ADVANCED EDUCATION AND TRAINING USING NEW DIGITAL SIMULATOR DESIGNS

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INTRODUCTION

The use of simulators in Power Systems education and training is not new. An example of educating dispatchers using advanced operator training simulators illustrates benefits of this approach [1]. However, the cost of the simulators and their relatively narrow application were prohibitive factors in the past for a wide use in advanced education and training at academia and utilities.

Recently, digital technology has advanced to the point where more versatile simulator applications at an affordable cost could be developed. The increased versatility included improved graphical user interfaces, enhanced power system modeling and simulation capabilities, and an ability to interface the simulator to outside devices providing real-time interaction required for detailed device testing and evaluation. The implementation of these features could be carried out ''h affordable single processor workstations. In some ...stances, depending on the level of complexity, either more powerful parallel processors or very simple PC configurations can be used. As a result, new digital simulator designs at a cost of an order of magnitude less than what was available earlier have been developed, and yet their features and performance have surpassed the old technologies used in analog or hybrid designs.

This paper concentrates on one direction of the digital simulator developments where electromagnetic transients associated with faults and other disturbances can be simulated and studied in great detail. Texas A&M University (TAMU) has had a major simulator development activity for the last ten years. Most recently several digital simulators were implemented and delivered to the industry [2]. The funding for these developments came from EPRI and individual utilities under various research and development contracts [3]. As a result, variety of commercial digital simulator products were developed and continue to be developed [4]. Texas A&M University has inherited most of the hardware and software used in the original simulator developments and with further support from the National Science Foundation (NSF) has implemented advanced teaching and training simulator facilities. Further NSF support is expected in the future to bring the simulator technology into classrooms for both undergraduate and graduate courses as well as for continuing education short courses.

This paper first summarizes the new digital simulator developments. The laboratory facilities at TAMU are described next. Two case studies of the use of new digital simulators in advanced education and training are also discussed. Future trends and conclusions are given at the end.

DIGITAL SIMULATOR DEVELOPMENTS

Main tools for the electromagnetic transient simulations in the past were Transient Network Analyzers (TNAs) that were built as scaled physical models of a power system. In the last twenty years a number of enhancements were made in this area by developing advanced hybrid and digital simulators. However, only in the last few years cost effective and yet very powerful digital real-time simulators were developed and commercially offered [5-7].

Advanced Applications

The new digital simulator developments were aimed at enhancing simulator applications in the power system modeling and simulation, as well as, control device evaluation and testing areas [8]. A typical digital simulator configuration is shown in Figure 1. The simulator can use a variety of electromagnetic transient programs such as EPRI EMTP, ATP, EMTDC, MORGAT, MicroTran, NETOMAC, and ARENE to simulate power system transients associated with faults and other disturbances [8]. In addition, these simulators are equipped with software packages for waveform processing and analysis, database management, user interfaces, and I/O interface control. The simulators also allow interfacing of the software models of various control devices including protective relays, static VAR compensators and voltage controllers, HVDC converters, etc. The simulator interfacing with the outside world provides importing of various files of waveforms recorded in the field by different types of fault recorders and other similar instruments. Likewise, it is possible to convert all digital waveform files into analog signals using D/A interfacing. These signals can be used for testing outside devices connected to the simulator to emulate actual field connections to the power systems.

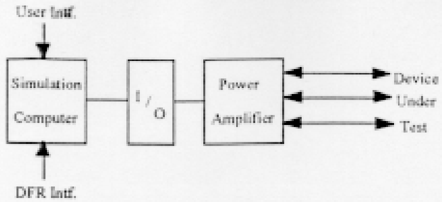

Figure 1. Typical Digital Simulator Configuration

The control output signal generated by the device under test can be taken back into the simulators in real-time to emulate the real-world interactions between the control device and power system.

