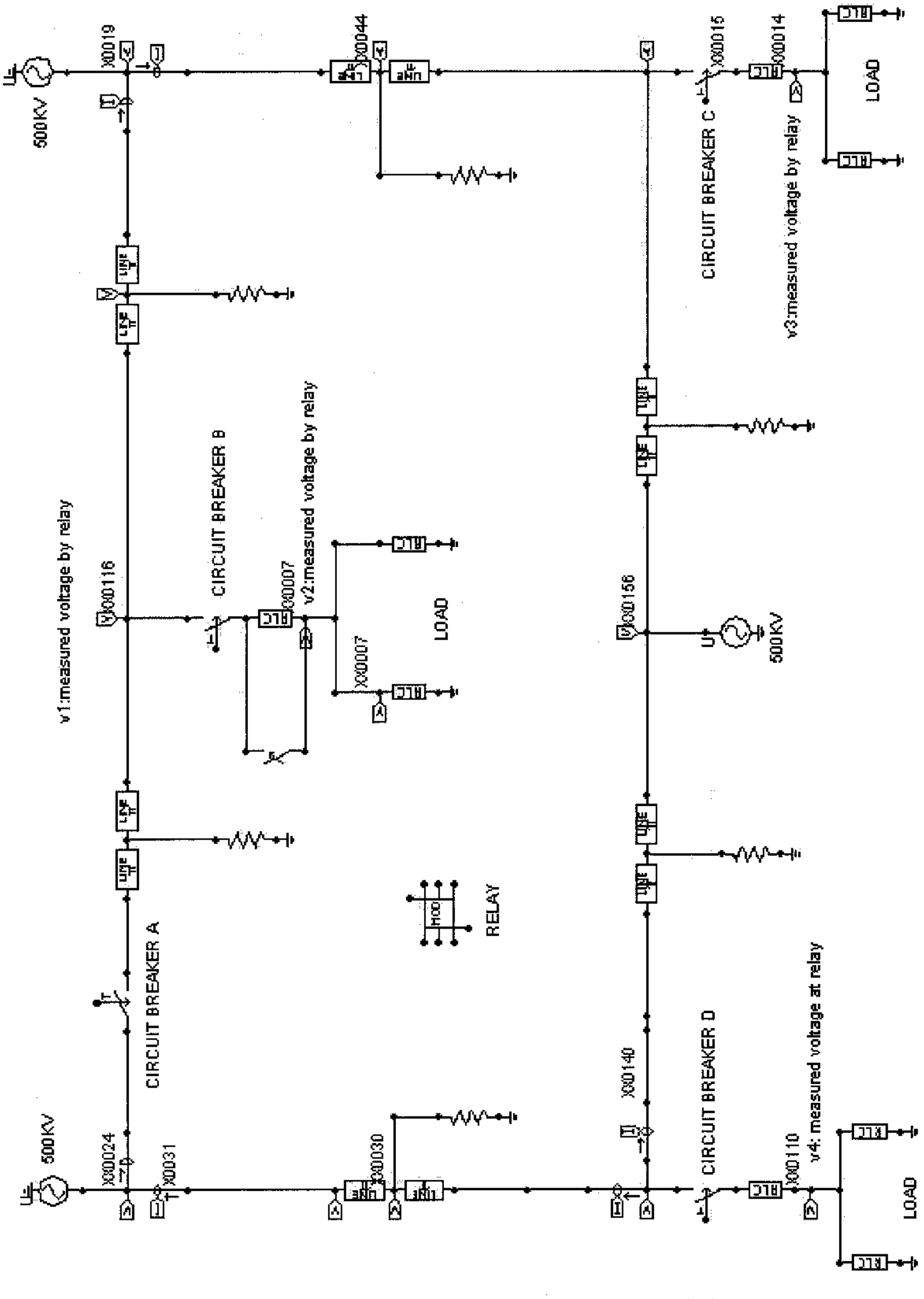

Figure 4.7 : A 9 bus system power network

Based on Figure 4.7 it is a power network modeled with 9 buses. A relay is modeled to control multiple circuit breakers which is 4 in this case, circuit breaker A,B,C and D. The algorithm designed for the relay in this case is to send signal to the circuit breaker nearest the fault to disconnect the systems which are affected by the fault and and the rest of the system will resume normal operation. In this case, a short circuit test is performed where a switch is placed at one of the loads in the system.(Refer to Figure 4.7). The MODELS code for the relay algorithm is shown in Appendix B. The ATP file for this scenario is shown in Appendix E.

4.3.1 Result for Scenario 3 simulation

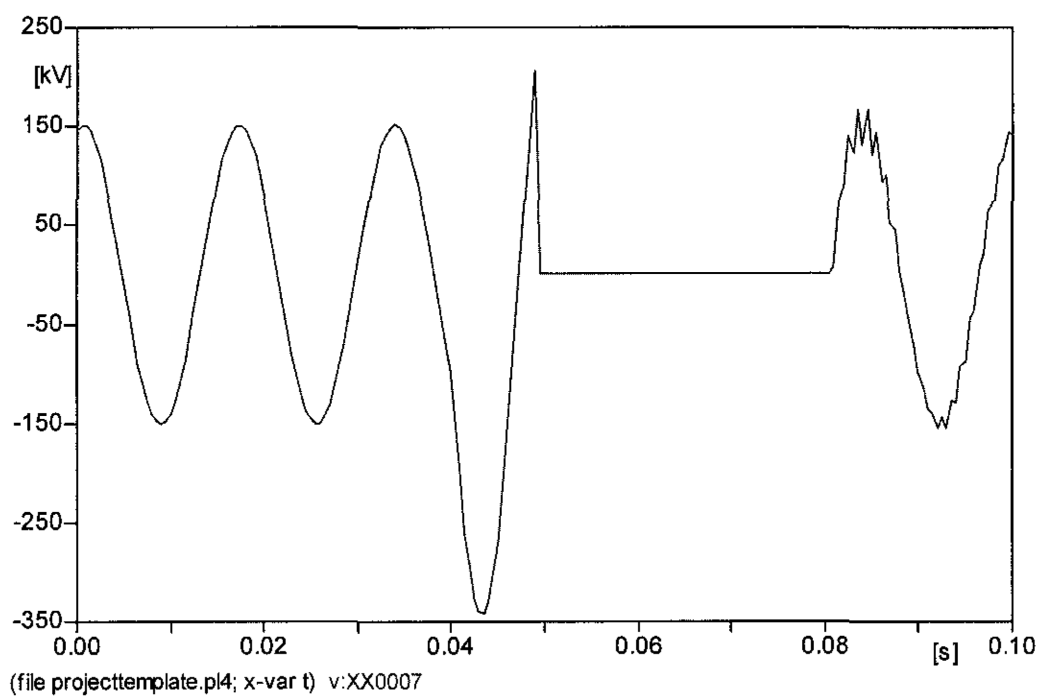

Figure 4.8: Voltage charateristics at node XX0007

The generated graph was measured at node XX0007. The short circuit had caused a rise of voltage which started at time 0.05 seconds. The relay immediately send signal to circuit breaker B which is nearest to the fault and disconnect the load from the system. After the fault is cleared, the relay send signal to circuit breaker B to reclose the system. The other 3 circuit breakers did not activate as no trip signals were given by the relay as intended for the simulation of this case. Figure 4.8 shows the plot graph measured at node XX0116, XX0014 and XX0110. These figures shows that the rest of the system resume its operation although there is a fault as the relay had disconnected the system which is the nearest to the short circuit fault.

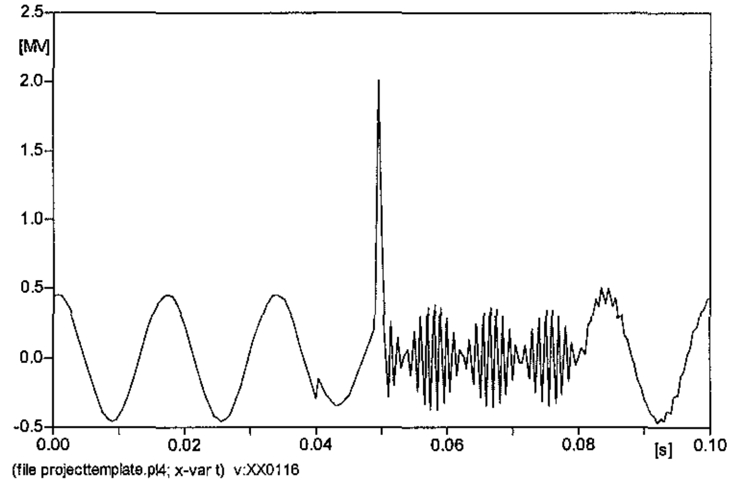

Figure 4.9 : Voltage measured at XX0116

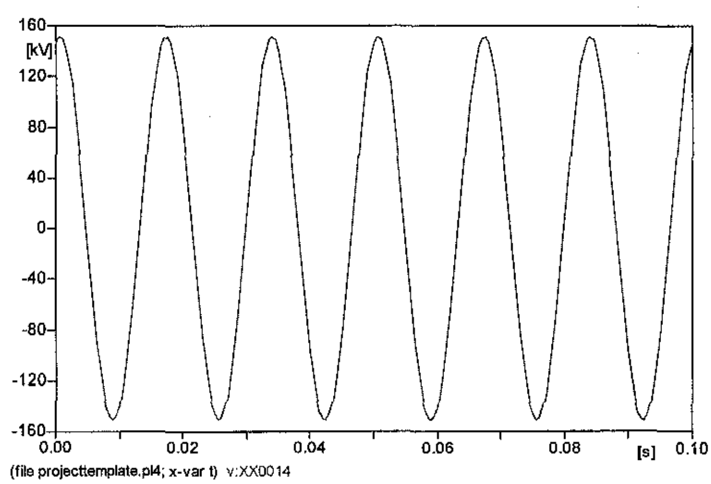

Figure 4.10 : Voltage measured at XX0014

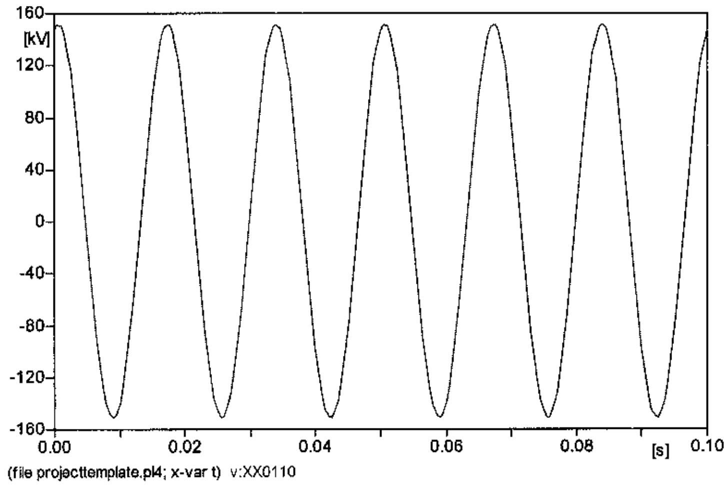

Figure 4.11 : Voltage measured at XX0110

Conclusion

1) The importance of power system protection and the functions of relays in preventing fault or minimizing the damage to the systems were studied. This provides adequate knowledge in the modeling of correct power network and designing the algorithm or relays. Magnitude relay was used in the study to prevent overcurrernt or overvoltages from damaging the transmission lines or load in the systems. The algorithm designed for the relay also ensured that it will feed signal back to the circuit breaker to reclose the system after the fault is cleared so that the operating system will resume normal operating condition.

2) Alternative Transient Program was used in modeling real power system network and faults such as lightning overvoltages and short circuit were given to the system. The simulation of the disturbance scenarios provides important charateristics of the power system or how the system behaves under this condition or fault. The PLOTXY function of the ATP software was very useful in providing the graphical result which is important for transient analysis.

3) Another major work in this project is the modeling of relays which were embeded in the system to provide 'feedback' to the system. This enables closed loop simulation which is important to study the relaying system performance. The algorithm of the relays designed for the purpose of simulation in this project were successfully simulated and working appropriately according to its operating procedures.

Recommendations for future work

Although ATP (Alternative Transient Program) is a very useful program for power system simulation it has a few shortcomings. It has small capacity and unable to simulate large network together with too many relays and faults and sometimes the simulations can be very long. This is due to too many datas were given to the software. One alternative to this problem is to interface Matlab, a powerful software with ATP. Systems parameters, relay settings and disturbance scenaris can be done using Matlab and Matlab can transfer data to ATP and vice versa therefore enhancing the simulation capabillity and more faults can be simulated automatically for the same power system.

REFERENCE

[1] M.Kezunovic, et.al. " An Advanced Method For Testing of Distance Relay Operating Charateristics," IEEE PES Winter Paper Meeting no.95 WM 028-1 PWRD, New York, Februrary 1995

[2] M. Kezunovic, et. al. "Distance Relay Application Testing Using a Digital Simulator," IEEE PES Winter Meeting, Paper no. 96 WM 017-4 PWRD, Baltimore, January 1996.

[3] J. Singh, M. S. Sachdev, R. J. Fleming, E. Krause, "Digital IDTM Overcurrent Relays," *Proceedings of IEE 1980 DPSP Conference*, IEE Publication No. 185, pp. 84-87.

