AC 2009-1871: APPLICATIONS OF A REAL-TIME DIGITAL SIMULATOR IN POWER-SYSTEM EDUCATION AND RESEARCH

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Applications of Real Time Digital Simulator in Power System Education and Research

Abstract

Students often perceive power engineering as an old or established field. This perception lies in the inability to show abstract concepts and new control technologies using hardware in the classroom or laboratory. New ways to effectively present the novel power system operation and control concepts are needed. Real Time Modeling and Simulation (RTMS) can be used as an approach for enhancing power engineering education and research. RTMS gives students and researchers the opportunity to witness first hand how a moderately large power system behaves and can be used to demonstrate modeling, hardware-in-the-loop (HIL) concepts, system disturbances of various types, and proper recovery actions, as well as to explain complex power system concepts. The Real Time Digital Simulator (RTDS) is an effective tool for modeling and simulation of power and control systems. RTDS hardware employs high-speed DSP (digital signal processor) chips, operating in parallel, to compute simulation results with simulation step sizes as small as two microseconds. This paper discusses projects and activities used in both teaching and research activities to provide exposure of the Real Time Digital Simulator (RTDS) for power system applications.

Introduction

The approach to teaching traditional power system topics needs to be revisited to ensure that the new graduates are equipped with the required knowledge needed in a more competitive industry. Also these new pedagogical approaches need to renew interest in power engineering to match with increasing demands for power engineering graduates in the coming years. Restructuring and deregulation of the power industry, recent blackouts and discussions about smart grids are helping to reinvigorate interest and provide increased attention to careers in power engineering. Investigating new approaches to teach power engineering courses was encouraged by the National Science Foundation (NSF) in 1997 by soliciting educational research projects targeted at developing innovative teaching tools in this area. Several grants from the funding agency were used to enhance undergraduate and graduate studies and research in energy systems[1]. Modeling and simulation emerged as one of the preferred teaching approaches based on several educational research studies done in the literature[2].

A project aimed at developing computer exercises for use in teaching undergraduate and graduate courses in the power engineering area is described in reference[3]. An extensive use of the simulation technology to enhance a student's understanding of the fundamentals including practical solutions has been discussed[4,5]. The authors have pointed out that current power engineering education has been influenced greatly by the difficulty of fully analyzing the large and complex power system, which is relatively inflexible in terms of adopting new technology developments. Power faculty are faced with a difficult choice between presenting small problems that students can grasp versus larger problems based on simulations which exhibit the true nature of the power system, but tend to overwhelm the student. The solution lies in exposing the students to a combined set of problems using modeling and simulation tools to demonstrate and utilize advancements in science and engineering.

The Real Time Digital Simulator (RTDS)[6] is an effective tool for modeling and simulation of power and control systems. RTDS hardware employs high-speed DSP (digital signal processor) chips, operating in parallel, to compute simulation results with simulation step sizes as small as two microseconds. The RTDS software includes a graphical user interface and detailed model library for power and control system components.

A very large system for Korean power system including 320 (3-phase) buses and 90 generators has been modeled and run in real time on the RTDS. The results of the real time electromagnetic transient simulation were validated by comparing to transient stability simulations run using PTI's PSS/E program. The differences in the results were primarily traced to the fact that the electromagnetic transient solution algorithm provides more detail and therefore greater accuracy than the transient stability algorithm[7].

A group of faculty and students are working to develop innovative ways of teaching and research utilizing modeling and simulation power of RTDS. Most of the activities relate to integrated adaptive protective controllers, hardware in the loop techniques, power system monitoring and control as well as power electronics applications utilizing other hardware in the research laboratories. This paper summarizes the use of Real Time Modeling and Simulation (RTMS) to improve teaching and research activities contributing towards improved learning for power engineering students.

Role of RTMS in Teaching Activities

With advancements in computational power, signal processing and physical electronics, the potential of modeling and simulation has been well recognized. The AC network analyzer was one of the first power system simulator in 1960's and was improved several times utilizing better modeling techniques and science advancements[8].

Development of a real-time digital simulation platform to explain design principles for power system controls was presented using controllers[9]. The developed platform utilizes dSPACE controller interfaced with a RTDS and successfully was used in a post-graduate university course.

At our university, the RTDS was used in several graduate courses. In graduate classes on "Power System Operations and Control" and "Power System Stability, Security and Vulnerability", students were given an opportunity to do some of their final project work on the RTDS system. There were 16 graduate students registered in "Power System Operations and Control" offered in the Fall Semester of 2006 and 25 graduate students registered in "Power System Stability, Security and Vulnerability" offered in the Fall Semester of 2007. Additionally, detailed modeling of a power system and an interface with a protection relay using the RTDS were demonstrated in the "Power System Modeling and Simulation" course. Operation of a protective relay for different types of faults and relay modeling were explained in this class using the hardware setup as shown in figure 1. Several students completed projects demonstrating the use of the RTDS system for training and educational activities.