Advanced Education and Training Requirements

Having the new simulator designs capable of performing emulation of the operation of actual power systems and related controllers, a challenging effort regarding their use in education and training needs to be carried out. Both the students and utility engineers are typically not exposed to the level of detail that a study of electromagnetic transients may require and/or produce. For example, protective relaying is traditionally taught at the level of short circuit study and phasor representation of fault waveforms. The relay operation is studied using the relay operating characteristics as a phasor representation of the operating principles. The utility engineers apply the same knowledge in calculating relay settings and testing relays. The use of electromagnetic transient modeling and simulation to obtain detailed fault transients, utilization of advanced modeling for study of instrument transformers transient behavior, and modeling and testing of the transient behavior of protective relay designs and algorithms are not commonly practiced today. Hence, both education and training in this area have to be extended to include the use of new digital simulator designs in studying and demonstrating related phenomena in more details. In addition, the use of these new simulators in everyday engineering practice has to be learned through training courses.

SIMULATOR BASED LABORATORY FACILITY AT TAMU

Recently, NSF awarded TAMU with an equipment grant to implement a Power Quality Laboratory. This award was aimed at developing a laboratory infrastructure to be used for research, education and training. This laboratory is also enhanced with a full blown digital simulator facility.

Functional Requirements

The laboratory has been designed to allow for a number of application studies related to power system faults and power quality disturbances to be carried out for different purposes and various levels of details such as:

- Power System Modeling. A variety of software packages for modeling of power system transients and other disturbances have been acquired and made available on a number of PCs. An electromagnetic transient program for generation of fault transients and harmonic load flow for study of harmonics are good examples.

- Digital Simulation. A multi-terminal workstation-based digital simulator configuration is implemented. The simulator is equipped with software and hardware enabling study of power system transients and behavior of related control and protection equipment both at the simulation level and through testing of actual devices.

- Programmable Signal Sources. Several high and low power signal sources are acquired. They allow generation of the power quality disturbance signals with a mixed frequency content. Also, generation of 3-phase phasors with varying amplitude and phase characteristics for relay testing is possible.

- Data Recording and Monitoring. A suite of digital instruments for recording and monitoring power system disturbances is acquired. The instruments include PQ Monitors, variety of high performance oscilloscopes and other types of digital multimeters.

- Signal Processing and Analysis. A number of custom software packages that support analysis of data from specific digital recording instrumentation as well as general purpose signal processing tools are available on both PCs and work-stations.

Equipment Arrangement

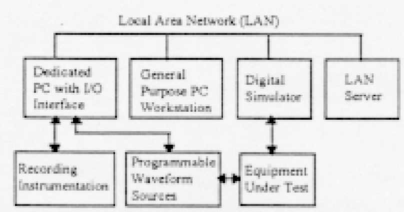

Figure 2. Laboratory Equipment Arrangement

The equipment arrangement is shown in Figure 2. The equipment is organized around certain types of computer and/or instrumentation study environments interconnected via a dedicated local area network (LAN).

.ie following is a brief description of the digital simulator capabilities as a part of the overall equipment arrangement.

- Waveform Generation. This function allows for generation of waveforms associated with fault and other disturbances either through importing of recorded data files or by simulating appropriate power system events. Data conversion routines are made available to convert data files coming from various recording instruments, such as Digital Fault Recorders (DFRs). A standard COMTRADE format is also used [9]. Data files available on the computer facilities anywhere in the laboratory can be downloaded to the simulator workstation.

- Evaluations Using Simulator Environment. This feature enables evaluation of various applications at the level of an algorithm or device behavior to be performed using digital models. An entire relaying system and its performance in a given power system application can be evaluated by simulating faults. Interactions between the power system and relaying system can be simulated as well.

  Testing Using Digital Simulator. This option allows for connection of various control and monitoring devices, such as relays and different types of advanced transient data monitors, to the simulator. A variety of test waveforms can be generated within the simulator and replayed to the devices under test. For special cases, the simulator computer may be used to control programmable signal sources to generate test waveforms with very particular power level and/or waveshape characteristics.

CASE STUDY #1: PROTECTIVE RELAYING

An example aimed at illustrating the use of digital simulators in protective relaying education and training is the performance assessment of transmission line protective relays.