[4] E. O. Schweitzer and A. Aliaga, "Digital Programmable Time-Parameter Relay Offers Versatility and Accuracy," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-89, No. 1, pp. 152-157, Jan./Feb. 1980.

[5] Z. Peng, M. S. Li, C. Y. Wu, T. C. Cheng, and T. S. Ning, "A dynamic State Space Model of a Mho Distance Relay," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-104, No. 12, December 1985.

[6] H. Dommel, "EMTP Reference Manual," Bonneville Power Administration 1986.

[7] H. W. Dommel, "Digital Computer Solution of Electromagnetic Transient in Single- and Multiphase Networks," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-88, No. 4, April 1969.

[8] Canadian/American EMTP users Group, Alternative Transient Program (ATP)-Rule book, Portland, Oregon, 1992.

[9] Kesunovic M., and Chen Q., "A novel approach for interactive protective system simulation," *IEEE Trans. on Power Systems*, vol. 12, no. 2, pp. 668-694, Apr. 1997

[10] IEEE Standard Dictionary of Electrical and Electronics Terms, *IEEE*, Wiley Interscience, 1972

[11] P. G. McLaren, K. Mustaphi, G. Benmouyal, S. Chano, A. Girgis, C. Henville, M. Kezunovic, L. Kojovic, R. Marttila, M. Meisinger, G. Michel, M. S. Sachdev, V. Skendzic, T. S. Sidhu, and D. Tziouvaras, " Software Models for Relays", *IEEE Transactions on Power Delivery*, Vol. 16, No. 12, April 2001, pp. 238-45,

APPENDICES

APPENDIX A

RELAY ALGORITHM FOR SCENARIO 1 & 2

```
MODEL relay_b

 INPUT  V1    -- Voltage measured                [V]

 DATA   Vset  -- Voltage threshold               [V]
        tset  -- Time fault

 VAR   trip   -- relay controlled signal         [0 or 1]

 OUTPUT  trip



 INIT trip:=1  -- close circuit breaker

 ENDINIT

 EXEC
  ------------------------------------------------------------
  IF V1<Vset   -- Measured voltage less the relay voltage setting (threshold)
  AND trip>0
  THEN
    trip:=1        -- circuit breaker remain closed
  ENDIF
  ------------------------------------------------------------

  IF V1>Vset   -- Measured voltage more than the relay voltage setting
```

```
AND trip>0
THEN
  trip:=0        -- relay send signal to open circuit breaker
ENDIF

-----------------------------------------------------------------

IF trip=0   -- circuit breaker open
AND t>tset  -- fault cleared
THEN
  trip:=1       -- relay send signal to reclose circuit breaker
ENDIF
-------------------------------------------------------------
ENDEXEC

ENDMODEL
```

APPENDIX B

RELAY ALGORITHM FOR SCENARIO 3

```
MODEL relay_f

INPUT  V1   -- Voltage measured at first node      [V]
    V2      -- Voltage mesaured at second node     [V]
       V3   -- Voltage measured at third node      [V]
       V4   -- Voltage measured at fourth node     [V]
```

```
DATA  Vset  -- Voltage threshold          [V]
    Vset2 -- Voltage threshold            [V]
      Vset3 -- Voltage threshold          [V]
    Vset4 -- Voltage threshold            [V]
    tset  -- Time fault


VAR  trip_A  -- relay controlled signal       [0 or 1]
    trip_B  -- relay controlled signal          [0 or 1]
      trip_C  -- relay controlled signal        [0 or 1]
    trip_D  -- relay controlled signal          [0 or 1]

OUTPUT trip_A
       trip_B
       trip_C
       trip_D
 INIT trip_A:=1  -- close circuit breaker
   trip_B:=1  -- close circuit breaker
   trip_C:=1  -- close circuit breaker
   trip_D:=1  -- close circuit breaker

ENDINIT

EXEC
 ----------------------------------------------------------------------------------------
 IF V1<Vset   -- Measured voltage less the relay voltage setting (threshold)
 AND trip_A>0
 THEN
  trip_A:=1    -- circuit breaker remain closed
 ENDIF
```

```
--------------------------------------------------------------------------------
IF V2<Vset2   -- Measured voltage less the relay voltage setting (threshold)
AND trip_B>0
THEN
  trip_B:=1     -- circuit breaker remain closed
ENDIF
--------------------------------------------------------------------------------
IF V3<Vset3   -- Measured voltage less the relay voltage setting (threshold)
AND trip_C>0
THEN
  trip_C:=1     -- circuit breaker remain closed
ENDIF
--------------------------------------------------------------------------------
IF V4<Vset4   -- Measured voltage less the relay voltage setting (threshold)
AND trip_D>0
THEN
  trip_D:=1     -- circuit breaker remain closed
ENDIF
--------------------------------------------------------------------------------
IF V1>Vset    -- Measured voltage more than the relay voltage setting
AND trip_A>0
THEN
  trip_A:=0   -- relay send signal open circuit breaker
ENDIF
--------------------------------------------------------------------------------
IF V2>Vset2   -- Measured voltage more than the relay voltage setting
AND trip_B>0
THEN
  trip_B:=0   -- relay send signal open circuit breaker
ENDIF
--------------------------------------------------------------------------------
```

```
IF V3>Vset3  -- Measured voltage more than the relay voltage setting
AND trip_C>0
THEN
 trip_C:=0  -- relay send signal open circuit breaker
ENDIF
-------------------------------------------------------------------------------
IF V4>Vset4  -- lightning voltage more than the relay voltage setting
AND trip_D>0
THEN
 trip_D:=0  -- relay send signal open circuit breaker
ENDIF
-------------------------------------------------------------------------------
IF trip_A=0  -- circuit breaker open
AND t>tset  -- fault cleared
THEN
 trip_A:=1  -- relay send signal to reclose circuit breaker
ENDIF
-------------------------------------------------------------------------------
IF trip_B=0  -- circuit breaker open
AND t>tset  -- fault cleared
THEN
 trip_B:=1  -- relay send signal to reclose circuit breaker
ENDIF
-------------------------------------------------------------------------------
IF trip_C=0  -- circuit breaker open
AND t>tset  -- fault cleared
THEN
 trip_C:=1  -- relay send signal to reclose circuit breaker
ENDIF
-------------------------------------------------------------------------------
IF trip_D=0  -- circuit breaker open
```

AND t>tset -- fault cleared

THEN

trip_D:=1 -- relay send signal to reclose circuit breaker

ENDIF

ENDEXEC

ENDMODEL

APPENDIX C

ATP FILE FOR SCENARIO 1

```
Alternative Transients Program (ATP), GNU Linux or DOS. All rights reserved by Can/Am user group of Portland, Oregon, USA.
 Date (dd-mth-yy) and time of day (hh.mm.ss) = 07-May-07  18:09:56  Name of disk plot file is  lightning.pl4
Consult the 860-page ATP Rule Book of the Can/Am EMTP User Group in Portland,  Oregon, USA.  Source code date is 19
December 2003.
Total size of LABCOM tables = 9872109 INTEGER words.  31 VARDIM  List Sizes follow:  6002  10K  192K  900  420K  1200
15K
 120K  2250  3800  720  1200  72800  510  90K  800  90  254  120K  100K  3K  15K  192K  120  30K  160K  600  210K  300  19
200
-----------------------------------------------+---------------------------------------------------------------
Descriptive interpretation of input data cards.  | Input data card images are shown below, all 80 columns, character by character
                                                  0         1         2         3         4         5         6         7         8
                                                  012345678901234567890123456789012345678901234567890123456789012345678901234567890
-----------------------------------------------+---------------------------------------------------------------
Comment card.  NUMDCD = 1.                       |C data:LIGHTNING.ATP
Marker card preceding new EMTP data case.        |BEGIN NEW DATA CASE
Comment card.  NUMDCD = 3.                       |C --------------------------------------------------------
Comment card.  NUMDCD = 4.                       |C Generated by ATPDRAW  May, Monday 7, 2007
Comment card.  NUMDCD = 5.                       |C A Bonneville Power Administration program
Comment card.  NUMDCD = 6.                       |C Programmed by H. K. Høidalen at SEfAS - NORWAY 1994-2003
Comment card.  NUMDCD = 7.                       |C --------------------------------------------------------
Comment card.  NUMDCD = 8.                       |C  dT  >< Tmax >< Xopt >< Copt >
Misc. data.   1.000E-03  1.000E+00  0.000E+00 |  .001     1.
Misc. data.   500   1  1  1  1  0  0  1  0  0  |  500     1     1     1     1     0     0     1     0
No TACS data,  but MODELS data begins (next).  |MODELS
    Another ordinary MODELS data card.         |INPUT
    Another ordinary MODELS data card.         | IX0001 {v(XX0008)}
    Another ordinary MODELS data card.         |OUTPUT
    Another ordinary MODELS data card.         | A
    Another ordinary MODELS data card.         |MODEL relay_b
    Another ordinary MODELS data card.         | INPUT  V1    -- Voltage measured                       [V]
    Another ordinary MODELS data card.         | DATA  Vset  -- Voltage setting                      [V]
    Another ordinary MODELS data card.         |       tset  -- Time fault
    Another ordinary MODELS data card.         | VAR  trip   -- relay controlled signal          [0 or 1]
    Another ordinary MODELS data card.         | OUTPUT  trip
    Another ordinary MODELS data card.         | INIT trip:=1  -- close circuit breaker
    Another ordinary MODELS data card.         | ENDINIT
    Another ordinary MODELS data card.         | EXEC
    Another ordinary MODELS data card.         |  --------------------------------------------------------
    Another ordinary MODELS data card.         |  IF V1<Vset   -- Measured voltage more less the relay voltage setting (thres
    Another ordinary MODELS data card.         |  AND trip>0
```

```
    Another ordinary MODELS data card.      |  THEN
    Another ordinary MODELS data card.      |   trip:=1          -- circuit breaker remain closed
    Another ordinary MODELS data card.      |  ENDIF
    Another ordinary MODELS data card.      |  ------------------------------------------------------------
    Another ordinary MODELS data card.      |  IF V1>Vset  -- lightning voltage more than the relay voltage setting
    Another ordinary MODELS data card.      |  AND trip>0
    Another ordinary MODELS data card.      |  THEN
    Another ordinary MODELS data card.      |   trip:=0   -- relay send signal open circuit breaker
    Another ordinary MODELS data card.      |  ENDIF
    Another ordinary MODELS data card.      |  -------------------------------------------------------------------
    Another ordinary MODELS data card.      |  IF trip=0   -- circuit breaker open
    Another ordinary MODELS data card.      |  AND t>tset  -- fault cleared
    Another ordinary MODELS data card.      |  THEN
    Another ordinary MODELS data card.      |   trip:=1          -- relay send signal to reclose circuit breaker
    Another ordinary MODELS data card.      |  ENDIF
    Another ordinary MODELS data card.      |  -------------------------------------------------------------
    Another ordinary MODELS data card.      | ENDEXEC
    Another ordinary MODELS data card.      |ENDMODEL
    Another ordinary MODELS data card.      |USE relay_b AS relay_b
    Another ordinary MODELS data card.      |INPUT
    Another ordinary MODELS data card.      | V1:= IX0001
    Another ordinary MODELS data card.      |DATA
    Another ordinary MODELS data card.      | Vset:=   7.9E5
    Another ordinary MODELS data card.      | tset:=   0.8
    Another ordinary MODELS data card.      |OUTPUT
    Another ordinary MODELS data card.      | A    :=trip
    Another ordinary MODELS data card.      |ENDUSE
Termination of data for Laurent Dube's MODELS.   |ENDMODELS
Comment card.  NUMDCD = 56.                 |C     1      2      3      4      5      6      7      8
Comment card.  NUMDCD = 57.                 |C
345678901234567890123456789012345678901234567890123456789012345678901234567890
Optional blank card follows last of MODELS data.  |BLANK MODELS
Comment card.  NUMDCD = 59.                 |C < n 1>< n 2><ref1><ref2>< R  >< L  >< C  >
Comment card.  NUMDCD = 60.                 |C < n 1>< n 2><ref1><ref2>< R  >< A  >< B  ><Leng><><>0
Series R-L-C.  2.000E+02  1.000E-05  4.000E-06  | XX0002              200.  .01   4.                         0
1st of PI-ckt.  2.000E+02  1.000E-02  1.000E-07 |1 XX0025XX0002        200.  10.   .1
Series R-L-C.  1.000E+03  0.000E+00  0.000E+00  |      XX0025          1.E3                                0
Blank card ending branches.  IBR, NTOT = 3  3    |BLANK BRANCH
Comment card.  NUMDCD = 65.                 |C < n 1>< n 2>< Tclose ><Top/Tde ><   Ie   ><Vf/CLOP >< type >
Permanently-closed switch used for metering.    | B    XX0008                          MEASURING            1
Switch.  TACS control = "A    "            |13XX0008XX0025                          CLOSED        A      0
Blank card ending switches.  KSWTCH = 2.       |BLANK SWITCH
Comment card.  NUMDCD = 69.                 |C < n 1><>< Ampl.  >< Freq.  ><Phase/T0><   A1   ><   T1   >< TSTART ><
TSTOP >
Source.  5.00E+05  6.00E+01  0.00E+00  0.00E+00  |14B    0     5.E5      60.                                 1.
Source.  6.00E+06 -5.00E-05 -1.20E-06  0.00E+00  |15B    0     6.E6    -5.E-5   -1.2E-6                         2.E-5
Source.  6.00E+06 -2.00E+01 -5.00E+01  2.00E-01  |15B    0     6.E6     -20.     -50.                  .2      .8
Blank card ends electric sources.  KCONST = 3    |BLANK SOURCE
```

