Modular Simulators Match Cost and Performance Criteria

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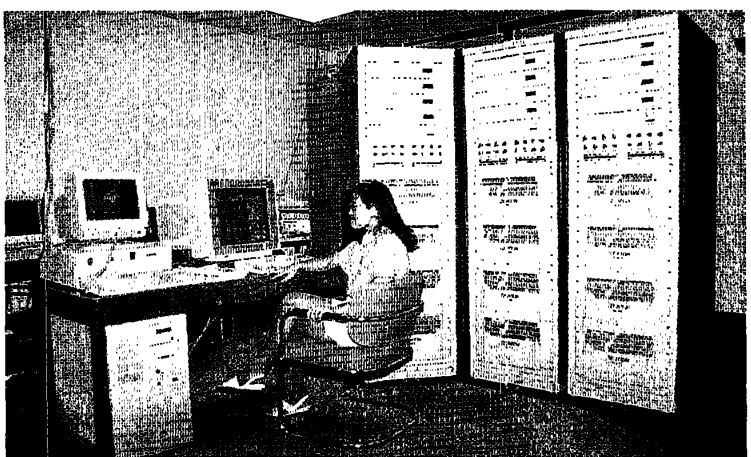
Modular digital simulator configurations range from low-cost single-user, to multiuser environments for open-loop testing and real-time application

Digital power system simulators for protective relay testing were introduced as a concept in the late 1970s with the first designs made available in the early 1980s. Since that time, a variety of digital simulator solutions have been implemented and used by utilities, universities, and relay vendors. 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 input/output (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 article features a new concept for a modular digital simulator design in which a variety of hardware and software modules have been developed and used to configure different simulator solutions.



The digital simulator was designed to make use, where feasible, of low-cost, commercially available computer hardware and system software support. The flexible implementation approach is aimed at meeting specific needs for relay testing and simulator upgrading.

This flexible implementation approach is aimed at meeting specific needs for relay testing and simulator upgrading. It also provides a choice between low and high cost simulator design options, depending on the performance and application requirements. The article focuses on:

- Relay testing requirements leading to classification of the categories of the simulator users
- Basic concept of the modular simulator design
- Various simulator implementation approaches made possible due to the modular design
- Future needs and benefits.

Relay Testing Requirements

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

- User type (goal)
- Relay type (design)
- Study type (methodology).

User Type

The user type is the most difficult category to define, since it may vary from one organization to another. However, the main difference is in the environment in which the user is working: relay vendor, utility, or university. In these environments, the

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goals for relay testing may be quite different, spanning from extensive evaluation of the relay designs undertaken by 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:

- Single user: An assumption is that the single user will execute each task separately, one at a time.
- 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.
- 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.
- Execution of tests: The user has the test files made available in a file system, and only needs to concentrate on an efficient way of performing tests and storing results.
- Analysis of test results: The user needs to access the results in a convenient manner, and must have appropriate tools to analyze both the relay responses and corresponding disturbance waveforms.

Flexible implementation provides a choice between low and high cost simulator design option, depending on the performance and application requirements

Relay Type

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 1.

Table 1. 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)

Study Type

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 shown in Figure 1.

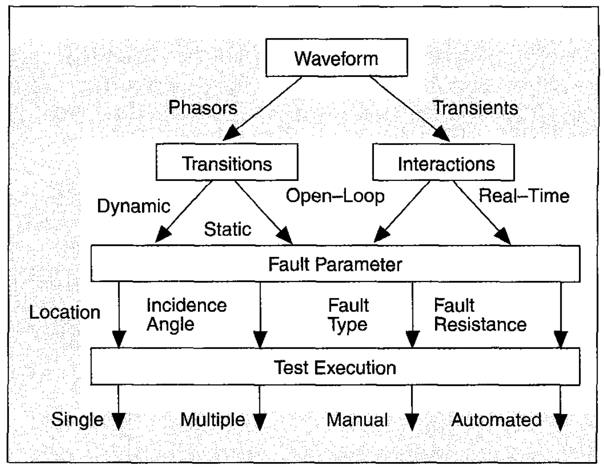

Figure 1. Study type requirements

Modular Simulator Design

In order to meet the variety of 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 is 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. 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, yet meets the requirements in the most suitable way.