Evaluation of Relaying Models

Understanding of operating and performance characteristics of a relay or relaying scheme is a prerequisite for correct selection and application of a protective relaying design. For example, with an advent of digital technology, a variety of transmission line protective relays are offered on the market. These relays appear, based on their commercial literature and manuals, as having very similar performance characteristics. However, their implementation and digital algorithms are quite different. An intimate understanding of the algorithms and application characteristics may be needed to have a full appreciation for advantages and disadvantages of various designs.

Recent developments of detailed models of digital relay hardware and software enable one to set up a simulation environment where the relaying performance can be evaluated using extensive simulations. Such a simulation environment is shown in Figure 3. Very detailed models of the power system, instrument transformers, relays and circuit breakers can be developed and used to gain understanding of different phenomena associated with protective relay application. One such study performed by TAMU indicated how current transformers (CTs) and capacitor coupling voltage transformers (CCVTs) behave under transient conditions [10, 11]. Yet another study gave a comparison of generic properties of some of the digital transmission line relaying algorithms [12]. Most recently, TAMU has developed a software interfacing scheme where a relay model developed in any high level language can be interfaced to a standard software package for simulation of electromagnetic transients [13]. This approach enables a very detailed simulation of the relaying behavior under a variety of application conditions. A real-time interaction between the power system and a relay can also be simulated with this set-up. An extensive graphical user interface and data base management facilities are developed to facilitate user interaction with the simulation environment.

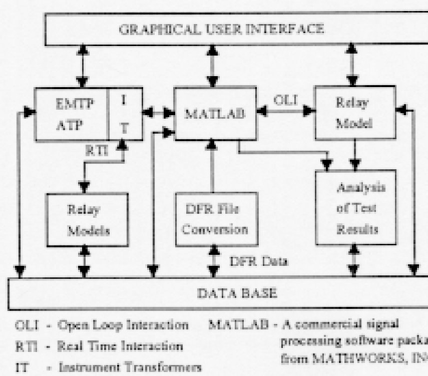

Figure 3. Simulation Environment for Relay Model Evaluation

Evaluation of Relaying Devices and Schemes

Typical tools used in the past to evaluate protective relays and relaying schemes were portable test sets. These test sets are primarily utilized to produce phasors as test signals. Introduction of digital simulators has enabled the use of transient waveforms as test signals. This approach has increased the resemblance of the test signals to the actual fault transients, which has made such testing approach very powerful. Some recent studies completed by TAMU illustrate how both design and application testing of transmission line relays, when performed using digital simulators, can reveal some very interesting features and serious drawbacks of some relay designs [14, 15].

For example, a project aimed at testing relay operating characteristics demonstrated a major discrepancy, under specific test cases, between actual and measured operating characteristic of a distance relay. Figure 4 gives some comparative results obtained by testing a distance relay operating characteristic under a variety of test conditions.

A relay application testing project was even more interesting since some selected distance relays were tested using models from an actual utility application. A complex EMTP model of a power system section of interest was developed and used to generate various types of faults. The transient waveforms caused by the faults were used for testing the relay application. An interesting result showing the operating time properties

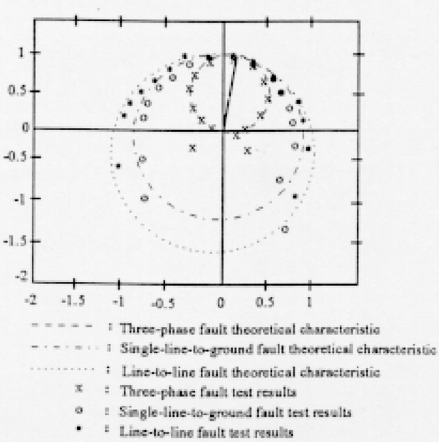

Figure. 4. Difference Between Actual and Measured Operating Characterics

of various relay designs to be quite different, can be observed in Figure 5.

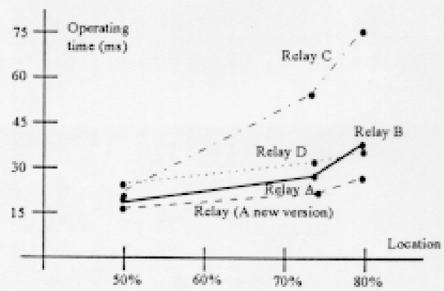

Figure 5. Operating Time Data For Various Distance

CASE STUDY #2: POWER QUALITY

An example aimed at illustrating the use of digital simulators in power quality education and training is the process of detecting, classifying and characterizing the disturbances.