List of input elements that are connected to each node. Only the physical connections of multi-phase lines are shown (capacitive and inductive coupling are ignored). Repeated entries indicate parallel connections. Switches are included, although sources (including rotating machinery) are omitted -- except that U.M. usage produces extra, internally-defined nodes "UMXXXX".

```
--------------+------------------------------
From bus name | Names of all adjacent busses.
--------------+------------------------------
     XX0002 |TERRA *XX0025*
     XX0025 |TERRA *XX0002*XX0008*
     B      |XX0008*
     XX0008 |XX0025*B     *
     TERRA  |XX0002*XX0025*
--------------+------------------------------
 +++ Node  "XX0008"  has no connected linear branches.  Add (to ground) the conductance  G = 1.00000000E-08  mhos.
Card of names for time-step loop output.        | XX0002XX0002XX0002B
Blank card ending requests for output variables.  |BLANK OUTPUT
```

Column headings for the 5 EMTP output variables follow. These are divided among the 5 possible classes as follows ....
 First 4   output variables are electric-network voltage differences (upper voltage minus lower voltage);
 Next 1   output variables are branch currents (flowing from the upper node to the lower node);

```
  Step    Time    XX0002    XX0002    XX0002   B       B
                                      XX0008
```

```
***          Switch "B     " to "XX0008" closed before 0.00000000E+00 sec.
***          Switch "XX0008" to "XX0025" closed before 0.00000000E+00 sec.
  0    0.0     0.0     0.0     0.0     0.0     0.0
 500    0.5 .434321939 .434321939 .434321939 514870.678 .005148707
 %%%%%%  Final time step, PLTFIL dumps plot data to ".PL4" disk file.
 Done dumping plot points to C-like disk file.
 1000    1.0 138643.256 138643.256 138643.256     0.0 -595.98361

Extrema of output variables follow.  Order and column positioning are the same as for the preceding time-step loop output.
Variable maxima :  779499.363 779499.363 779499.363 .2444866E7 1380.67497
Times of maxima :       .21       .21       .21      .233      .1E-2
Variable minima :  -455382.43 -455382.43 -455382.43  -500000. -1071.7269
Times of minima :      .009      .009      .009      .025       .09

Blank card terminating all plot cards.       |BLANK PLOT

Memory storage figures for the preceding, now-completed data case. ------------------------------ Present  Program
A value of "-9999" indicates that no figure is available.      07-May-07  18:09:56        figure    limit (name)
   Size List 1.  Number of electric network nodes.                                     5    6000 (LBUS)
   Size List 2.  Number of electric network branches.                                  3   10000 (LBRNCH)
   Size List 3.  Number of data values in R, L, C tables.                              3  192000 (LDATA)
   Size List 4.  Number of electric network sources.                                   3     900 (LEXCT)
   Size List 5.  Storage for [Y] and triangularized [Y].  No. times =  3   Factors =  2    9  420000 (LYMAT)
   Size List 6.  Number of entries in switch table.          No. flops = 4             2    1200 (LSWTCH)
   Size List 7.  Number of distinct ALPHANUMERIC data names plus program SPY variables.     5   15000 (LSIZE7)
   Size List 8.  History points of distributed lines.                                  0  120000 (LPAST)
   Size List 9.  Number of nonlinear elements.                                         0    2250 (LNONL)
   Size List 10. Points of nonlinear characteristics.                                  0    3800 (LCHAR)
   Size List 11. Number of Type-59 S.M. outputs.                                       0     720 (LSMOUT)
   Size List 12. Total number of EMTP output variables.                                5    1200 (LSIZ12)
   Size List 13. Working space for batch/SPY plotting.                             -9999   72800 (LSIZ13)
   Size List 14. S.M./U.M. connections to TACS.                                    -9999     510 (LBSTAC)
   Size List 15. Character storage in bytes for MODELS.                             1875   90000 (LCTACS)
   Size List 16. Total number of Type-59 S.M. masses.                                  0     800 (LIMASS)
   Size List 17. Number of Type-59 Synchronous machines.                               0      90 (LSYN)
   Size List 18. Branch and switch power/energy outputs.                               0     254 (MAXPE)
   Size List 19. Total floating-point TACS table space.                               23  120000 (LTACST)
   Size List 20. Non-copied recursive convolution data.                                0  100000 (LFSEM)
   Size List 21. Total modal/phase [T] matrix storage.                                 0    3000 (LFD)
   Size List 22. Total recursive convolution history.                                  0   15000 (LHIST)
   Size List 23. Giant vectors for renumbering, phasors.                               3  192000 (LSIZ23)
   Size List 24. Peak phases of compensation for data.                                 0     120 (LCOMP)
   Size List 25. Total table space for all U.M usage.                              -9999   30000 (LSPCUM)
   Size List 26. Square of max number of coupled phases.                               1  160000 (LSIZ26)
   Size List 28. MODELS.  Total work space is divided into INTEGER and REAL.  1st, REAL:     1700  210000 (LRTACS)
                 Second and last, statistics for INTEGER work space.              3602       0 (LITACS)
   Size List 29. RAM disk used by "TAPSAV" table saving (limit is "LABCOM" size LTLABL).   -9999     300 (LSIZ29)
   Size List 30. Taku Noda frequency-dependent circuits.                               0      19 (LSIZ30)
Timing figures characterizing central processor (CP) solution speed. --------------------------- CP sec  Wait sec  Real sec
   Data input time (through blank card ending branches) ....                       0.000     0.000     0.000
   Node renumbering and phasor solution ....                                       0.000     0.000     0.000
   After phasor solution, but before time-step loop ....                           0.000     0.000     0.000
   Integration of equations (time-step loop) ....                                  0.031     0.000     0.031
   Plotting or STATISTICS termination overlays ....                                0.000     0.000     0.000
                                                                             ----------------------------
                                                                   Totals    0.031     0.000     0.031
```

APPENDIX D
ATP FILE FOR SCENARIO 2

```
Alternative Transients Program (ATP), GNU Linux or DOS. All rights reserved by Can/Am user group of Portland, Oregon, USA.
 Date (dd-mth-yy) and time of day (hh.mm.ss) = 07-May-07 18:42:53 Name of disk plot file is shortcircuit.pl4
Consult the 860-page ATP Rule Book of the Can/Am EMTP User Group in Portland, Oregon, USA. Source code date is 19
December 2003.
Total size of LABCOM tables = 9872109 INTEGER words. 31 VARDIM List Sizes follow: 6002 10K 192K 900 420K 1200
15K
 120K 2250 3800 720 1200 72800 510 90K 800 90 254 120K 100K 3K 15K 192K 120 30K 160K 600 210K 300 19
200
--------------------------------------------------+--------------------------------------------------------------------------------
Descriptive interpretation of input data cards. | Input data card images are shown below, all 80 columns, character by character
                                                   0         1         2         3         4         5         6         7         8
                                                   012345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------+--------------------------------------------------------------------------------
Comment card.  NUMDCD = 1.                        |C data:SHORTCIRCUIT.ATP
Marker card preceding new EMTP data case.         |BEGIN NEW DATA CASE
Comment card.  NUMDCD = 3.                        |C -------------------------------------------------------
Comment card.  NUMDCD = 4.                        |C Generated by ATPDRAW  May, Monday 7, 2007
Comment card.  NUMDCD = 5.                        |C A Bonneville Power Administration program
Comment card.  NUMDCD = 6.                        |C Programmed by H. K. Høidalen at SEfAS - NORWAY 1994-2003
Comment card.  NUMDCD = 7.                        |C -------------------------------------------------------
Comment card.  NUMDCD = 8.                        |C  dT  >< Tmax >< Xopt >< Copt >
Misc. data.   1.000E-06  2.000E-01  0.000E+00 |  1.E-6     .2
Misc. data.   500   1  1  1  1  0  0  1  0  0 |     500      1      1      1      1      0      0      1      0
No TACS data, but MODELS data begins (next).  |MODELS
   Another ordinary MODELS data card.         |INPUT
   Another ordinary MODELS data card.         |  IX0001 {v(XX0002)}
   Another ordinary MODELS data card.         |OUTPUT
   Another ordinary MODELS data card.         |  A
   Another ordinary MODELS data card.         |MODEL relay_b
   Another ordinary MODELS data card.         |  INPUT  V1     --  Voltage measured                      [V]
   Another ordinary MODELS data card.         |  DATA   Vset   --  Voltage setting                   [V]
   Another ordinary MODELS data card.         |         tset   --  Time fault
   Another ordinary MODELS data card.         |  VAR  trip     --  relay controlled signal          [0 or 1]
   Another ordinary MODELS data card.         |  OUTPUT  trip
   Another ordinary MODELS data card.         |  INIT trip:=1  -- close circuit breaker
   Another ordinary MODELS data card.         |  ENDINIT
   Another ordinary MODELS data card.         |  EXEC
   Another ordinary MODELS data card.         |    -------------------------------------------------------------
   Another ordinary MODELS data card.         |    IF V1<Vset   -- Measured voltage more less the relay voltage setting (thres
   Another ordinary MODELS data card.         |    AND trip>0
   Another ordinary MODELS data card.         |    THEN
   Another ordinary MODELS data card.         |      trip:=1            -- circuit breaker remain closed
   Another ordinary MODELS data card.         |    ENDIF
   Another ordinary MODELS data card.         |    -------------------------------------------------------------
   Another ordinary MODELS data card.         |    IF V1>Vset   -- lightning voltage more than the relay voltage setting
   Another ordinary MODELS data card.         |    AND trip>0
   Another ordinary MODELS data card.         |    THEN
   Another ordinary MODELS data card.         |      trip:=0     -- relay send signal open circuit breaker
   Another ordinary MODELS data card.         |    ENDIF
   Another ordinary MODELS data card.         |    -------------------------------------------------------------------
   Another ordinary MODELS data card.         |    IF trip=0    -- circuit breaker open
   Another ordinary MODELS data card.         |    AND t>tset   -- fault cleared
   Another ordinary MODELS data card.         |    THEN
   Another ordinary MODELS data card.         |      trip:=1            -- relay send signal to reclose circuit breaker
   Another ordinary MODELS data card.         |    ENDIF
   Another ordinary MODELS data card.         |    -------------------------------------------------------------
   Another ordinary MODELS data card.         |  ENDEXEC
   Another ordinary MODELS data card.         |ENDMODEL
   Another ordinary MODELS data card.         |USE relay_b AS relay_b
   Another ordinary MODELS data card.         |INPUT
   Another ordinary MODELS data card.         |  V1:= IX0001
   Another ordinary MODELS data card.         |DATA
   Another ordinary MODELS data card.         |  Vset:=  3.75E5
   Another ordinary MODELS data card.         |  tset:=    0.09
```

```
   Another ordinary MODELS data card.        |OUTPUT
   Another ordinary MODELS data card.        | A   :=trip
   Another ordinary MODELS data card.        |ENDUSE
Termination of data for Laurent Dube's MODELS.  |ENDMODELS
Comment card.  NUMDCD = 56.                  |C   1   2   3   4   5   6   7   8
Comment card.  NUMDCD = 57.                  |C
345678901234567890123456789012345678901234567890123456789012345678901234567890
Optional blank card follows last of MODELS data.  |BLANK MODELS
Comment card.  NUMDCD = 59.                  |C < n 1>< n 2><ref1><ref2>< R  >< L  >< C  >
Comment card.  NUMDCD = 60.                  |C < n 1>< n 2><ref1><ref2>< R  >< A  >< B  ><Leng><><>0
Series R-L-C.  2.000E+01 1.000E-05 4.000E-06  | XX0002          20.  .01  4.                    0
1st of PI-ckt.   2.000E+03 2.000E-02 0.000E+00 |1 XX0022XX0020       2.E3  20.
Series R-L-C.  1.000E+03 0.000E+00 0.000E+00  |      XX0020       1.E3                          0
Blank card ending branches.  IBR, NTOT = 3  4   |BLANK BRANCH
Comment card.  NUMDCD = 65.                  |C < n 1>< n 2>< Tclose ><Top/Tde ><  Ie  ><Vf/CLOP >< type >
Permanently-closed switch used for metering.   | XX0020XX0002                   MEASURING          1
Switch.  4.00E-02  9.00E-02  0.00E+00  0.00E+00 | XX0022XX0028    .04     .09                       0
Permanently-closed switch used for metering.   | XX0028XX0020                   MEASURING          1
Switch.  TACS control = "A     "            |13XX0024XX0022                   CLOSED      A     0
Blank card ending switches.  KSWTCH = 4.      |BLANK SWITCH
Comment card.  NUMDCD = 71.                  |C < n 1><>< Ampl.  >< Freq.  ><Phase/T0><   A1   ><   T1   >< TSTART ><
TSTOP  >
Source.  5.00E+05  6.00E+01  0.00E+00 -1.00E+00 |14XX0024 0    5.E5      60.                         -1.      1.
Blank card ends electric sources.  KCONST = 1    |BLANK SOURCE
```