Note that this section is intentionally 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.

Incremental improvements may be implemented as users' goals and experiences change and new applications and testing methodology emerge

Hardware Modules

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

Simulation Computer

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.

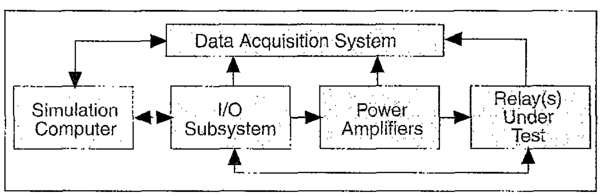

Figure 2. Simulator hardware architecture

The Texas A&M University (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.

I/O Subsystem

The I/O subsystem solution may greatly vary in its complexity depending on the simulator performance requirements. However, some basic characteristics are highly desirable, including 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 with power amplifiers, and standard interface with the 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 design of the I/O subsystem is based on a commercial digital signal processing (DSP) board that serves 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: one-, 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 subsystem is connected by a fast serial data link to the custom I/O boards for analog waveform and contact interfacing.

Power Amplifiers

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

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

Data Acquisition System

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.

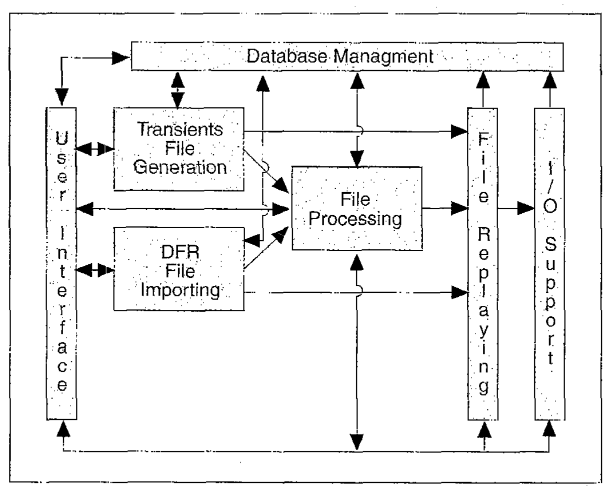

Figure 3. Simulator software architecture

Software Modules

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

Modularity enables the use of various computer platforms that are capable of meeting cost, ease-of-upgrade, and performance requirements

User Interface Module

The user interface module must 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.

An example of the GUI, representing network model and a waveform display, is shown in Figure 4.

Transients File Generation

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 choices of the commercial programs include: 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, as 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.

DFR File Replaying

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 DFR presently on the market. The TAMU design supports COMTRADE file formats.

File Processing

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 design supports the MATLAB signal processing package. This package is widely used, and it is available on virtually all standard computer platforms.

Database management

Database management may be implemented using a simple file system or an elaborate database scheme. A variety of commercial packages are on the market, but 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 design.

Other Modules

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

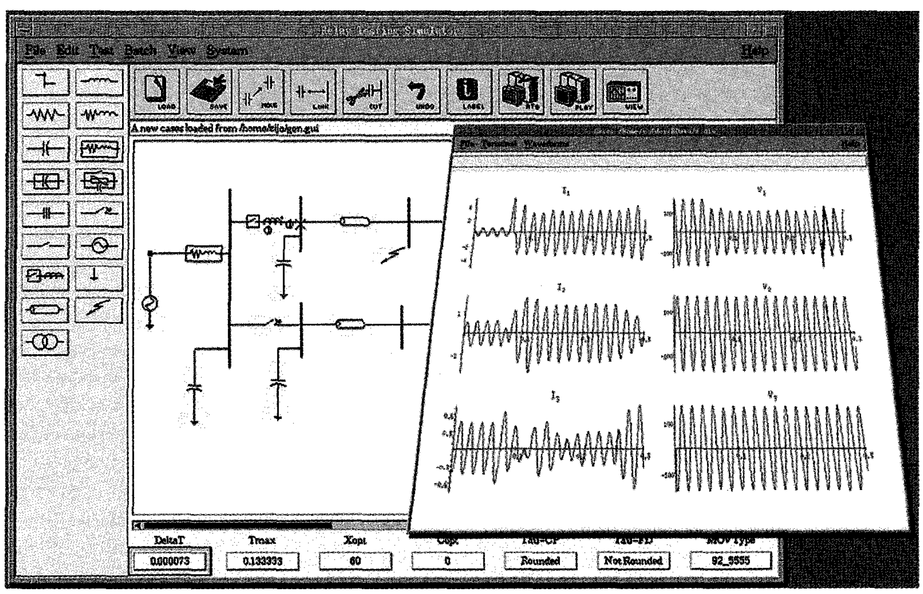

Figure 4. Graphical user interface example

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 design allows for creation of models of instrument transformers and circuit breaker logic that can be located and executed on the DSP board. This resembles the physical location and separation of these components in the power system.

