A MODULAR DIGITAL SIMULATOR DESIGN FOR OPEN–LOOP AND REAL–TIME APPLICATIONS

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Abstract: This paper introduces a new concept of a modular digital simulator design for testing protective relays. A brief discussion of the relay testing requirements leads to the need for the modular design. The basic features of the modular design are outlined. Several digital simulator implementation approaches are presented and their characteristics described. The benefits of such a modular design concept are summarized at the end.

Keywords: Digital Simulator, Protective Relay, Protective Relay Testing, EMTP, Power System Modeling

INTRODUCTION

Digital power system simulators for protective relay testing were introduced as a concept in the late seventies with the first designs made available in the early eighties [1]. Since that time, a variety of different digital simulator solutions have been implemented and used by the utilities [2–4], universities [5–8], and the relay vendors [9]. It is interesting to note that all of the designs had quite different implementation approaches and performance characteristics. In particular, the selection of the simulation computer, transient simulation program, and I/O subsystem made these designs uniquely distinct with no apparent similarity or compatibility. This situation has probably occurred in part due to the difference in the initial design requirements, and in part, due to the variety of options available for simulator hardware and software component selections.

This paper presents a new concept of a modular digital simulator design where a variety of hardware and software modules have been developed and used to configure different simulator solutions. This enables a flexible implementation approach aimed at meeting specific needs for relay testing and simulator upgrading. This approach also provides a choice between the low and high cost simulator design options depending on the performance and application requirements.

The first part of the paper gives discussion of the relay testing requirements leading to classification of the categories of the simulator users. The basic concept of the modular simulator design is presented next. An illustration of various simulator implementation approaches made possible due to the modular design is also provided. The future needs and benefits are outlined at the end.

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RELAY TESTING REQUIREMENTS

An analysis of the relay testing requirements indicates three major categories:

- User Type (goal)
- Relay Type (design)
- Study Type (methodology)

The user type is the most difficult category to define since it may vary from one organization to another. However, the main difference is if the user comes from the relay vendor, utility or university environment. In this case, the goals for relay testing may be quite different, spanning from extensive evaluation of the relay designs undertaken by the vendors, to the application evaluations done by the utilities, and investigation of the relaying principles undertaken by the universities. Depending on the goals, a general classification of the user requirements can be summarized as follows:

The Single User – An assumption is that the single user will execute each task separately, one at a time.

The Multiple Users/Tasks – In this mode, different tasks may be invoked by different users, and yet, all can be related to the use of the same simulator.

The Preparation of Test Cases – This may require a highly qualified user, and extensive graphical capabilities may be needed to facilitate the process of creating a large number of test cases.

The Execution of Tests – The user has the test files made available in a file system, and he only needs to concentrate on an efficient way of performing tests and storing results.

The Analysis of Test Results – The user needs to access the results in a convenient manner, and has to have appropriate tools to analyze both the relay responses and corresponding disturbance waveforms.

The relay type determines several major requirements placed on the simulator I/O subsystem performance and configuration. This is, in particular, related to relay design characteristics including the relay burden (technology), number and type of inputs and outputs, and relaying scheme. As a result, the requirements can be defined as given in Table I.

Table I. The Relay Type Requirements

Requirement	Description
Relay Burden	• value (fraction of an ohm to several ohms) • behavior (linear, nonlinear) • property (capacitive, resistive, inductive)
Relay Inputs	• number (one to several) • type (voltage, current, contacts, polarized quantities) • length (fraction of a cycle to several hundreds of cycles)
Relay Outputs	• number (from one to several) • type (trip contacts, targets, user messages)
Relaying Schemes	• number of relays involved (one to several) • type (direct local measurement, differential local or remote) • interaction (direct connection, communication channels)

The study type is also quite difficult to define due to the lack of common practice or standards. However, it is well recognized that a study of either the relay design or application can be a target. In any case, a variety of requirements can be defined as given in Figure 1.