List of input elements that are connected to each node. Only the physical connections of multi-phase lines are shown (capacitive and inductive coupling are ignored). Repeated entries indicate parallel connections. Switches are included, although sources (including rotating machinery) are omitted -- except that U.M. usage produces extra, internally-defined nodes "UMXXXX".

```
--------------+------------------------------
From bus name |  Names of all adjacent busses.
--------------+------------------------------
     XX0002 |TERRA *XX0020*
     XX0022 |XX0020*XX0028*XX0024*
     XX0020 |TERRA *XX0002*XX0022*XX0028*
     XX0028 |XX0022*XX0020*
     XX0024 |XX0022*
     TERRA  |XX0002*XX0020*
--------------+------------------------------
```

Sinusoidal steady-state phasor solution, branch by branch. All flows are away from a bus, and the real part, magnitude, or "P" is printed above the imaginary part, the angle, or "Q". The first solution frequency = 6.00000000E+01 Hertz.

```
 Bus K              Phasor  node  voltage          Phasor  branch  current            Power flow       Power loss
       Bus M      Rectangular          Polar         Rectangular           Polar          P  and  Q        P  and  Q

 XX0002        82736.471644944  115902.33569001    126.04532083873   174.698164172     305194.48565068
305194.48565068
              -81166.66605291    -44.4512583     120.9629102648     43.8212555     -.1011936143E8  10119361.4296309

      TERRA              0.0             0.0    -126.0453208387    174.698164172              0.0
                 0.0             0.0    -120.9629102648    -136.1787445              0.0

 XX0022                500000.         500000.    208.78179248368  212.54076768015    .521954481209E8  .451735779261E8
                 0.0             0.0     39.796244211889     10.7917878      -.9949061053E7  170300.3766587

      XX0020   82736.471644944  115902.33569001    -208.7817924837  212.54076768015   -.70218701948E7
              -81166.66605291    -44.4512583    -39.79624421189   -169.2082122      .101193614296E8

 TERRA                   0.0             0.0    -82.73647164494  115.90233569001           0.0  .67166757092E7
                 0.0             0.0     81.166666052906     135.5487417           0.0    0.0000000

      XX0020   82736.471644944  115902.33569001    82.736471644944  115.90233569001      .67166757092E7
              -81166.66605291    -44.4512583    -81.16666605291     -44.4512583      .40154191083E-9
  Total network loss  P-loss  by summing injections =   5.219544812092E+07
```

Output for steady-state phasor switch currents.

```
   Node-K   Node-M          I-real           I-imag           I-magn        Degrees       Power          Reactive
   XX0020   XX0002     1.26045321E+02   1.20962910E+02   1.74698164E+02    43.8213   3.05194486E+05  -
1.01193614E+07
   XX0022   XX0028          Open             Open             Open            Open          Open            Open
```

```
   XX0028   XX0020      0.00000000E+00  0.00000000E+00  0.00000000E+00     0.0000   0.00000000E+00
0.00000000E+00
   XX0024   XX0022      2.08781792E+02  3.97962442E+01  2.12540768E+02    10.7918   5.21954481E+07  -
9.94906105E+06
```

Solution at nodes with known voltage. Nodes that are shorted together by switches are shown as a group of names, with the printed result applying to the composite group. The entry "MVA" is SQRT(P**2 + Q**2) in units of power, while "P.F." is the associated power factor.

```
       Node         Source node voltage        Injected source current        Injected source power
       name     Rectangular        Polar     Rectangular          Polar      P and Q    MVA and P.F.

        XX0024
       XX0022         500000.        500000.    208.78179248368  212.54076768015     .521954481209E8   .5313519192E8
                   0.0           0.0     39.796244211889       10.7917878        -.9949061053E7       0.9823141
```

+++ Node "XX0028" has no connected linear branches. Add (to ground) the conductance G = 1.00000000E-08 mhos.
Card of names for time-step loop output. | XX0002XX0002XX0002
Blank card ending requests for output variables. |BLANK OUTPUT

