DESIGN CHARACTERISTICS OF AN ADVANCED TWO-TERMINAL DIGITAL SIMULATOR FOR RELAY TESTING

M. Kezunovic, A. Gopalakrishnan, J. Domaszewicz, Q. Chen, F. Ji[1], X. Qi, I. Rikalo
Texas A&M University

C.W.Fromen, D.R.Sevcik
Houston Lighting & Power

S.M.McKenna
Western Area Power Administration

M.Hammam
Electric Power Research Institute

U.S.A

Abstract—This paper gives a description of the hardware and software features of a digital simulator designed for relay testing . The simulator is designed using a high performance IBM RISC 6000 workstation and supports two terminal back-to-back testing of protective relay systems. Software features include: Graphical user interface (GUI) for the EMTP solver ; Signal processing and relay testing ; Automated analysis of test results ; Data base management ; and the Test File Replay support. All the software modules are developed in an X-windows/ Motif based environment under the AIX operating system.

Keywords: Digital Simulator , Protective Relay Testing , Hardware , Software, EMTP, MATLAB

INTRODUCTION

Initial development of digital simulators for relay testing dates back to early 1980s [1]. Since that time , several digital simulators have been developed and used as a part of various utility [2-4] and industry sponsored [5-8] projects.

This paper describes some major characteristics of the hardware and software design of a digital simulator for relay testing being presently developed at Texas A&M University under sponsorship of the Electric Power Research Institute (EPRI), Houston Lighting & Power Company (HL&P) and the Department of Energy—Western Area Power Administration (WAPA). The project was initiated in late 1989 and has resulted in several modeling and simulation studies, as well as simulator hardware and software designs [7-12]. The project is due for completion in September of 1995. The simulator discussed in this paper is going to be installed for beta-site testing at WAPA in the Spring of 1995. This simulator has been extensively evaluated at Texas A&M University, with the close cooperation of HL&P and WAPA.

The first part of the paper is devoted to a brief description of the simulator requirements . The second part of the paper gives some details of the simulator hardware and application software.

This paper has been presented at the First International Conference on Digital Power System Simulators - ICDS '95, College Station, Texas, U.S.A., April 5-7, 1995.

SIMULATOR REQUIREMENTS

The main hardware requirements were defined as follows:

- Simulator implementation should be based on high performance workstation computer hardware.
- Simulator design should be based as much as possible on commercial hardware available off the shelf.
- Simulator I/O subsystem should be developed with high precision , high power features.
- Outputs on both simulator test terminals should be synchronized by the same clock.

The main application software requirements were defined as follows:

- Simulator should have extensive graphical user interface (GUI) features.
- Extensive signal processing capability should available for test waveform analysis, editing and replaying for relay testing purposes.
- A software module for automated analysis of relay test results should be available.
- A comprehensive data base management scheme should be provided to store test waveforms as well as intermediate results of other software modules.

[1]The work has been done while the author was with Texas A&M University

- Relay test software should support a two terminal waveform replay feature for back to back testing of protective relaying systems.
- Commercially available application software packages for signal processing and database management should be used to expedite developments.

The system software requirements were defined as follows:

- UNIX (AIX) operating system software should be used for support of the multi-tasking operation.
- X windows / Motif graphical tools should be used for development of graphical user interfaces for various application software modules.
- The programming language "C" should be used as much as possible to assure easy handling of upgrades and portability.

HARDWARE IMPLEMENTATION

The two terminal simulator architecture is shown in Figure 1.

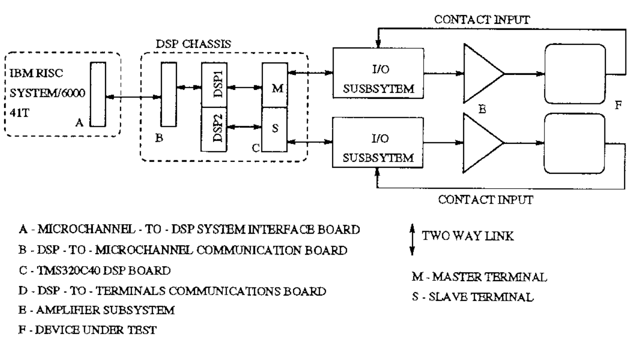

Figure 1: Two Terminal Simulator Architecture

The host computer (IBM RISC System/6000, Model 41T) generates the transient data file to be replayed to the device under test. After the user requests a file replay, the file is transferred to the DSPs via the Micro Channel - DSP System Interface Board (inside the RISC) and the DSP - Micro Channel Communication Board (inside the DSP chassis).