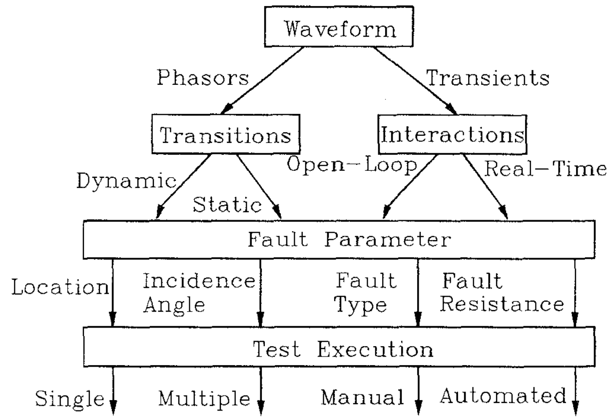

Figure 1. The Study Type Requirements

MODULAR SIMULATOR DESIGN

In order to meet the variety of the requirements, a modular simulator design may be needed. This idea is quite attractive if a single vendor wants to provide an array of products that are aimed at meeting different requirements. The modular concept is also important if compatibility between different designs is to be considered, since some modules can be used with a number of different designs. Finally, future upgrades of a given design may benefit from the fact that only certain modules need to be replaced to move from one level of design complexity to the next. Last, but not least, the modularity also implies great flexibility in configuring and pricing a simulator product. This may give the user the desired flexibility in selecting a design that is affordable, and yet meets the user's requirements in the most suitable way.

Discussion given in this section is kept rather generic in order to illustrate the options and possibilities. However, the background information is based on an actual simulator design described in several recent publications [10,11].

Hardware Modules

A generic block diagram of the simulator hardware architecture is given in Figure 2.

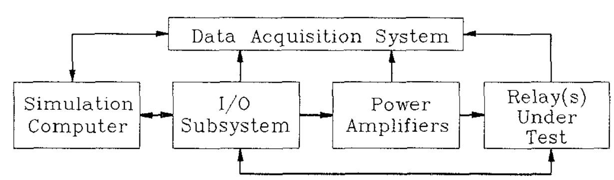

Figure 2. Simulator Hardware Architecture

The simulation computer can vary from a PC design to a high performance workstation, and a multiprocessor system. Obviously, the main difference is in the computing power, memory capacity, I/O capabilities, operating system support, and application software support. The main goal of the modularity is to provide a variety of computer platforms that are capable of meeting the major criteria, including cost options, ease of upgrading, and wide performance requirements. A detailed analysis of this issue leads to a conclusion that selection of a commercially available platform, rather than a custom design one, would meet all of the requirements in a cost effective way.

The choice of the TAMU modular design allows for the use of either an IBM compatible PC or an IBM RISC 6000 machine. It is interesting to note that this choice allows for simulator implementations ranging from low cost single user configurations, to multiple user environments for open–loop testing of relaying schemes, and the real–time application option.

The I/O subsystem solution may greatly vary in its complexity depending on the simulator performance requirements. However, some basic characteristics are highly desirable. They include: 16–bit D/A conversion, double buffering capability, high data transfer rate, support of a variety of output waveform sampling frequencies, bidirectional data transfer, sufficient number of I/O channels, synchronization among data channels, standard interface towards power amplifiers, standard interface towards simulation computer. Obviously, an I/O subsystem design with the desired characteristics is not commercially available, and it is understandable that each simulator may have a different solution. However, it is expected that the solution is flexible enough to allow for a common design to be used for a variety of simulator configurations.

The TAMU design of the I/O subsystem is based around a commercial DSP board that servers as a common interface to any of the selected simulation computers. The DSP board can be programmed to support a number of options such as: single, two and three terminal operation; open–loop or real–time mode; inclusion of instrument transformer and circuit breaker models; single or batch replaying of the test waveforms. The DSP board(s) subsystem is connected by a fast serial data link to the custom I/O boards for analog waveform and contact interfacing.

The power amplifiers are relatively easy to find on the commercial market. However, each of the designs needs to be carefully evaluated in order to assess its performance for a given application.

The amplifiers used in the TAMU design are either an in–house design (voltage amplifiers) or a commercial product (TECHRON 7780 and 3600 series) of current and voltage amplifiers.

The data acquisition system is extremely important for the proper use of the simulators. However, this system is considered an outside item that can either be custom designed or a commercial solution.

Software Modules

A generic block diagram of the simulator software architecture is given in Figure 3.