Column headings for the 5 EMTP output variables follow. These are divided among the 5 possible classes as follows ....
First 3 output variables are electric-network voltage differences (upper voltage minus lower voltage);
Next 2 output variables are branch currents (flowing from the upper node to the lower node);

```
 Step    Time    XX0002   XX0002   XX0002   XX0020   XX0028
                                   XX0002   XX0020

 26000    .026  -106805.66 -106805.66 -106805.66 -72.663804 .001068057
 26500   .0265  -113347.69 -113347.69 -113347.69  -41.60773 .001133477
 27000    .027  -115874.32 -115874.32 -115874.32 -9.0776811 .001158743
 27500   .0275  -114296.05 -114296.05 -114296.05 23.7739493  .00114296
 28000    .028  -108668.78 -108668.78 -108668.78 55.7833756 .001086688
 28500   .0285  -99191.866 -99191.866 -99191.866 85.8166481 .991919E-3
 29000    .029  -86201.031 -86201.031 -86201.031 112.809823  .86201E-3
 29500   .0295  -70156.482 -70156.482 -70156.482 135.806654 .701565E-3
 30000     .03  -51626.604 -51626.604 -51626.604 153.992466 .516266E-3
 30500   .0305  -31267.828 -31267.828 -31267.828 166.723018 .312678E-3
 31000    .031  -9801.3737 -9801.3737 -9801.3737 173.547325 .980137E-4
 31500   .0315  12012.2992 12012.2992 12012.2992 174.223631 -.12012E-3
 32000    .032  33400.4304 33400.4304 33400.4304 168.727977   -.334E-3
 32500   .0325  53605.3347 53605.3347 53605.3347 157.255052 -.53605E-3
 33000    .033  71911.2433 71911.2433 71911.2433 140.211287 -.71911E-3
 33500   .0335  87669.6603 87669.6603 87669.6603 118.200468  -.8767E-3
 34000    .034  100322.336 100322.336 100322.336 92.0023383 -.00100322
 34500   .0345  109421.043 109421.043 109421.043 62.5449799 -.00109421
 35000    .035  114643.454 114643.454 114643.454 30.8719344 -.00114643
 35500   .0355  115804.565 115804.565 115804.565 -1.8947647 -.00115805
 36000    .036   112863.24  112863.24  112863.24 -34.594341 -.00112863
 36500   .0365   105923.68  105923.68  105923.68 -66.068395 -.00105924
 37000    .037  95231.7199 95231.7199 95231.7199 -95.201944 -.95232E-3
 37500   .0375  81166.1288 81166.1288 81166.1288 -120.96292 -.81166E-3
 38000    .038  64225.1872 64225.1872 64225.1872 -142.43872 -.64225E-3
 38500   .0385  45009.0363 45009.0363 45009.0363 -158.86855 -.45009E-3
 39000    .039  24198.4179 24198.4179 24198.4179  -169.6704 -.24198E-3
 39500   .0395  2530.55839 2530.55839 2530.55839 -174.46158 -.25306E-4
***                              Close switch "XX0022" to "XX0028" after 4.00000000E-02 sec.
 40000     .04  -19226.947 -19226.947 -19226.947 -173.07237 .192269E-3
 40500   .0405  -452413.53 -452413.53 -452413.53  -377.1868 -829.60033
 41000    .041  -484291.58 -484291.58 -484291.58 -209.41041 -693.70199
 41500   .0415  -499013.36 -499013.36 -499013.36 -69.974637   -568.988
 42000    .042  -496057.35 -496057.35 -496057.35 71.8736768 -424.18367
 42500   .0425  -475528.26 -475528.26 -475528.26 211.175707 -264.35255
 43000    .043  -438153.34 -438153.34 -438153.34 342.996732 -95.156608
 43500   .0435  -385256.62 -385256.62 -385256.62 462.666927 77.4103052
 44000    .044  -318711.99 -318711.99 -318711.99 565.946915  247.23492
 44500   .0445  -240876.84 -240876.84 -240876.84 649.177951 408.301114
 45000    .045   -154508.5  -154508.5  -154508.5 709.411536 554.903038
 45500   .0455  -62666.617 -62666.617 -62666.617 744.513862 681.847246
 46000    .046  31395.2598 31395.2598 31395.2598 753.241414 784.636674
 46500   .0465  124344.944 124344.944 124344.944 735.285014 859.629957
 47000    .047  212889.646 212889.646 212889.646 691.280775 904.170421
 47500   .0475  293892.626 293892.626 293892.626  622.78757 916.680196
 48000    .048  364484.314 364484.314 364484.314 532.231805 896.716119
 48500   .0485  322918.937 322918.937 322918.937 -322.92217 -.00322919
 49000    .049   285673.86  285673.86  285673.86 -285.67672 -.00285674
 49500   .0495  252724.584 252724.584 252724.584 -252.72711 -.00252725
 50000     .05  223575.637 223575.637 223575.637 -223.57787 -.00223576
 50500   .0505  197788.694 197788.694 197788.694 -197.79067 -.00197789
 51000    .051  174975.987 174975.987 174975.987 -174.97774 -.00174976
```

```
51500   .0515  154794.469 154794.469 154794.469 -154.79602 -.00154794
52000   .052  136940.663 136940.663 136940.663 -136.94203 -.00136941
52500   .0525  121146.093 121146.093 121146.093  -121.1473 -.00121146
53000   .053   107173.25  107173.25  107173.25 -107.17432 -.00107173
53500   .0535  94812.0171 94812.0171 94812.0171 -94.812965 -.94812E-3
54000   .054  83876.5142 83876.5142 83876.5142 -83.877353 -.83877E-3
54500   .0545  74202.2989 74202.2989 74202.2989 -74.203041 -.74202E-3
55000   .055  65643.8958 65643.8958 65643.8958 -65.644552 -.65644E-3
55500   .0555  58072.6086 58072.6086 58072.6086 -58.073189 -.58073E-3
56000   .056  51374.5844 51374.5844 51374.5844 -51.375098 -.51375E-3
56500   .0565  45449.1022 45449.1022 45449.1022 -45.449557 -.45449E-3
% % % % % %  Suspended simulation; plot data space exhausted; SPY SPACE is required.  LIMBUF = 340000.
% % % % % %  Suspended simulation; plot data space exhausted; SPY SPACE is required.  LIMBUF = 340000.
+++ Time-sharing disabled.  Send user-keyed interrupt to silence alarm.
 Current values. INDBUF INDBEG LIMBUF MFLUSH NUMDCD KCARD1 KCARD2
          339998    50 340000  1000    75    1    76
114000   .114   -24195.9  -24195.9  -24195.9 169.666613 .241959E-3
114500   .1145 -2528.4598 -2528.4598 -2528.4598 174.458425 .252846E-4
115000   .115  19228.6963 19228.6963 19228.6963 173.069744 -.19229E-3
115500   .1155  40304.7865 40304.7865 40304.7865  165.5498 -.40305E-3
116000   .116  59953.1597 59953.1597 59953.1597 152.165022 -.59953E-3
116500   .1165  77477.7458 77477.7458 77477.7458 133.389596 -.77478E-3
117000   .117  92257.7137 92257.7137 92257.7137 109.888673 -.92258E-3
117500   .1175  103769.464 103769.464 103769.464 82.4948022 -.00103769
118000   .118  111605.178 111605.178 111605.178  52.178439 -.00111605
118500   .1185  115487.263 115487.263 115487.263  20.013568 -.00115487
119000   .119  115278.187 115278.187 115278.187 -12.860344 -.00115278
119500   .1195  110985.353 110985.353 110985.353 -45.278714 -.00110985
120000    .12   102760.83  102760.83  102760.83 -76.093098 -.00102761
120500   .1205  90895.9731 90895.9731 90895.9731 -104.21187 -.90896E-3
121000   .121  75811.0971 75811.0971 75811.0971 -128.63892 -.75811E-3
121500   .1215  58040.5887 58040.5887 58040.5887 -148.50888 -.58041E-3
122000   .122  38213.9748 38213.9748 38213.9748 -163.11787 -.38214E-3
122500   .1225  17033.6212 17033.6212 17033.6212 -171.94833 -.17034E-3
123000   .123  -4750.1492 -4750.1492 -4750.1492 -174.68745 .475015E-4
123500   .1235  -26365.637 -26365.637 -26365.637 -171.23819 .263656E-3
124000   .124  -47047.103 -47047.103 -47047.103 -161.72274 .470471E-3
124500   .1245  -66061.897 -66061.897 -66061.897 -146.47819 .660619E-3
125000   .125  -82736.413 -82736.413 -82736.413 -126.04458 .827364E-3
125500   .1255  -96479.946 -96479.946 -96479.946 -101.14578 .964799E-3
126000   .126  -106805.63 -106805.63 -106805.63 -72.663852 .001068056
126500   .1265  -113347.66 -113347.66 -113347.66  -41.60777 .001133477
127000   .127   -115874.3  -115874.3  -115874.3 -9.0777142 .001158743
127500   .1275  -114296.03 -114296.03 -114296.03 23.7739217  .00114296
128000   .128  -108668.76 -108668.76 -108668.76 55.7833526 .001086688
128500   .1285  -99191.853 -99191.853 -99191.853 85.8166289 .991919E-3
129000   .129  -86201.021 -86201.021 -86201.021 112.809807  .86201E-3
129500   .1295  -70156.473 -70156.473 -70156.473  135.80664 .701565E-3
130000    .13  -51626.597 -51626.597 -51626.597 153.992455 .516266E-3
130500   .1305  -31267.822 -31267.822 -31267.822 166.723009 .312678E-3
131000   .131  -9801.3686 -9801.3686 -9801.3686 173.547317 .980137E-4
131500   .1315  12012.3034 12012.3034 12012.3034 174.223624 -.12012E-3
132000   .132  33400.4339 33400.4339 33400.4339 168.727972   -.334E-3
132500   .1325  53605.3377 53605.3377 53605.3377 157.255047 -.53605E-3
133000   .133  71911.2458 71911.2458 71911.2458 140.211283 -.71911E-3
133500   .1335  87669.6623 87669.6623 87669.6623 118.200465  -.8767E-3
134000   .134  100322.338 100322.338 100322.338 92.0023357 -.00100322
134500   .1345  109421.044 109421.044 109421.044 62.5449778 -.00109421
135000   .135  114643.456 114643.456 114643.456 30.8719326 -.00114643
135500   .1355  115804.566 115804.566 115804.566 -1.8947662 -.00115805
136000   .136  112863.241 112863.241 112863.241 -34.594342 -.00112863
136500   .1365   105923.68  105923.68  105923.68 -66.068396 -.00105924
137000   .137  95231.7204 95231.7204 95231.7204 -95.201945 -.95232E-3
137500   .1375  81166.1293 81166.1293 81166.1293 -120.96292 -.81166E-3
138000   .138  64225.1876 64225.1876 64225.1876 -142.43872 -.64225E-3
138500   .1385  45009.0366 45009.0366 45009.0366 -158.86856 -.45009E-3
139000   .139  24198.4181 24198.4181 24198.4181  -169.6704 -.24198E-3
139500   .1395  2530.55862 2530.55862 2530.55862 -174.46158 -.25306E-4
140000    .14  -19226.947 -19226.947 -19226.947 -173.07237 .192269E-3
140500   .1405  -40303.329 -40303.329 -40303.329 -165.55199 .403033E-3
141000   .141  -59951.945 -59951.945 -59951.945 -152.16685 .599519E-3
141500   .1415  -77476.733 -77476.733 -77476.733 -133.39112 .774767E-3
142000   .142   -92256.87  -92256.87  -92256.87 -109.88994 .922569E-3
142500   .1425  -103768.76 -103768.76 -103768.76 -82.495858 .001037688
143000   .143  -111604.59 -111604.59 -111604.59 -52.179319 .001116046
143500   .1435  -115486.77 -115486.77 -115486.77 -20.014301 .001154868
144000   .144  -115277.78 -115277.78 -115277.78 12.8597327 .001152778
144500   .1445  -110985.01 -110985.01 -110985.01 45.2782044  .00110985
145000   .145  -102760.55 -102760.55 -102760.55 76.0926731 .001027605
145500   .1455  -90895.737 -90895.737 -90895.737 104.211521 .908957E-3
```

```
146000   .146 -75810.901 -75810.901 -75810.901 128.638624 .758109E-3
146500   .1465 -58040.425 -58040.425 -58040.425 148.508639 .580404E-3
147000   .147 -38213.838 -38213.838 -38213.838 163.117662 .382138E-3
147500   .1475 -17033.508 -17033.508 -17033.508 171.94816 .170335E-3
148000   .148 4750.24392 4750.24392 4750.24392 174.687309 -.47502E-4
148500   .1485 26365.7156 26365.7156 26365.7156 171.238073 -.26366E-3
149000   .149 47047.1687 47047.1687 47047.1687 161.722643 -.47047E-3
149500   .1495 66061.9523 66061.9523 66061.9523 146.478108 -.66062E-3
150000   .15 82736.4584 82736.4584 82736.4584 126.044512 -.82736E-3
150500   .1505 96479.9841 96479.9841 96479.9841 101.145727 -.9648E-3
151000   .151 106805.658 106805.658 106805.658 72.6638044 -.00106806
151500   .1515 113347.689 113347.689 113347.689 41.60773 -.00113348

Plot timespan now in memory (in sec) = 1.13314003E-01  1.69972000E-01
 ++++ Begin plot-data copy from memory to disk.  MFLUSH, INDBUF, N4, Tbeg, Tend = 1003 339998     1 -1.00000E+00
1.00000E+19
SPY: 170000    .17 102760.547 102760.547 102760.547 -76.092673 -.00102761
170500   .1705 90895.7375 90895.7375 90895.7375 -104.21152 -.90896E-3
171000   .171 75810.9008 75810.9008 75810.9008 -128.63862 -.75811E-3
171500   .1715 58040.4251 58040.4251 58040.4251 -148.50864 -.5804E-3
172000   .172 38213.8385 38213.8385 38213.8385 -163.11766 -.38214E-3
172500   .1725 17033.5075 17033.5075 17033.5075 -171.94816 -.17034E-3
173000   .173 -4750.2439 -4750.2439 -4750.2439 -174.68731 .475024E-4
173500   .1735 -26365.716 -26365.716 -26365.716 -171.23807 .263657E-3
174000   .174 -47047.169 -47047.169 -47047.169 -161.72264 .470472E-3
174500   .1745 -66061.952 -66061.952 -66061.952 -146.47811 .66062E-3
175000   .175 -82736.458 -82736.458 -82736.458 -126.04451 .827365E-3
175500   .1755 -96479.984 -96479.984 -96479.984 -101.14573 .9648E-3
176000   .176 -106805.66 -106805.66 -106805.66 -72.663804 .001068057
176500   .1765 -113347.69 -113347.69 -113347.69 -41.60773 .001133477
177000   .177 -115874.32 -115874.32 -115874.32 -9.0776811 .001158743
177500   .1775 -114296.05 -114296.05 -114296.05 23.7739493 .00114296
178000   .178 -108668.78 -108668.78 -108668.78 55.7833756 .001086688
178500   .1785 -99191.866 -99191.866 -99191.866 85.8166481 .991919E-3
179000   .179 -86201.031 -86201.031 -86201.031 112.809823 .86201E-3
179500   .1795 -70156.482 -70156.482 -70156.482 135.806654 .701565E-3
180000   .18 -51626.604 -51626.604 -51626.604 153.992466 .516266E-3
180500   .1805 -31267.828 -31267.828 -31267.828 166.723018 .312678E-3
181000   .181 -9801.3737 -9801.3737 -9801.3737 173.547325 .980137E-4
181500   .1815 12012.2992 12012.2992 12012.2992 174.223631 -.12012E-3
182000   .182 33400.4304 33400.4304 33400.4304 168.727977 -.334E-3
182500   .1825 53605.3347 53605.3347 53605.3347 157.255052 -.53605E-3
183000   .183 71911.2433 71911.2433 71911.2433 140.211287 -.71911E-3
183500   .1835 87669.6603 87669.6603 87669.6603 118.200468 -.8767E-3
184000   .184 100322.336 100322.336 100322.336 92.0023383 -.00100322
184500   .1845 109421.043 109421.043 109421.043 62.5449799 -.00109421
185000   .185 114643.454 114643.454 114643.454 30.8719344 -.00114643
185500   .1855 115804.565 115804.565 115804.565 -1.8947647 -.00115805
186000   .186 112863.24 112863.24 112863.24 -34.594341 -.00112863
186500   .1865 105923.68 105923.68 105923.68 -66.068395 -.00105924
187000   .187 95231.7199 95231.7199 95231.7199 -95.201944 -.95232E-3
187500   .1875 81166.1288 81166.1288 81166.1288 -120.96292 -.81166E-3
188000   .188 64225.1872 64225.1872 64225.1872 -142.43872 -.64225E-3
188500   .1885 45009.0363 45009.0363 45009.0363 -158.86855 -.45009E-3
189000   .189 24198.4179 24198.4179 24198.4179 -169.6704 -.24198E-3
189500   .1895 2530.55839 2530.55839 2530.55839 -174.46158 -.25306E-4
190000   .19 -19226.947 -19226.947 -19226.947 -173.07237 .192269E-3
190500   .1905 -40303.329 -40303.329 -40303.329 -165.55199 .403033E-3
191000   .191 -59951.945 -59951.945 -59951.945 -152.16685 .599519E-3
191500   .1915 -77476.733 -77476.733 -77476.733 -133.39112 .774767E-3
192000   .192 -92256.87 -92256.87 -92256.87 -109.88994 .922569E-3
192500   .1925 -103768.76 -103768.76 -103768.76 -82.495858 .001037688
193000   .193 -111604.59 -111604.59 -111604.59 -52.179319 .001116046
193500   .1935 -115486.77 -115486.77 -115486.77 -20.014301 .001154868
194000   .194 -115277.78 -115277.78 -115277.78 12.8597327 .001152778
194500   .1945 -110985.01 -110985.01 -110985.01 45.2782044 .00110985
195000   .195 -102760.55 -102760.55 -102760.55 76.0926732 .001027605
195500   .1955 -90895.738 -90895.738 -90895.738 104.211521 .908957E-3
196000   .196 -75810.901 -75810.901 -75810.901 128.638624 .758109E-3
196500   .1965 -58040.425 -58040.425 -58040.425 148.508639 .580404E-3
197000   .197 -38213.838 -38213.838 -38213.838 163.117662 .382138E-3
197500   .1975 -17033.508 -17033.508 -17033.508 171.94816 .170335E-3
198000   .198 4750.24391 4750.24391 4750.24391 174.687309 -.47502E-4
198500   .1985 26365.7156 26365.7156 26365.7156 171.238073 -.26366E-3
199000   .199 47047.1687 47047.1687 47047.1687 161.722643 -.47047E-3
199500   .1995 66061.9523 66061.9523 66061.9523 146.478108 -.66062E-3
 %%%%% Final time step, PLTFIL dumps plot data to ".PL4" disk file.
 Done dumping plot points to C-like disk file.
200000     0.2 82736.4584 82736.4584 82736.4584 126.044512 -.82736E-3
```

Extrema of output variables follow. Order and column positioning are the same as for the preceding time-step loop output.
Variable maxima : 375013.98 375013.98 375013.98 753.64385 916.895959
Times of maxima : .048083 .048083 .048083 .045913 .047442
Variable minima : -500000. -500000. -500000. -19292.424 -19531.439
Times of minima : .041667 .041667 .041667 .040002 .040002

Blank card terminating all plot cards. |BLANK PLOT

Memory storage figures for the preceding, now-completed data case. ------------------------------ Present Program
A value of "-9999" indicates that no figure is available. 07-May-07 18:42:58 figure limit (name)
Size List 1. Number of electric network nodes. 6 6000 (LBUS)
Size List 2. Number of electric network branches. 3 10000 (LBRNCH)
Size List 3. Number of data values in R, L, C tables. 3 192000 (LDATA)
Size List 4. Number of electric network sources. 1 900 (LEXCT)
Size List 5. Storage for [Y] and triangularized [Y]. No. times = 4 Factors = 2 8 420000 (LYMAT)
Size List 6. Number of entries in switch table. No. flops = 7 4 1200 (LSWTCH)
Size List 7. Number of distinct ALPHANUMERIC data names plus program SPY variables. 5 15000 (LSIZE7)
Size List 8. History points of distributed lines. 0 120000 (LPAST)
Size List 9. Number of nonlinear elements. 0 2250 (LNONL)
Size List 10. Points of nonlinear characteristics. 0 3800 (LCHAR)
Size List 11. Number of Type-59 S.M. outputs. 0 720 (LSMOUT)
Size List 12. Total number of EMTP output variables. 5 1200 (LSIZ12)
Size List 13. Working space for batch/SPY plotting. -9999 72800 (LSIZ13)
Size List 14. S.M./U.M. connections to TACS. -9999 510 (LBSTAC)
Size List 15. Character storage in bytes for MODELS. 1877 90000 (LCTACS)
Size List 16. Total number of Type-59 S.M. masses. 0 800 (LIMASS)
Size List 17. Number of Type-59 Synchronous machines. 0 90 (LSYN)
Size List 18. Branch and switch power/energy outputs. 0 254 (MAXPE)
Size List 19. Total floating-point TACS table space. 23 120000 (LTACST)
Size List 20. Non-copied recursive convolution data. 0 100000 (LFSEM)
Size List 21. Total modal/phase [T] matrix storage. 0 3000 (LFD)
Size List 22. Total recursive convolution history. 0 15000 (LHIST)
Size List 23. Giant vectors for renumbering, phasors. 8 192000 (LSIZ23)
Size List 24. Peak phases of compensation for data. 0 120 (LCOMP)
Size List 25. Total table space for all U.M usage. -9999 30000 (LSPCUM)
Size List 26. Square of max number of coupled phases. 1 160000 (LSIZ26)
Size List 28. MODELS. Total work space is divided into INTEGER and REAL. 1st, REAL: 1700 210000 (LRTACS)
Second and last, statistics for INTEGER work space. 3602 0 (LITACS)
Size List 29. RAM disk used by "TAPSAV" table saving (limit is "LABCOM" size LTLABL). -9999 300 (LSIZ29)
Size List 30. Taku Noda frequency-dependent circuits. 0 19 (LSIZ30)
Timing figures characterizing central processor (CP) solution speed. -------------------------- CP sec Wait sec Real sec
Data input time (through blank card ending branches) 0.016 0.000 0.016
Node renumbering and phasor solution 0.000 0.000 0.000
After phasor solution, but before time-step loop 0.000 0.000 0.000
Integration of equations (time-step loop) 3.891 0.000 3.891
Plotting or STATISTICS termination overlays 0.000 0.000 0.000