The DSP subsystem contains two TMS 320C40 DSPs. DSP1 is responsible for communicating with the RISC, and replaying waveforms on I/O Terminal 1, (Master Terminal). DSP2 is responsible for replaying waveforms on I/O Terminal 2, (Slave Terminal).

Digital replay information from the DSPs is converted to serial data and transferred to the I/O subsystem by the DSP - to - Terminals Communication Board.

The I/O subsystem is divided into a communication interface to receive/send serial data from/to the DSP subsystem, a D/A subsystem for reconstructing the analog signals, a digital I/O subsystem to monitor contact status changes of the device under test and a hardware mechanism for clock synchronization between the Master and Slave I/O terminals. Clock Synchronization between the two terminals is achieved by using Phase Locked Loop ICs, which tie the Slave Terminal clock to the Master Terminal clock.

The I/O subsystem and the amplifier subsystem are packaged into a custom designed cabinet.

SOFTWARE IMPLEMENTATION

The simulator software consists of several modules as follows:

- Graphical User Interface (GUI) for EMTP Solver
- Signal Processing and Relay Testing (SPRT)
- Automated Analysis of Test Results (AATR)
- Data Base Management (DBM)
- File Replaying Support (FRS)

All of the software modules are developed in an X-Windows / Motif based environment under the AIX operating system.

GUI for EMTP Solver

This software module is aimed at providing a friendly graphical environment for users to edit power system network models and to generate transient waveform signals for relay testing using the well-known Electromagnetic Transient Program (EMTP) [13]. The GUI provides data for each network component as required by preparing their EMTP cards. Most of the laborious tasks are therefore hidden from the user and taken care of by the GUI software internally.

The main modules of the GUI software are depicted in Figure 2. The relationship of the GUI to the EMTP solver and its auxiliary programs is also shown in the Figure 2.

In the data preparation stage, the user can load and view previously created network models, modify them, or create new ones. Whenever a new model is created, or an existing model modified, it is automatically checked for completeness and correctness. After a successful check, the model is converted to the standard EMTP format and the EMTP solver can be started, i.e., activated to produce the desired output waveforms. Because the EMTP calculations can be time consuming, the EMTP is activated in batch mode and the control is returned to the GUI layer without waiting for the calculations to be completed. In the mean time, the user is able to perform other GUI tasks. When the EMTP calculations have been completed, the user will be prompted by a message about the state of the process. The EMTP auxiliary programs are invoked by the user as necessary for some network components to compute their parameters, e.g. Line Constant auxiliary routine for transmission lines, etc.

The GUI software integrates with the System Database for the storage of input and output files including: graphical representation or GUI format file, EMTP input file, EMTP output waveform file, as well as fault set-up file for the purpose of fault analysis. For the user's convenience, display functions are available from inside the GUI software. The user is able to view and edit each file either in text form or in the graphical format through the MATLAB facility [14].

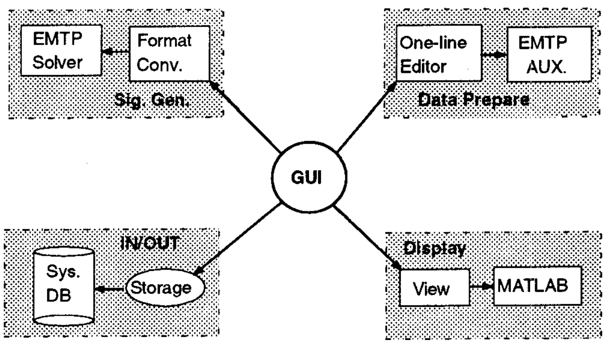

Figure 2. GUI for EMTP Solver

Signal Processing and Relay Testing

The signal processing and relay testing (SPRT) software is capable of performing data conversion , signal processing , signal analysis, relay testing and graphical user interface functions.

Data conversion is needed for both Digital Fault Recorder (DFR) and EMTP files. DFR files from different type of recorders usually have different formats. A similar situation is present with EMTP output files where they may be either binary or ASCII and may have a unique format. In SPRT, the IEEE standard common format for transient data exchange (COMTRADE) is chosen as the common data format for signal manipulating [15]. All the transient data with other formats is first converted to COMTRADE.

Signal Processing is required if test signal properties have to be altered or various parameters have to be determined. A typical need for signal processing appears when the sensitivity of relays to various signal characteristics is to be tested. Signal filtering , change of signal length, and various scaling operations are examples of the useful signal processing operations.