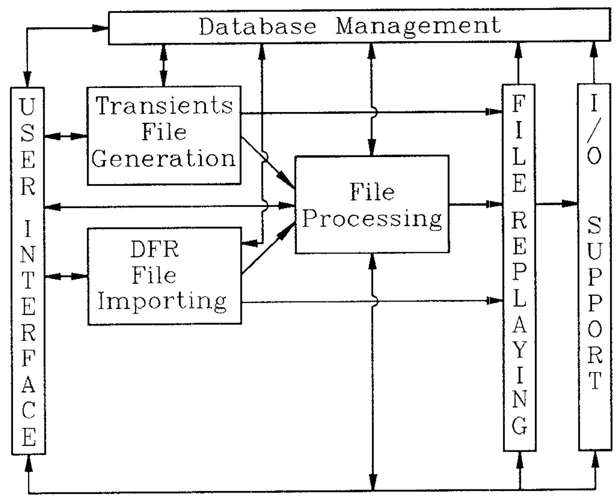

Figure 3. Simulator Software Architecture

The user interface module needs to support a variety of functions such as: simulation; initiation and interaction with other modules; import of the Digital Fault Recorder (DFR) files; selection and control of the file processing functions; interface with file replaying, storing, and I/O supporting modules.

The choice of the user interfaces in the TAMU simulator design consists of several modules including: Graphical User Interface (GUI) for the transient programs, dedicated user interface for signal processing and analysis, system user interface for database management, and other supporting functions.

The transients file generation may consist of several different electromagnetic transient programs that are commercially available. In addition, some custom designed programs may be required for the real–time interaction. Typical choice of the commercial programs includes: EMTP (EPRI, BPA), ATP (American–Canadian–European User's Groups), EMTDC (Manitoba Hydro), MORGAT (EdF), MICROTRAN (UBC).

The choice of the transient programs in the

TAMU design is quite wide. Almost any of the commercial packages can be supported. A custom program has been developed for the real–time applications. A common GUI for both EMTP and Real–Time System (RTS) modules is implemented to allow for transparent use of these programs by the users.

The DFR file replaying module should be capable of supporting the standard common format for transient data exchange (COMTRADE). This allows for replaying of data files coming from virtually any digital fault recorder (DFR) presently on the market. The TAMU design supports COMTRADE file formats [12].

The file processing module is needed to perform both the analysis and editing of test waveforms and contacts. The easiest way to implement this module is to use a commercially available signal processing package.

The TAMU design supports the MATLAB signal processing package [13]. This package is widely used and it is available on virtually all standard computer platforms.

The database management may be implemented using a simple file system or an elaborate database scheme. A variety of commercial packages that can be used exist on the market. The main problem is to interface the simulator application software to the commercial packages.

A publicly available Relational Information Management (RIM) database is used in the TAMU design [14].

The other software modules are usually custom designed and need to be developed for each of the simulators to fit different I/O requirements. However, this software may not be difficult to develop if a standard hardware is used for I/O interfacing.

The TAMU design has a set of DSP programs that are downloaded to the DSP based I/O subsystem to enable configuring of the appropriate simulator application. Incidentally, the TAMU design allows for creation of models of instrument transformers and circuit breaker logic that can be located and executed on the DSP board. This is resembling the physical location and separation of these components in the power system.

IMPLEMENTATION APPROACHES

This section gives some examples of the possible simulator implementation approaches. The examples are based on the use of the modules available in the TAMU designs. Each of the implementation approaches discussed here has been developed per the customer's specifications into a particular simulator configuration.

PC–Based Simulator

This simulator utilizes a low cost hardware solution for the simulation computer. The hardware is shown in Figure 4 [15].

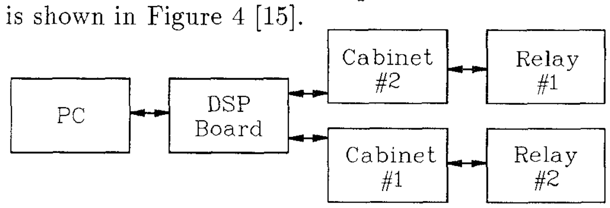

Figure 4. PC–Based Simulator Hardware

As can be seen, it supports up to two terminals (cabinets). Each cabinet contains up to four current and four voltage channels. The I/O circuitry is also packaged in the cabinets. The I/O subsystem enables collection of the trip signals as well. They are passed to the PC for the relay operation analysis. A low cost DSP board is used when only a single terminal testing is to be implemented, while a more expensive DSP board, with two DSP chips, is used for the two terminal configuration. The cabinet designs, including the I/O boards are the same for all the simulators. The only difference may be in the amplifiers, which can be selected to meet various output power requirements.

The software modules are shown in Figure 5 [15].