Totals 3.906 0.000 3.906

APPENDIX E

ATP FILE FOR SCENARIO 3

Alternative Transients Program (ATP), GNU Linux or DOS. All rights reserved by Can/Am user group of Portland, Oregon, USA.
Date (dd-mth-yy) and time of day (hh.mm.ss) = 07-May-07 18:52:36 Name of disk plot file is projecttemplate.pl4
Consult the 860-page ATP Rule Book of the Can/Am EMTP User Group in Portland, Oregon, USA. Source code date is 19 December 2003.
Total size of LABCOM tables = 9872109 INTEGER words. 31 VARDIM List Sizes follow: 6002 10K 192K 900 420K 1200 15K
120K 2250 3800 720 1200 72800 510 90K 800 90 254 120K 100K 3K 15K 192K 120 30K 160K 600 210K 300 19 200

```
--------------------------------------------------+--------------------------------------------------------------------------------
Descriptive interpretation of input data cards.  | Input data card images are shown below, all 80 columns, character by character
                                                  0         1         2         3         4         5         6         7         8
                                                  012345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------+--------------------------------------------------------------------------------
Comment card.  NUMDCD = 1.                       |C data:PROJECTTEMPLATE.ATP
Marker card preceding new EMTP data case.        |BEGIN NEW DATA CASE
Comment card.  NUMDCD = 3.                       |C ----------------------------------------------------
Comment card.  NUMDCD = 4.                       |C Generated by ATPDRAW  May, Monday 7, 2007
Comment card.  NUMDCD = 5.                       |C A Bonneville Power Administration program
Comment card.  NUMDCD = 6.                       |C Programmed by H. K. Høidalen at SEfAS - NORWAY 1994-2003
Comment card.  NUMDCD = 7.                       |C ----------------------------------------------------
Comment card.  NUMDCD = 8.                       |C  dT  >< Tmax >< Xopt >< Copt >
Misc. data.   5.000E-04  1.000E-01  0.000E+00 |  .0005    .1
Misc. data.   500   1  1  1  1  0  0  1  0  0  |    500     1     1     1     1     0     0     1     0
No TACS data,  but MODELS data begins (next).    |MODELS
    Another ordinary MODELS data card.           |INPUT
    Another ordinary MODELS data card.           | IX0001 {v(XX0116)}
    Another ordinary MODELS data card.           | IX0002 {v(XX0007)}
    Another ordinary MODELS data card.           | IX0003 {v(XX0014)}
    Another ordinary MODELS data card.           | IX0004 {v(XX0110)}
    Another ordinary MODELS data card.           |OUTPUT
    Another ordinary MODELS data card.           | A
    Another ordinary MODELS data card.           | B
    Another ordinary MODELS data card.           | C
    Another ordinary MODELS data card.           | D
    Another ordinary MODELS data card.           |MODEL relay_f
    Another ordinary MODELS data card.           | INPUT  V1    -- Voltage measured at first node        [V]
    Another ordinary MODELS data card.           |        V2           -- Voltage mesured at second node              [V]
    Another ordinary MODELS data card.           |          V3     -- Voltage measured at third node         [V]
    Another ordinary MODELS data card.           |          V4     -- Voltage measured at fourth node        [V]
    Another ordinary MODELS data card.           | DATA  Vset  -- Voltage threshold                                [V]
    Another ordinary MODELS data card.           |        Vset2  -- Voltage threshold                              [V]
    Another ordinary MODELS data card.           |          Vset3  -- Voltage threshold                            [V]
    Another ordinary MODELS data card.           |        Vset4  -- Voltage threshold                              [V]
    Another ordinary MODELS data card.           |        tset  -- Time fault
    Another ordinary MODELS data card.           | VAR  trip_A   -- relay controlled signal            [0 or 1]
    Another ordinary MODELS data card.           |       trip_B  -- relay controlled signal               [0 or 1]
    Another ordinary MODELS data card.           |         trip_C  -- relay controlled signal             [0 or 1]
    Another ordinary MODELS data card.           |       trip_D  -- relay controlled signal               [0 or 1]
    Another ordinary MODELS data card.           | OUTPUT  trip_A
    Another ordinary MODELS data card.           |          trip_B
    Another ordinary MODELS data card.           |          trip_C
    Another ordinary MODELS data card.           |          trip_D
    Another ordinary MODELS data card.           | INIT trip_A:=1  -- close circuit breaker
    Another ordinary MODELS data card.           |      trip_B:=1  -- close circuit breaker
    Another ordinary MODELS data card.           |      trip_C:=1  -- close circuit breaker
    Another ordinary MODELS data card.           |      trip_D:=1  -- close circuit breaker
    Another ordinary MODELS data card.           | ENDINIT
    Another ordinary MODELS data card.           | EXEC
    Another ordinary MODELS data card.           |  -----------------------------------------------------------------
    Another ordinary MODELS data card.           |  IF V1<Vset    -- Measured voltage less the relay voltage setting (threshold)
    Another ordinary MODELS data card.           |  AND trip_A>0
    Another ordinary MODELS data card.           |  THEN
    Another ordinary MODELS data card.           |   trip_A:=1        -- circuit breaker remain closed
    Another ordinary MODELS data card.           |  ENDIF
    Another ordinary MODELS data card.           |  -----------------------------------------------------------------
    Another ordinary MODELS data card.           |  IF V2<Vset2   -- Measured voltage less the relay voltage setting (threshold)
    Another ordinary MODELS data card.           |  AND trip_B>0
    Another ordinary MODELS data card.           |  THEN
    Another ordinary MODELS data card.           |   trip_B:=1        -- circuit breaker remain closed
    Another ordinary MODELS data card.           |  ENDIF
    Another ordinary MODELS data card.           |  -----------------------------------------------------------------
    Another ordinary MODELS data card.           |  IF V3<Vset3   -- Measured voltage less the relay voltage setting (threshold)
    Another ordinary MODELS data card.           |  AND trip_C>0
    Another ordinary MODELS data card.           |  THEN
    Another ordinary MODELS data card.           |   trip_C:=1        -- circuit breaker remain closed
    Another ordinary MODELS data card.           |  ENDIF
    Another ordinary MODELS data card.           |  -----------------------------------------------------------------
    Another ordinary MODELS data card.           |  IF V4<Vset4   -- Measured voltage less the relay voltage setting (threshold)
```

```
Another ordinary MODELS data card.      |  AND trip_D>0
Another ordinary MODELS data card.      |  THEN
Another ordinary MODELS data card.      |   trip_D:=1        -- circuit breaker remain closed
Another ordinary MODELS data card.      |  ENDIF
Another ordinary MODELS data card.      |  ------------------------------------------------------------------------
Another ordinary MODELS data card.      |  IF V1>Vset   -- Measured voltage more than the relay voltage setting
Another ordinary MODELS data card.      |  AND trip_A>0
Another ordinary MODELS data card.      |  THEN
Another ordinary MODELS data card.      |   trip_A:=0  -- relay send signal open circuit breaker
Another ordinary MODELS data card.      |  ENDIF
Another ordinary MODELS data card.      |  ------------------------------------------------------------------------
Another ordinary MODELS data card.      |  IF V2>Vset2  -- Measured voltage more than the relay voltage setting
Another ordinary MODELS data card.      |  AND trip_B>0
Another ordinary MODELS data card.      |  THEN
Another ordinary MODELS data card.      |   trip_B:=0  -- relay send signal open circuit breaker
Another ordinary MODELS data card.      |  ENDIF
Another ordinary MODELS data card.      |  ------------------------------------------------------------------------
Another ordinary MODELS data card.      |  IF V3>Vset3  -- Measured voltage more than the relay voltage setting
Another ordinary MODELS data card.      |  AND trip_C>0
Another ordinary MODELS data card.      |  THEN
Another ordinary MODELS data card.      |   trip_C:=0  -- relay send signal open circuit breaker
Another ordinary MODELS data card.      |  ENDIF
Another ordinary MODELS data card.      |  ------------------------------------------------------------------------
Another ordinary MODELS data card.      |  IF V4>Vset4  -- lightning voltage more than the relay voltage setting
Another ordinary MODELS data card.      |  AND trip_D>0
Another ordinary MODELS data card.      |  THEN
Another ordinary MODELS data card.      |   trip_D:=0  -- relay send signal open circuit breaker
Another ordinary MODELS data card.      |  ENDIF
Another ordinary MODELS data card.      |  ------------------------------------------------------------------------
Another ordinary MODELS data card.      |  IF trip_A=0   -- circuit breaker open
Another ordinary MODELS data card.      |  AND t>tset  -- fault cleared
Another ordinary MODELS data card.      |  THEN
Another ordinary MODELS data card.      |   trip_A:=1       -- relay send signal to reclose circuit breaker
Another ordinary MODELS data card.      |  ENDIF
Another ordinary MODELS data card.      |  ------------------------------------------------------------------------
Another ordinary MODELS data card.      |  IF trip_B=0   -- circuit breaker open
Another ordinary MODELS data card.      |  AND t>tset  -- fault cleared
Another ordinary MODELS data card.      |  THEN
Another ordinary MODELS data card.      |   trip_B:=1       -- relay send signal to reclose circuit breaker
Another ordinary MODELS data card.      |  ENDIF
Another ordinary MODELS data card.      |  ------------------------------------------------------------------------
Another ordinary MODELS data card.      |  IF trip_C=0   -- circuit breaker open
Another ordinary MODELS data card.      |  AND t>tset  -- fault cleared
Another ordinary MODELS data card.      |  THEN
Another ordinary MODELS data card.      |   trip_C:=1       -- relay send signal to reclose circuit breaker
Another ordinary MODELS data card.      |  ENDIF
Another ordinary MODELS data card.      |  ------------------------------------------------------------------------
Another ordinary MODELS data card.      |  IF trip_D=0   -- circuit breaker open
Another ordinary MODELS data card.      |  AND t>tset  -- fault cleared
Another ordinary MODELS data card.      |  THEN
Another ordinary MODELS data card.      |   trip_D:=1       -- relay send signal to reclose circuit breaker
Another ordinary MODELS data card.      |  ENDIF
Another ordinary MODELS data card.      |  ------------------------------------------------------------------------
Another ordinary MODELS data card.      | ENDEXEC
Another ordinary MODELS data card.      |ENDMODEL
Another ordinary MODELS data card.      |USE relay_f AS relay_f
Another ordinary MODELS data card.      |INPUT
Another ordinary MODELS data card.      | V1:= IX0001
Another ordinary MODELS data card.      | V2:= IX0002
Another ordinary MODELS data card.      | V3:= IX0003
Another ordinary MODELS data card.      | V4:= IX0004
Another ordinary MODELS data card.      |DATA
Another ordinary MODELS data card.      | Vset:=   4.6E5
Another ordinary MODELS data card.      | Vset2:=   1.6E5
Another ordinary MODELS data card.      | Vset3:= 1.111E15
Another ordinary MODELS data card.      | Vset4:= 1.111E16
Another ordinary MODELS data card.      | tset:=   0.08
Another ordinary MODELS data card.      |OUTPUT
Another ordinary MODELS data card.      | A    :=trip_A
Another ordinary MODELS data card.      | B    :=trip_B
```

```
   Another ordinary MODELS data card.      | C   :=trip_C
   Another ordinary MODELS data card.      | D   :=trip_D
   Another ordinary MODELS data card.      |ENDUSE
Termination of data for Laurent Dube's MODELS.  |ENDMODELS
Comment card.  NUMDCD = 140.               |C    1    2    3    4    5    6    7    8
Comment card.  NUMDCD = 141.               |C
3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
Optional blank card follows last of MODELS data.  |BLANK MODELS
Comment card.  NUMDCD = 143.               |C < n 1>< n 2><ref1><ref2>< R  >< L  >< C  >
Comment card.  NUMDCD = 144.               |C < n 1>< n 2><ref1><ref2>< R  >< A  >< B  ><Leng><><>0
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0174XX0003        1.  10.  .1
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0003XX0116        1.  10.  .1
Series R-L-C.  2.000E+01 1.000E-06 0.000E+00  | XX0007XX0008        20.  .001                  0
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0140XX0011        1.  10.  .1
Series R-L-C.  1.000E+03 0.000E+00 0.000E+00  |    XX0003        1.E3                      0
Series R-L-C.  2.000E+01 1.000E-06 0.000E+00  | XX0014XX0015        20.  .001                  0
Series R-L-C.  2.000E+01 1.000E-06 0.000E+00  |    XX0110        20.  .001                  0
Series R-L-C.  2.000E+01 1.000E-06 0.000E+00  | XX0110XX0021        20.  .001                  0
Series R-L-C.  2.000E+01 1.000E-06 0.000E+00  |    XX0110        20.  .001                  0
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0116XX0027        1.  10.  .1
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0027XX0164        1.  10.  .1
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0030XX0031        1.  10.  .1
Series R-L-C.  2.000E+01 1.000E-06 0.000E+00  |    XX0007        20.  .001                  0
Series R-L-C.  2.000E+01 1.000E-06 0.000E+00  |    XX0007        20.  .001                  0
Series R-L-C.  1.000E+03 0.000E+00 0.000E+00  |    XX0011        1.E3                      0
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0134XX0030        1.  10.  .1
Series R-L-C.  1.000E+03 0.000E+00 0.000E+00  |    XX0027        1.E3                      0
Series R-L-C.  1.000E+03 0.000E+00 0.000E+00  |    XX0044        1.E3                      0
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0044XX0166        1.  10.  .1
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0011XX0156        1.  10.  .1
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0156XX0049        1.  10.  .1
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0049XX0138        1.  10.  .1
1st of PI-ckt.  1.000E+00 1.000E-02 1.000E-07 |1 XX0138XX0044        1.  10.  .1
Series R-L-C.  1.000E+03 0.000E+00 0.000E+00  |    XX0030        1.E3                      0
Series R-L-C.  2.000E+01 1.000E-06 0.000E+00  |    XX0014        20.  .001                  0
Series R-L-C.  2.000E+01 1.000E-06 0.000E+00  |    XX0014        20.  .001                  0
Series R-L-C.  1.000E+03 0.000E+00 0.000E+00  |    XX0049        1.E3                      0
Blank card ending branches.  IBR, NTOT = 27  22  |BLANK BRANCH
Comment card.  NUMDCD = 173.              |C < n 1>< n 2>< Tclose ><Top/Tde ><  Ie  ><Vf/CLOP >< type >
Permanently-closed switch used for metering.  | X0164AX0019A                   MEASURING          1
Permanently-closed switch used for metering.  | X0164BX0019B                   MEASURING
Permanently-closed switch used for metering.  | X0164CX0019C                   MEASURING
Permanently-closed switch used for metering.  | XX0024XX0106                   MEASURING          1
Permanently-closed switch used for metering.  | XX0075XX0140                   MEASURING          1
Switch.  TACS control = "D    "          |13XX0021XX0075               CLOSED     D     0
Switch.  TACS control = "A    "          |13XX0106XX0174               CLOSED     A     0
Permanently-closed switch used for metering.  | X0019AX0166A                   MEASURING          1
Permanently-closed switch used for metering.  | X0019BX0166B                   MEASURING
Permanently-closed switch used for metering.  | X0019CX0166C                   MEASURING
Permanently-closed switch used for metering.  | XX0075XX0134                   MEASURING          1
Permanently-closed switch used for metering.  | X0031AXX0024                   MEASURING          1
Permanently-closed switch used for metering.  | X0031BXX0024                   MEASURING
Permanently-closed switch used for metering.  | X0031CXX0024                   MEASURING
Switch.  TACS control = "B    "          |13XX0008XX0116               CLOSED     B     0
Switch.  TACS control = "C    "          |13XX0015XX0138               CLOSED     C     0
Switch.  4.00E-02 8.00E-02 0.00E+00 0.00E+00  | XX0007XX0008     .04     .08                  0
Blank card ending switches.  KSWTCH = 17.     |BLANK SWITCH
Comment card.  NUMDCD = 192.            |C < n 1><>< Ampl.  >< Freq.  ><Phase/T0><  A1  ><  T1  >< TSTART >< TSTOP  >
Source.  5.00E+05 6.00E+01 0.00E+00 -1.00E+00 |14XX0024 0    5.E5     60.                    -1.     1.
Source.  5.00E+05 6.00E+01 0.00E+00 -1.00E+00 |14X0019A 0    5.E5     60.                    -1.     1.
Source.  5.00E+05 6.00E+01 0.00E+00 -1.00E+00 |14XX0156 0    5.E5     60.                    -1.     1.
Blank card ends electric sources.  KCONST = 3   |BLANK SOURCE
```