Signal Analysis in the time and frequency domains is essential since fault transients have significant frequency content across the spectrum. Since relay designs may be sensitive to a given signal component , it is important to have means of analyzing the signal in order to determine its properties.

Operator Interface provides the user a GUI to access all the SPRT functions and invoke the database management system.

Relay Testing is one of the most important requirements since it includes functions for performing relay test , test result viewing, and R-X diagram plotting. The R-X diagram software module calculates and plots, in case of distance relay testing, the impedance trajectory using the voltage and current transient waveforms. The R-X plane is used to represent the calculated trajectory versus relay settings to evaluate relay performance.

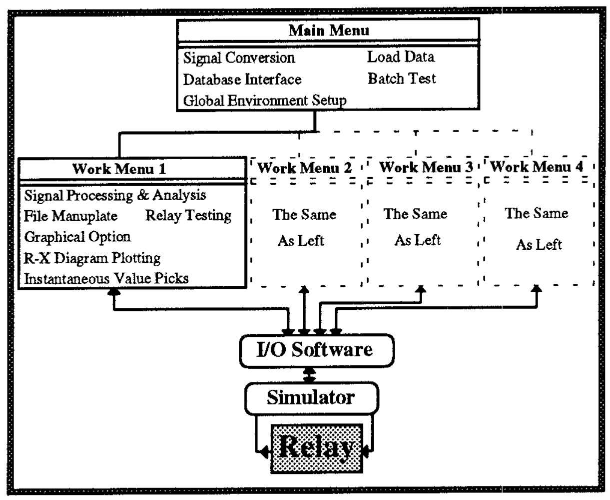

Figure 3. SPRT Organization

The SPRT menus can be divided into several levels. Figure 3 shows the hierarchical organization. As illustrated in Figure 3, most of the functions are integrated in one of the two GUI Menus: main menu or work menu.

The Main Menu GUI is an integrated environment to access the following functions: data loading and conversion , software global environment setup , database interface and batch relay test functions.

The Work Menu GUI is activated every time a file is loaded. In SPRT, up to four data files can be loaded, therefore, the maximum number of work menus is equal to four. Most of the signal processing, signal analysis and relay testing functions are accessed from the work menu GUI.

Automated Analysis of Test Results

The automated analysis of test results (AATR) is a tool that helps the operator (or user) in evaluating the relay performance for a given set of test runs. The number of test runs during a relay testing may be very large, which makes the task of sorting the results and making a summary reports tedious if done manually. The block diagram for the AATR module is shown in Figure 4.

Fault Set-Up File is used to specify the fault characteristics and to determine expected operation of the relay under a simulated fault.

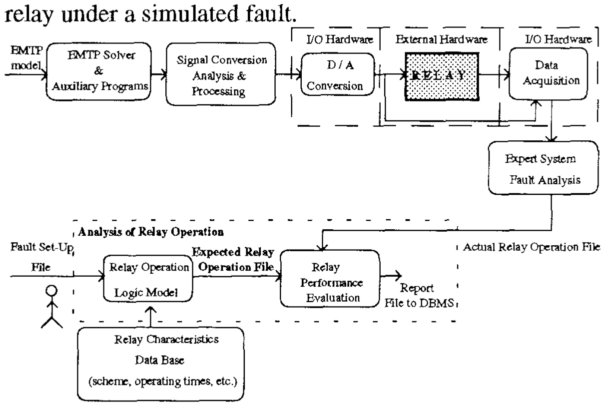

Figure 4. Block Diagram of the AATR Module

Analysis of Relay Operation is designed to help the operator decide if a given relay is operating as expected under the test conditions. An operator generates a fault scenario ahead of the actual testing session. The fault scenario is stored in Fault Set-Up File and contains the following information:

- name of the disturbed (faulted) circuit
- fault type
- fault location
- fault incidence angle
- fault resistance

Table I. Relay Performance Evaluation Logic

Relay Misoperation
Trips when not supposed to
Fails to trip when supposed to
Trips the wrong phase(s)
Recloses when not supposed to
Fails to reclose when supposed to
Expected tone(s) not sent
Relay Operates Too Slowly
Does not trip instantaneously for zone 1 fault
Does not trip within specified time for zone 2 fault
Actual reclose time exceeds expected reclose time by 10%
Tone transmission time exceeds threshold
Relay Target Failure
Target indicates wrong phase
Target indicates wrong zone

The purpose of the Relay Operation Logic Model is to determine the expected zone, expected tone(s) sent, expected phase(s) tripped, expected trip time, and expected reclosure.