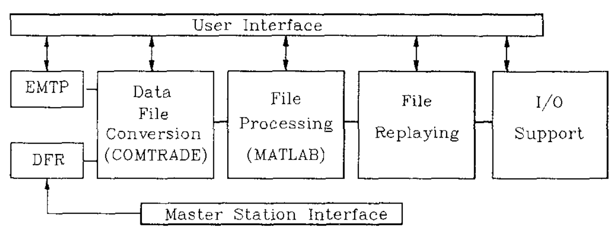

Figure 5. PC–Based Simulator Software

The user interface is written using the MATLAB shell. This simulator enables the use of either EMTP or DFR generated data files. An elaborate signal processing and analysis set–up is provided for viewing, filtering, and editing of the test signals. This simulator has been extensively used for several relaying studies so far [16–18].

RISC–Based Simulator

This simulator uses most of the modules developed for the PC–based simulator [19]. The only differences are as follows:

- The IBM RISC machine (RISC 6000/320, 340, 41T, or 250) was selected due to its powerful multi-user multi-tasking operating system (AIX)

- The hardware modules include the same I/O cabinet design and the same DSP board with two DSP chips as used in the PC-based simulator. The main differences are some additional I/O boards aimed at interfacing the RISC computer to the DSP chassis and the DSP chassis to the I/O cabinets.
- The software modules are very similar for the file processing function since the MATLAB package is used. This software version has some additional signal analysis functions. A more elaborate user interface is provided for both the EMTP solver [20] and the MATLAB shell [19]. The system support software for the replaying and I/O support is similar to the one used for the PC-based simulator.

RISC-Based Real-Time Simulator

This version of the simulator has been developed for testing relays in real-time [21]. The simulator generates fault signals and passes them as they are generated on to the relays. Any trip signal generated by the relays will alter the computation matrices in real-time and the next iteration of the transients computation will be based on the new power system configuration.

This simulator uses exactly the same hardware modules as for the previous designs, except for the simulation computer. In this case, a high performance IBM workstation (RISC 6000/580, 58H, or 590) is used to run the real-time simulations. This design also requires two DSP boards with a total of 4 DSP chips to support three terminal operation and real-time data transfer. This simulator can also incorporate a low cost RISC workstation dedicated to the GUI software, if such an option is specified by the user.

The software modules in this simulator design are the same as used earlier for the GUI and I/O support functions. However, the transients simulation program is a custom designed Real-Time System (RTS). The I/O support software can be enhanced to include the instrument transformer and circuit breaker models.

A Simulator for Combined Open-Loop and Real-Time Operation

This simulator uses exactly the same hardware as the previous RISC-based configurations. The main difference is in the software where both RTS and EMTP can be used to run real-time and open-loop simulations, respectively [22]. This simulator version enables operators to test relays in two modes: open-loop mode with "continuous" replaying capability for test waveforms, and real-time mode capable of carrying out interactive relay testing.

FUTURE NEEDS AND BENEFITS

The modular simulator design was developed having in mind the following future needs and benefits:

- Changing user's goals and experiences
- Emerging applications and testing methodology
- Incremental cost and performance improvements
- Future upgrading and maintaining

The changing user's goals and experiences are always expected in such a new field as the relay testing using digital simulators. It is important to have the modular design that provides for both the required design flexibility and utilization of the previous application experiences to be explored when moving from the goals of relatively simple testing to more elaborate goals of complex relay design and application evaluations.

The emerging applications do require an ability to extend the required performance by simply selecting and adding more complex hardware and software modules. In addition, the testing methodology is going to evolve in the future requiring various performance configurations that should easily be met by selecting the hardware and software modules with the corresponding characteristics.

Most of the simulator users do not have the initial funds required to purchase a full blown digital simulator configuration. At the same time, due to the limited initial user and application experiences, it may not be easy to justify the required investment. The modular design enables tailoring of the cost/performance needs by allowing for future incremental expansion and performance improvements by providing simple design expansion through addition of new modules. In this way, the initial investment is still well utilized.

The future upgrading is an important feature since the computer technology is changing so fast. The modular design enables a simple upgrade of the computer platforms while the basic software is easily ported. This assures a long life cycle of the simulator software. This, in turn, can justify the investments in future software upgrades since all the software is going to be utilized regardless of the hardware updates. At the same time, the experience in maintaining the software and hardware can be fully preserved if only an incremental change is done when the simulator is upgraded.

CONCLUSIONS

Based on the discussion given in the paper, the following can be concluded:

- The modular simulator design concept is feasible.
- Several implementations of the simulators illustrate the capability to meet different cost/performance criteria using the modular design.
- The future needs of changing user goals and experiences as well as emerging applications and testing methodology can be met by the modular design allowing incremental cost and performance improvements as well as providing easy future upgrading and maintaining.

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