Modeling and Simulation Study

A number of power quality disturbances such as voltage sags and swells, flickers, current harmonic distortion, spikes and transients may occur in the same power system under various fault and/or normal operating conditions. Detailed power system modeling using an electromagnetic transient program can be utilized to represent the power system components and phenomena involved in creating a disturbance of interest. This allows for simulations of various power quality related events. Such an approach produces a very good understanding of the power quality disturbances since their cause is traced to a controlled selection of the power system component models and events. A straight forward example is the use of fault studies to capture the voltage sag problems created by the autoreclosing schemes. In addition, recorded data of such events can also be utilized to "calibrate" simulation studies. The power disturbance waveform assessment is an important educational and training step for developing and understanding the procedures and algorithms for automated detection, classification and characterization of the disturbance.

Digital Algorithms for Power Quality Disturbance Assessment

A typical example of a variety of power quality sturbances is shown in Figure 6.

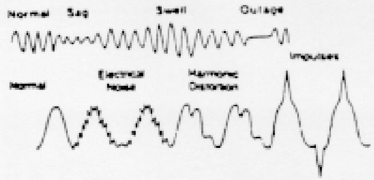

Figure 6. Examples of Power Quality Disturbances

One of the prevailing trends in the industry is to develop digital algorithms and related recording instruments to capture and analyze disturbance waveforms. An automated detection, classification and characterization of power quality disturbance is a process where advanced signal processing and intelligent system techniques may be used [16, 17]. Digital algorithms were developed for this purpose and embedded in a variety of instruments and software packages. Understanding of these algorithms and witnessing their performance characteristics can contribute to the knowledge enhancement.

Digital simulators enable an evaluation of the algorithms at two levels of detail. One level is a simulation study where the algorithm models are interfaced to the power system models. The other level is testing of existing and/or new devices, that contain some of the algorithms, by using digital simulators to generate test waveforms.

FUTURE TRENDS

As discussed in this paper, digital simulators are becoming widely available and much more affordable. Their use in education and training can be summarized as given in Table I.

Table I. Uses of Digital Simulators

GOALS	MEANS
Study of power system phenomena	Modeling of power system components and simulation of events of interest
Study of operating principles of control, monitoring and protection devices	Modeling of digital alogrithms and hardware components of the devices and simulation of their operation
Study of the interaction between the power system and related instrumentation	Modeling of the interactions and simulation of various events and related control scenarious

Future trends in this area will be aimed at enhancing the simulator facilities with a variety of features that will make the education and training more efficient an effective. The following are some of the features that need special attention:

- Graphical User Interfaces. It is obvious that a graphical user interface (GUI) can tremendously simplify the use of the simulators by both instructors and students. In particular the input data entry for power system models and simulated event description can be made very efficient by an appropriate GUI facility. Eventhough availability of a flexible GUI in a commercial software package for power system simulators is an industry trend, further improvements are still needed.

- Database Management. It is well known that most of the power system simulation packages would have its own database management scheme. For the education and training purposes it is extremely important that the data used for typical study cases is made available by providing it in a common database format. This would allow for exchange of data between programs as needed and appropriate.

- Result Presentation and Analysis. The education and training process heavily depends on an ability of both teachers and students to get a quick assessment of the results produced during a simulation study. The existing software packages for power system simulation need to be evaluated with "smart" postprocessing routines capable of automated analysis and visual presentation of test results.

- Integrated Simulation Environment. Dedicated simulation environments aimed at specific studies where several different software packages may be used are not readily available and yet are needed for such study scenarios as protective relaying and power quality. A common GUI, access to a common data base and common approaches for result presentation and analysis are highly desirable.

CONCLUSIONS

As reported in the paper, digital simulators can be utilized for a variety of educational and training activities such as:

- Modeling and simulation studies for understanding of different power system phenomena.

- Evaluation of devices and systems for monitoring, protection and control using digital modeling and simulation.
- Testing of devices and systems using real-time digital simulators

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