The expected operation of the relay is determined from the relay operation logic model. This is compared with the actual operation of the relay based on the Actual Relay Operation File (captured by the simulator I/O hardware). The knowledge embedded in the Relay Performance Evaluation module is given in Table I.

These modules generate a report, based on the relay performance during testing, and pass that report to the Data Base Management System (DBMS).

Data Base Management

The digital simulator for protective relay testing is a complex system which involves the large volume of data which are produced during simulation and relay testing. These data have complex structures and are either formatted or unformatted.

The database management for digital simulator application is implemented using the Relational Information Management (RIM) database system. An overview of the implementation is shown in Figure 5.

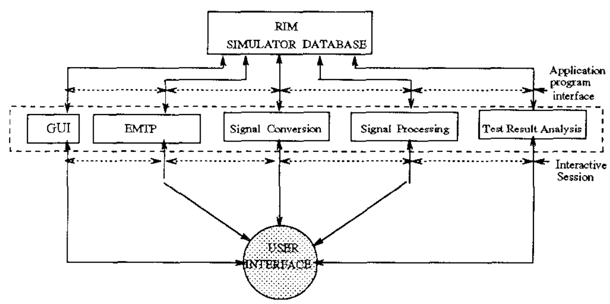

Figure 5. Overview of the DBM Implementation

The first step of implementation is the design of the database and tables for the GUI, EMTP, Signal Processing and Test Result Analysis using RIM. All other subsystems of the simulator interact with the database through an application program written in C , and user interface written in X/Motif. The application program interface is used to access the database and to perform basic database functions (store, retrieve, delete, update). It is also used to provide several other database functions, such as backup and restore , which are used to prevent accidental loss of data in the database. The user interface resides at the uppermost level of the database system. Its prime concern is to place the entire functionality of the database management at the disposal of the user. It provides the user graphical elements to facilitate the access of the database and execution of the database functions.

All functions of the database are grouped and can be accessed through pull down menus and push buttons. The hierarchical structure of the database user interface is shown in Figure 6. Its interface functions are classified into File, Display, Tool and Help functions. The main menu of the user interface will appear when a user invokes the software.

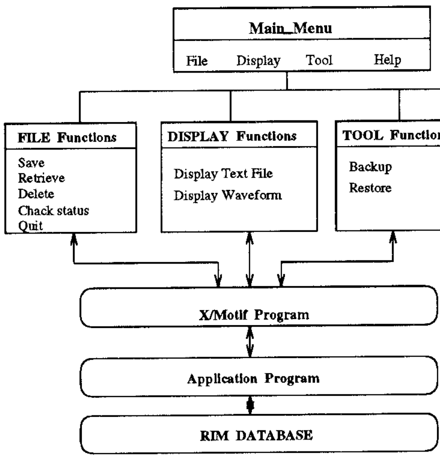

Figure 6. Database User Interface Hierarchical Organization

File Replay Support

The replaying software enables replaying waveforms generated by the software modules and collection of the relay response data. The software is composed of two major modules: the host (RISC) module and the DSP module.

The host module reads the waveforms from disk files , makes the necessary conversions to the format of D/A's, and downloads the waveforms to the local memory of the DSP subsystem prior to actual replaying. After the replaying, it uploads the relay response data from the DSP subsystem.

The DSP module, which is executed by two TMS320C40 Digital Signal Processors, downloads the waveforms to local DSP memory, programs the replaying hardware to generate a correct sampling frequency, does the actual waveform replaying and recording of the relay response data . Finally, it uploads the relay response data to the host. The relay response data are stored in disk files to be analyzed by other modules of the simulator software.

The replaying software supports a number of hardware configurations; there may be one or two cabinets, each hosting three or four voltage and current channels. The user specifies a configuration to the host module with command line options. For efficiency, there are four customized versions of the DSP module. A proper version is downloaded to the DSP subsystem prior to a replaying session.

The replaying software accepts waveforms stored in three different formats: MATLAB binary, MATLAB ASCII, and COMTRADE ASCII. The replaying software makes possible some simple manipulations of the waveforms. It is possible to partition a waveform into two segments: the prefault one and the postfault one. Replaying of each segment can then be repeated a number of times. The number of repetitions of the prefault segment may be different from the number of repetitions of the postfault segment. The segments are replayed continuously and appear as a single waveform. Also, it is possible to replay only a fragment of the waveform stored in a disk file.