List of input elements that are connected to each node. Only the physical connections of multi-phase lines are shown (capacitive and inductive coupling are ignored). Repeated entries indicate parallel connections. Switches are included, although sources (including rotating machinery) are omitted -- except that U.M. usage produces extra, internally-defined nodes "UMXXXX".

```
--------------+------------------------------
From bus name |  Names of all adjacent busses.
--------------+------------------------------
     XX0174 |XX0003*XX0106*
     XX0003 |TERRA *XX0174*XX0116*
     XX0116 |XX0003*XX0008*XX0027*
     XX0007 |TERRA *TERRA *XX0008*XX0008*
     XX0008 |XX0116*XX0007*XX0007*
     XX0140 |XX0011*XX0075*
     XX0011 |TERRA *XX0140*XX0156*
     XX0014 |TERRA *TERRA *XX0015*
     XX0015 |XX0014*XX0138*
     XX0110 |TERRA *TERRA *XX0021*
```

```
XX0021 |XX0110*XX0075*
XX0027 |TERRA *XX0116*XX0164*
XX0164 |XX0027*
XX0030 |TERRA *XX0031*XX0134*
XX0031 |XX0030*
XX0134 |XX0030*XX0075*
XX0044 |TERRA *XX0166*XX0138*
XX0166 |XX0044*
XX0156 |XX0011*XX0049*
XX0049 |TERRA *XX0156*XX0138*
XX0138 |XX0015*XX0044*XX0049*
X0164A |X0019A*
X0019A |X0164A*X0166A*
X0164B |X0019B*
X0019B |X0164B*X0166B*
X0164C |X0019C*
X0019C |X0164C*X0166C*
XX0024 |XX0106*X0031A*X0031B*X0031C*
XX0106 |XX0174*XX0024*
XX0075 |XX0140*XX0021*XX0134*
X0166A |X0019A*
X0166B |X0019B*
X0166C |X0019C*
X0031A |XX0024*
X0031B |XX0024*
X0031C |XX0024*
TERRA  |XX0003*XX0007*XX0007*XX0011*XX0014*XX0014*XX0110*XX0110*XX0027*XX0030*XX0044*XX0049*
```

Sinusoidal steady-state phasor solution, branch by branch. All flows are away from a bus, and the real part, magnitude, or "P" is printed above the imaginary part, the angle, or "Q". The first solution frequency = 6.00000000E+01 Hertz.

```
Bus K          Phasor node voltage        Phasor branch current         Power flow     Power loss
     Bus M     Rectangular      Polar      Rectangular       Polar        P and Q       P and Q

XX0174              500000.           500000.    15631.144621674 16067.448379222  .39077861554E10 .129116542927E9
                        0.0               0.0   -3718.899734502   -13.3827799     .929724933625E9 82288276.4968863

     XX0003  470313.40310007 473541.66055676   -15630.1041318  16070.67957831   -.3778669612E10
            -55199.70242032   -6.6940607       3737.1897112548   166.5529241    -.44743665713E9

XX0003           470313.40310007 473541.66055676   15159.790728696 15600.522599036  .36665487604E10 .121705060483E9
                -55199.70242032   -6.6940607      -3681.990008834  -13.6515846     .447436657129E9 54757630.7134733

     XX0116  441240.45653435 454421.90141834   -15156.70212167 15601.586317031   -.35448437E10
            -108655.9892781  -13.8339098       3699.1723942871  166.2844199     .732097358496E7

XX0007           147080.15217812 151473.96713945   -14707.94694201 15147.396711254  -.1147218136E10 .22944362713E10
                -36218.66309271  -13.8339098       3622.1435475398  166.1650102    -21624.55240199  43249.1048039

     XX0008  441240.45653435 454421.90141834    14707.946942014 15147.396711254   .34416544069E10
            -108655.9892781  -13.8339098      -3622.14354754   -13.8349898     64873.657205902

XX0140           441240.45653435 454421.90141834   -15156.70212167 15601.586317031  -.35448437E10 .121705060483E9
                -108655.9892781  -13.8339098       3699.1723942871  166.2844199     .732097358496E7 54757630.7134735

     XX0011  470313.40310007 473541.66055676    15159.790728696 15600.522599036   .36665487604E10
            -55199.70242032   -6.6940607      -3681.990008834  -13.6515846     .447436657129E9

TERRA                   0.0           0.0   -470.3134031001 473.54166055676              0.0 .112120852141E9
                        0.0           0.0    55.199702420318  173.3059393                0.0   0.0000000

     XX0003  470313.40310007 473541.66055676    470.31340310007 473.54166055676   .112120852141E9
            -55199.70242032   -6.6940607      -55.19970242032   -6.6940607     -.5193214747E-9

XX0014           147080.15217812 151473.96713945   -14707.94694201 15147.396711254  -.1147218136E10 .22944362713E10
                -36218.66309271  -13.8339098       3622.1435475398  166.1650102    -21624.55240199  43249.1048039

     XX0015  441240.45653435 454421.90141834    14707.946942014 15147.396711254   .34416544069E10
            -108655.9892781  -13.8339098      -3622.14354754   -13.8349898     64873.657205902

TERRA                   0.0           0.0   -7353.973471007 7573.6983556268              0.0 .57360906782E9
                        0.0           0.0    1811.0717737699  166.1650102                0.0  10812.2762010

     XX0110  147080.15217812 151473.96713945    7353.9734710072 7573.6983556268   .57360906782E9
            -36218.66309271  -13.8339098      -1811.07177377   -13.8349898     10812.276200976

XX0110           147080.15217812 151473.96713945   -14707.94694201 15147.396711254  -.1147218136E10 .22944362713E10
                -36218.66309271  -13.8339098       3622.1435475398  166.1650102    -21624.55240195  43249.1048039

     XX0021  441240.45653435 454421.90141834    14707.946942014 15147.396711254   .34416544069E10
            -108655.9892781  -13.8339098      -3622.14354754   -13.8349898     64873.657205855
```

```
TERRA            0.0        0.0   -7353.973471007 7573.6983556268          0.0 .57360906782E9
            0.0        0.0   1811.0717737699    166.1650102          0.0  10812.2762010

     XX0110  147080.15217812 151473.96713945   7353.9734710072 7573.6983556268    .57360906782E9
          -36218.66309271   -13.8339098   -1811.07177377   -13.8349898   10812.276200976

XX0116          441240.45653435 454421.90141834   448.75517965811  455.3181903913   .103189292945E9 103415.57255826
          -108655.9892781   -13.8339098   -77.02884674733   -9.7399053   -.73858472422E7 -3499464.5130083

     XX0027  440472.00250596 454061.31907626   -444.6288105824  454.38404987028   -.10308587737E9
          -110254.6891958   -14.0529765   93.648735050727   168.1060769   .388638272916E7

XX0027          440472.00250596 454061.31907626   4.1568080764324 17.118316694451    36.63219885161 36.632198883101
          -110254.6891958   -14.0529765   16.605954145042   75.9464834   -.38863827292E7 -3886382.7291512

     XX0164  440501.22647429 454093.58740888   .9982878239E-13 .1991890605E-12   .31490894607E-7
          -110270.8284204   -14.0540566   -.172367329E-12   -59.9221640   .3245990859E-7

XX0030          440472.00250596 454061.31907626   4.1568080764324 17.118316694451    36.632198851351 36.632198883265
          -110254.6891958   -14.0529765   16.605954145042   75.9464834   -.38863827292E7 -3886382.7291512

     XX0031  440501.22647429 454093.58740888   .102846117E-12 .1969621613E-12   .31913483329E-7
          -110270.8284204   -14.0540566   -.167978478E-12   -58.5226271   .31326899604E-7

TERRA            0.0        0.0   -7353.973471007 7573.6983556268          0.0 .57360906782E9
            0.0        0.0   1811.0717737699    166.1650102          0.0  10812.2762010

     XX0007  147080.15217812 151473.96713945   7353.9734710072 7573.6983556268    .57360906782E9
          -36218.66309271   -13.8339098   -1811.07177377   -13.8349898   10812.276200993

TERRA            0.0        0.0   -7353.973471007 7573.6983556268          0.0 .57360906782E9
            0.0        0.0   1811.0717737699    166.1650102          0.0  10812.2762010

     XX0007  147080.15217812 151473.96713945   7353.9734710072 7573.6983556268    .57360906782E9
          -36218.66309271   -13.8339098   -1811.07177377   -13.8349898   10812.276200993

TERRA            0.0        0.0   -470.3134031001 473.54166055676          0.0 .112120852141E9
            0.0        0.0   55.199702420318    173.3059393          0.0     0.0000000

     XX0011  470313.40310007 473541.66055676   470.31340310007 473.54166055676   .112120852141E9
          -55199.70242032   -6.6940607   -55.19970242032   -6.6940607   -.8858478395E-9

XX0134          441240.45653435 454421.90141834   448.75517965811  455.3181903913   .103189292945E9 103415.57255826
          -108655.9892781   -13.8339098   -77.02884674733   -9.7399053   -.73858472422E7 -3499464.5130083

     XX0030  440472.00250596 454061.31907626   -444.6288105824  454.38404987028   -.10308587737E9
          -110254.6891958   -14.0529765   93.648735050727   168.1060769   .388638272916E7

TERRA            0.0        0.0   -440.472002506  454.06131907626          0.0 .103085840741E9
            0.0        0.0   110.25468919581    165.9470235          0.0     0.0000000

     XX0027  440472.00250596 454061.31907626   440.47200250596 454.06131907626   .103085840741E9
          -110254.6891958   -14.0529765   -110.2546891958   -14.0529765   .29831426218E-9

TERRA            0.0        0.0   -440.472002506  454.06131907626          0.0 .103085840741E9
            0.0        0.0   110.25468919581    165.9470235          0.0     0.0000000

     XX0044  440472.00250596 454061.31907626   440.47200250596 454.06131907626   .103085840741E9
          -110254.6891958   -14.0529765   -110.2546891958   -14.0529765   .29831426218E-9

XX0044          440472.00250596 454061.31907626   4.1568080764324 17.118316694451    36.63219885161 36.632198883101
          -110254.6891958   -14.0529765   16.605954145042   75.9464834   -.38863827292E7 -3886382.7291512

     XX0166  440501.22647429 454093.58740888   .9982878239E-13 .1991890605E-12   .31490894607E-7
          -110270.8284204   -14.0540566   -.172367329E-12   -59.9221640   .3245990859E-7

XX0011          470313.40310007 473541.66055676   -15630.1041318  16070.67957831   -.3778669612E10 .129116542927E9
          -55199.70242032   -6.6940607   3737.1897112547   166.5529241   -.44743665713E9 82288276.4968865

     XX0156       500000.       500000.   15631.144621674 16067.448379222   .39077861554E10
            0.0        0.0   -3718.899734502   -13.3827799   .929724933625E9

XX0156          500000.       500000.   15631.144621674 16067.448379222   .39077861554E10 .129116542927E9
            0.0        0.0   -3718.899734502   -13.3827799   .929724933625E9 82288276.4968863

     XX0049  470313.40310007 473541.66055676   -15630.1041318  16070.67957831   -.3778669612E10
          -55199.70242032   -6.6940607   3737.1897112548   166.5529241   -.44743665713E9

XX0049          470313.40310007 473541.66055676   15159.790728696 15600.522599036   .36665487604E10 .121705060483E9
```

```
     -55199.70242032   -6.6940607   -3681.990008834   -13.6515846   .447436657129E9 54757630.7134733

  XX0138  441240.45653435 454421.90141834   -15156.70212167 15601.586317031    -.35448437E10
     -108655.9892781   -13.8339098   3699.1723942871   166.2844199   .732097358496E7

XX0138         441240.45653435 454421.90141834   448.75517965811  455.3181903913   .103189292945E9 103415.57255826
     -108655.9892781   -13.8339098   -77.02884674733   -9.7399053   -.73858472422E7 -3499464.5130083

  XX0044  440472.00250596 454061.31907626   -444.6288105824 454.38404987028   -.10308587737E9
     -110254.6891958   -14.0529765   93.648735050727   168.1060769   .388638272916E7

TERRA            0.0       0.0   -440.472002506 454.06131907626          0.0 .103085840741E9
           0.0       0.0   110.25468919581   165.9470235          0.0      0.0000000

  XX0030  440472.00250596 454061.31907626   440.47200250596 454.06131907626   .103085840741E9
     -110254.6891958   -14.0529765   -110.2546891958   -14.0529765   -.225554686E-9

TERRA            0.0       0.0   -7353.973471007 7573.6983556268          0.0 .57360906782E9
           0.0       0.0   1811.0717737699   166.1650102          0.0   10812.2762010

  XX0014  147080.15217812 151473.96713945   7353.9734710072 7573.6983556268   .57360906782E9
     -36218.66309271   -13.8339098   -1811.07177377   -13.8349898   10812.276200993

TERRA            0.0       0.0   -7353.973471007 7573.6983556268          0.0 .57360906782E9
           0.0       0.0   1811.0717737699   166.1650102          0.0   10812.2762010

  XX0014  147080.15217812 151473.96713945   7353.9734710072 7573.6983556268   .57360906782E9
     -36218.66309271   -13.8339098   -1811.07177377   -13.8349898   10812.276200993

TERRA            0.0       0.0   -470.3134031001 473.54166055676          0.0 .112120852141E9
           0.0       0.0   55.199702420318   173.3059393          0.0      0.0000000

  XX0049  470313.40310007 473541.66055676   470.31340310007 473.54166055676   .112120852141E9
     -55199.70242032   -6.6940607   -55.19970242032   -6.6940607   -.5193214747E-9
 Total network loss  P-loss  by summing injections =  1.172335846626E+10
```