Open-loop mode enables continuous replaying for test waveforms, and real-time mode enables interactive relay testing

Implementation Approaches

The following examples of simulator implementation approaches are based on the use of the modules available in the TAMU designs. Each of these implementation approaches has been developed according to a customer's specifications for a particular simulator configuration.

PC-Based Simulator

The PC-based simulator offers a low-cost hardware solution for the simulation computer. The hardware is shown in Figure 5. 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 one-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 of the simulators. The only difference may be in the amplifiers, which can be selected to meet various output power requirements.

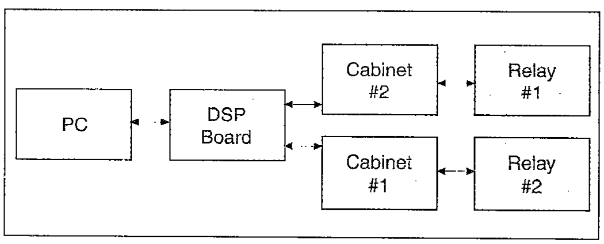

Figure 5. PC-based simulator hardware

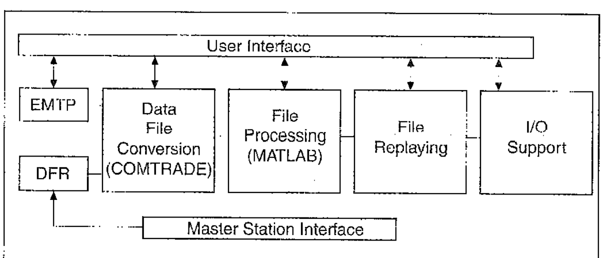

Figure 6. PC-based simulator software

The software modules are shown in Figure 6. 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 setup is provided for viewing, filtering, and editing of the test signals. This simulator has been used extensively for several relaying studies.

RISC-Based Simulator

The RISC-based simulator uses most of the modules developed for the PC-based simulator, and the differences are as follows:

- The IBM RISC machine (RISC 6000/320, 340, 41T, or 250) was selected due to its powerful multiuser, multitasking operating system (AIX)
- Hardware modules include the same I/O cabinet design and DSP board with two DSP chips as used in the PC-based simulator, but some I/O boards were added to interface 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, but some signal analysis functions were added. A more elaborate user interface is provided for both the EMTP solver and the MATLAB shell. 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. 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 four 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. The I/O support software can be enhanced to include the instrument transformer and circuit breaker models.

The design of the I/O subsystem is based on a commercial DSP board that serves as a common interface to selected simulation computers

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, as both RTS and EMTP can be used to run real-time and open-loop simulations, respectively. 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 with the following future needs and benefits in mind:

- Changing user's goals and experiences
- Emerging applications and testing methodology
- Incremental cost and performance improvements
- Ability to upgrade and maintain.

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 a 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 require an ability to extend the required performance by simply selecting and adding more complex hardware and software modules. 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.

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, helps justify 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.

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For Further Reading

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Biography

Mladen Kezunovic received his Dipl. Ing. degree in electrical engineering in 1974, and MS and PhD degrees from the University of Kansas, in electrical engineering in 1977 and 1980, respectively. His industrial experience is with Westinghouse Electric Corporation in the United States and the Energoinvest Company in Sarajevo. His academic experience is with the University of Sarajevo and Washington State University, and he has been with Texas A&M University since 1987, where he is an associate professor. He is a senior member of the IEEE, member of the IEEE Power Systems Relaying Committee (PSRC), member of CIGRE, and a registered professional engineer in Texas. He is the chair of the PSRC Working Group F-8 on Digital Simulator Performance Requirements.