CONCLUSIONS

As a result of the presented digital simulator characteristics, the following can be concluded:

- Application requirements can be met by using a multi-user, multi-tasking environment supported by a high performance RISC workstation.
- Software implementation needs to provide extensive graphical user interface that requires high performance X-Window environment with powerful tools such as Motif.
- Application needs for protective relay testing require operator support for GUI interface to EMTP, signal processing and analysis, automated analysis of test results, database management, and replay of test files.

ACKNOWLEDGMENTS

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Mladen Kezunovic (S'77, M'80, SM'85) received his Dipl. Ing. degree in electrical engineering in 1974, and the MS. and Ph.D. degree from the University of Kansas, in electrical engineering in 1977 and 1980 respectively. His industrial experience is with Westinghouse Electric Corporation in the U.S.A., and the Energoinvest Company in Sarajevo. His academic experience is with the University of Sarajevo and Washington State University. He has been with Texas A&M University since 1987 where he is an Associate Professor. He is member of the IEEE Power Systems Relaying Committee (PSRC) , member of CIGRE and a registered Professional Engineer in the State of Texas. Dr. Kezunovic is the chairman of the PSRC working group F-8 on " Digital Simulator Performance Requirements".

A. Gopalakrishnan received his B.E. in Electrical and Electronics Engg. from BITS, Pilani, India in 1989. From 1989 to 1992, he was with The English Electric Co. of India Ltd., in Madras India. Mr. Gopalakrishnan is currently a graduate student in the EE department at TAMU.

J. Domaszewicz (S'89) earned his M.Sc.E.E. degree from Warsaw Technical University, Poland, in 1986. From 1986 to 1989 he was with the Department of Electronics at Warsaw Technical University. Mr. Domaszewicz is currently a graduate student at Texas A&M University.

Qinghua Chen received his BS. and MS. degrees in Electrical Engineering from Tsinghua University, Beijing, China in 1990 and 1993 respectively. He is currently a graduate student in the department of Electrical Engineering at Texas A&M University.

Fang Ji received her BS. and MS. degrees in electrical engineering from Tianjin University, Tianjin, China in 1985 and 1988 respectively. Ms Ji had been employed with Tianjin University from 1988 to 1991 as a teaching and research assistant. In 1994 she received MS. degree in electrical engineering from Texas A&M University. Currently she is with the Texas Instruments in Houston.

Xiaoxia Qi received her BS. and MS. degrees in Electrical Engineering from Southeast University, Nanjing, China in 1985 and 1988 respectively. From 1988 to 1991, She was with Nanjing Electrical Device Institute. She is currently a graduate student in the department of Electrical Engineering at Texas A&M University.

Igor Rikalo received his Dipl. Ing. degree from the University of Sarajevo, Bosnia and Herzegovina, and MSc degree from Texas A&M University, all in electrical engineering in 1992, and 1994, respectively. Currently, he is working for TLI, Inc. as a systems engineer and for Texas A&M University as a research engineer. His main interests are in the area of intelligent system applications to power systems.

Charles W. Fromen (M'68, SM'85) received his B.Sc. degree in Electrical Engineering from Texas A&M University in 1968. He joined Houston Lighting & Power Company upon graduation. Since 1984, he has held the title of Senior Consulting Engineer. Mr. Fromen has been the HL&P Company representative to the IEEE Power Systems Relaying Committee since 1973 and is a member of that committee. He is a registered Professional Engineer in the State of Texas.

Donald R. Sevick (M'81) received his B.Sc. in Electrical Engineering from Texas A&M University in 1975. He was employed by Houston Lighting & Power Company in 1975 and is currently a Lead Engineer. He has worked in the following areas: Power Plant Electrical System (1975 to 1977), System Studies (1977 to 1979), and Transmission and Generation Protection (1979 to present). He is a registered Professional Engineer in the State of Texas.

S. M. McKenna was born in Spokane, Washington in 1951. He earned his B.S. Degree from the Colorado School of Mines in 1978. Mr. McKenna joined the Western Area Power Administration (Western) in September 1980. Mr. McKenna is currently in the Substation Control Branch where he is involved in control system design for advanced technology devices, protective relaying application and testing, and power system testing. Mr. McKenna is a Registered Professional Engineer in Colorado.

M. Hammam is a Project Manager at EPRI responsible for the Protective Relay Workstation Project. Ms. Hammam has been with EPRI since the Fall of 1993.