Output for steady-state phasor switch currents.

Node-K	Node-M	I-real	I-imag	I-magn	Degrees	Power	Reactive
X0164A	X0019A	0.00000000E+00	0.00000000E+00	0.00000000E+00	0.0000	0.00000000E+00	0.00000000E+00
X0164B	X0019B	0.00000000E+00	0.00000000E+00	0.00000000E+00	0.0000	0.00000000E+00	0.00000000E+00
X0164C	X0019C	0.00000000E+00	0.00000000E+00	0.00000000E+00	0.0000	0.00000000E+00	0.00000000E+00
XX0024	XX0106	1.56311446E+04	-3.71889973E+03	1.60674484E+04	-13.3828	3.90778616E+09	9.29724934E+08
XX0075	XX0140	-1.51567021E+04	3.69917239E+03	1.56015863E+04	166.2844	-3.54484370E+09	7.32097358E+06
XX0021	XX0075	-1.47079469E+04	3.62214355E+03	1.51473967E+04	166.1650	-3.44165441E+09	-6.48736572E+04
XX0106	XX0174	1.56311446E+04	-3.71889973E+03	1.60674484E+04	-13.3828	3.90778616E+09	9.29724934E+08
X0019A	X0166A	0.00000000E+00	0.00000000E+00	0.00000000E+00	0.0000	0.00000000E+00	0.00000000E+00
X0019B	X0166B	0.00000000E+00	0.00000000E+00	0.00000000E+00	0.0000	0.00000000E+00	0.00000000E+00
X0019C	X0166C	0.00000000E+00	0.00000000E+00	0.00000000E+00	0.0000	0.00000000E+00	0.00000000E+00
XX0075	XX0134	4.48755180E+02	-7.70288467E+01	4.55318190E+02	-9.7399	1.03189293E+08	-7.38584724E+06
X0031A	XX0024	0.00000000E+00	0.00000000E+00	0.00000000E+00	0.0000	0.00000000E+00	0.00000000E+00
X0031B	XX0024	0.00000000E+00	0.00000000E+00	0.00000000E+00	0.0000	0.00000000E+00	0.00000000E+00
X0031C	XX0024	0.00000000E+00	0.00000000E+00	0.00000000E+00	0.0000	0.00000000E+00	0.00000000E+00
XX0008	XX0116	-1.47079469E+04	3.62214355E+03	1.51473967E+04	166.1650	-3.44165441E+09	-6.48736572E+04
XX0015	XX0138	-1.47079469E+04	3.62214355E+03	1.51473967E+04	166.1650	-3.44165441E+09	-6.48736572E+04
XX0007	XX0008	Open	Open	Open	Open	Open	Open

Solution at nodes with known voltage. Nodes that are shorted together by switches are shown as a group of names, with the printed result applying to the composite group. The entry "MVA" is SQRT(P**2 + Q**2) in units of power, while "P.F." is the associated power factor.

```
      Node        Source node voltage         Injected source current          Injected source power
      name      Rectangular        Polar      Rectangular         Polar        P and Q   MVA and P.F.

      XX0156       500000.       500000.   31262.289243348 32134.896758444    .78155723108E10 .80337241896E10
              0.0          0.0   -7437.799469003   -13.3827799   .18594498673E10      0.9728455

      X0019A
      X0166A
      X0164A       500000.       500000.          0.0          0.0          0.0          0.0
              0.0          0.0          0.0          0.0          0.0          0.0

      XX0024
      X0031C
      X0031B
      X0031A
      XX0174
      XX0106       500000.       500000.   15631.144621674 16067.448379222    .39077861554E10 .40168620948E10
              0.0          0.0   -3718.899734502   -13.3827799   .929724933625E9      0.9728455
```

Card of names for time-step loop output. |
XX0014XX0156XX0027XX0027XX0027XX0031XX0030XX0075XX0044XX0138XX0116X0019AXX0024

Card of names for time-step loop output. | XX0007XX0007XX0110
Blank card ending requests for output variables. |BLANK OUTPUT

Column headings for the 22 EMTP output variables follow. These are divided among the 5 possible classes as follows ....
First 16 output variables are electric-network voltage differences (upper voltage minus lower voltage);
Next 6 output variables are branch currents (flowing from the upper node to the lower node);
Step Time XX0014 XX0156 XX0027 XX0027 XX0027 XX0031 XX0030 XX0075 XX0044 XX0138

XX0116 X0019A XX0024 XX0007 XX0007 XX0110 X0164A XX0024 XX0075 X0019A
X0019A XX0106 XX0140 X0166A

XX0075 X0031A
XX0134 XX0024
0 0.0 147080.152 500000. 440472.003 440472.003 440472.003 440501.226 440472.003 441240.457 440472.003 441240.457
441240.457 500000. 500000. 147080.152 147080.152 147080.152 0.0 15631.1446 -15156.702 0.0
448.75518 0.0

Done dumping plot points to C-like disk file.
200 0.1 147031.082 500000. 504091.685 504091.685 504091.685 440352.462 440323.073 441093.224 440323.095
441093.246
423716.305 500000. 500000. 141287.441 141287.441 147031.075 -.005 15015.7393 -15151.696 .005
448.652837 -.005

Extrema of output variables follow. Order and column positioning are the same as for the preceding time-step loop output.
Variable maxima : 151442.859 500000. .1901582E7 .1901582E7 .1901582E7 454013.767 453981.268 454328.561 453981.283
454328.576
.2011455E7 500000. 500000. 206529.472 206529.472 151442.854 .005 21123.4598 15598.0573 .005
455.222787 .005
Times of maxima : .084 0.0 .0495 .0495 .0495 .034 .084 .084 .084 .084
.0495 0.0 0.0 .049 .049 .084 .025 .049 .009 .05
.5E-3 .025
Variable minima : -151442.86 -500000. -604231.18 -604231.18 -604231.18 -454013.77 -453981.27 -454328.56 -453981.28 -
454328.58
-467443.78 -500000. -500000. -341270.52 -341270.52 -151442.85 -.005 -34809.863 -15598.057 -.005
-455.17799 -.005
Times of minima : .009 .025 .0925 .0925 .0925 .059 .059 .009 .059 .009
.092 .025 .025 .0435 .0435 .009 .05 .0435 .084 .025
.0255 .05

Blank card terminating all plot cards. |BLANK PLOT

Memory storage figures for the preceding, now-completed data case. ------------------------------ Present Program
A value of "-9999" indicates that no figure is available. 07-May-07 18:52:37 figure limit (name)
Size List 1. Number of electric network nodes. 37 6000 (LBUS)
Size List 2. Number of electric network branches. 27 10000 (LBRNCH)
Size List 3. Number of data values in R, L, C tables. 27 192000 (LDATA)
Size List 4. Number of electric network sources. 3 900 (LEXCT)
Size List 5. Storage for [Y] and triangularized [Y]. No. times = 6 Factors = 44 108 420000 (LYMAT)
Size List 6. Number of entries in switch table. No. flops = 22 17 1200 (LSWTCH)
Size List 7. Number of distinct ALPHANUMERIC data names plus program SPY variables. 11 15000 (LSIZE7)
Size List 8. History points of distributed lines. 0 120000 (LPAST)
Size List 9. Number of nonlinear elements. 0 2250 (LNONL)
Size List 10. Points of nonlinear characteristics. 0 3800 (LCHAR)
Size List 11. Number of Type-59 S.M. outputs. 0 720 (LSMOUT)
Size List 12. Total number of EMTP output variables. 22 1200 (LSIZ12)
Size List 13. Working space for batch/SPY plotting. -9999 72800 (LSIZ13)
Size List 14. S.M./U.M. connections to TACS. -9999 510 (LBSTAC)
Size List 15. Character storage in bytes for MODELS. 2583 90000 (LCTACS)
Size List 16. Total number of Type-59 S.M. masses. 0 800 (LIMASS)
Size List 17. Number of Type-59 Synchronous machines. 0 90 (LSYN)
Size List 18. Branch and switch power/energy outputs. 0 254 (MAXPE)
Size List 19. Total floating-point TACS table space. 23 120000 (LTACST)
Size List 20. Non-copied recursive convolution data. 0 100000 (LFSEM)
Size List 21. Total modal/phase [T] matrix storage. 0 3000 (LFD)
Size List 22. Total recursive convolution history. 0 15000 (LHIST)
Size List 23. Giant vectors for renumbering, phasors. 66 192000 (LSIZ23)
Size List 24. Peak phases of compensation for data. 0 120 (LCOMP)
Size List 25. Total table space for all U.M usage. -9999 30000 (LSPCUM)
Size List 26. Square of max number of coupled phases. 1 160000 (LSIZ26)
Size List 28. MODELS. Total work space is divided into INTEGER and REAL. 1st, REAL: 1748 210000 (LRTACS)

```
                Second and last, statistics for INTEGER work space.          5594       0 (LITACS)
   Size List 29. RAM disk used by "TAPSAV" table saving (limit is "LABCOM" size LTLABL).    -9999     300 (LSIZ29)
   Size List 30. Taku Noda frequency-dependent circuits.                            0      19 (LSIZ30)
Timing figures characterizing central processor (CP) solution speed. --------------------------- CP sec  Wait sec  Real sec
   Data input time (through blank card ending branches) ....                    0.016    0.000    0.016
   Node renumbering and phasor solution ....                                  0.000    0.000    0.000
   After phasor solution, but before time-step loop ....                       0.000    0.000    0.000
   Integration of equations (time-step loop) ....                           0.016    0.000    0.016
   Plotting or STATISTICS termination overlays ....                              0.000    0.000    0.000
                                                          ---------------------------
                                                 Totals    0.031    0.000    0.031
```