Some of the final group projects for the ‘Power system operation and control’ course, are listed here.

i. Frequency droop characteristics of a generator: Frequency management is a one of the important goals in the control of an electric power system. The frequency droop characteristics have been studied by students through simulation. The practical and theoretical values were compared.
ii. Power system security enhancement using FACTS (Flexible AC Transmission Systems) devices: This project relates to the impact of FACTS devices on the enhancement of power system security. An approach based on sensitivity analysis to enhance power system security was simulated. Sensitivity analysis was done for FACTS device control parameters with respect to reduction in real power flow performance index. The effectiveness of this approach was tested on a 5-bus test system and simulations were performed using the RTDS[10].

Figure 1: Actual hardware setup with RTDS for real time Hardware in the Loop test

In the 'Power system stability, security and vulnerability' course, students have done several group projects and some projects are listed here.

i. Dynamic analysis of voltage stability using Real-Time Digital Simulator: Using a small test system, time domain simulations were done to understand the concept of voltage stability. Here voltages at the generator buses were studied while different types of faults were introduced.
ii. Transient stability analysis using the Real Time Digital Simulator: A five bus power system consisting of synchronous generator and dynamic loads based on classical model of a synchronous generator was developed in the RSCAD and the system transients were studied when a fault occurs on one of the transmission line. The effect of a Power system stabilizer (PSS) on the stability of the system was also analyzed. The outcome of this work was extended to find the critical clearing time which gives the maximum duration before which necessary preventive actions have to be taken for a given system. This project helped students to understand a proof of concept for the Power System Stabilizer (PSS) effect.

Feedback from students on usage of the RTDS to understand the concept of power system operation, control and stability was very positive. One of the student provided the comment, "I found the final project very helpful. It gave me a platform to apply the knowledge I gained from the lectures." These courses were offered for the first time at Mississippi State University, so assessment data was not collected to allow comparison with previously taught classes that did not integrate the RTDS. However anecdotal results from discussions with the students demonstrated a comfort zone with advanced modeling and simulation activities that was not apparent in previous graduate students. Out of the 16 students in "Power System Operations and Control", five chose to continue working with the RTDS as part of the research work, and 10 out of the 25 students in "Power System Stability, Security and Vulnerability" integrated the RTDS in their research work.

Role of RTMS in Research Activities

Electrical equipment manufacturers are developing advanced devices to meet the demand of higher reliability and efficiency. A simulation platform to test these devices under real system constraints before they are installed in an actual power system is extremely helpful. The RTDS allows efficient modeling and simulation of electrical power systems and provides a platform to test the equipment in loop with a modeled power system.

Most of the research activities related to the RTDS relate to closed-loop testing of physical devices such as protection and control equipment. The use of playback simulation, including the possibility of interfacing real hardware and reproducing voltage and current waveforms in real-time is a key advantage of the RTDS. The RTDS can also be used for simulation studies utilizing power electronics, renewable energy and HVDC dynamics[11, 12, 13, 14].

The stability of a Shipboard Power System (SPS) was analyzed using RTDS[15]. When a system becomes physically unstable, divergent or sustained oscillations appear in the system response after it is disturbed. In a further case study, the stability of SPS with different magnitudes of pulsed loads switched into the system was studied. Implementation of neural network based controller for multi-machine power system using RTDS and DSP controller was presented[16] to damp the power oscillations during disturbances. Damping controller design and implementation based on wide area measurements as inputs have been evaluated using digital signal processor and RTDS[17].

From the utility perspective, the RTDS gives several important advantages that were previously not available allowing additional testing of new controllers and investigation of the impact of the new installations[18].

At our university, a group of researchers are working on research projects mainly related to hardware in the loop, relay modeling and controller in the loop using relays, dSPACE and National Instruments controllers. Researchers are also involved in power system monitoring and control test bed development using phasor measurement unit, global positioning system (GPS), data concentrator and measurement sensor devices with RTDS. Some of the research projects are listed here.

i. Hardware in the loop (HIL) with protective relay[19, 20, 21, 22]: Hardware platform was setup for performing closed loop relay operation with a power system test case. At MSU's Power and Energy Research Lab (PERL), some of the relay hardware capabilities include a Schweitzer Engineering Laboratory (SEL) 351 over-current directional relay, 421 distance relay and 487 differential relay.

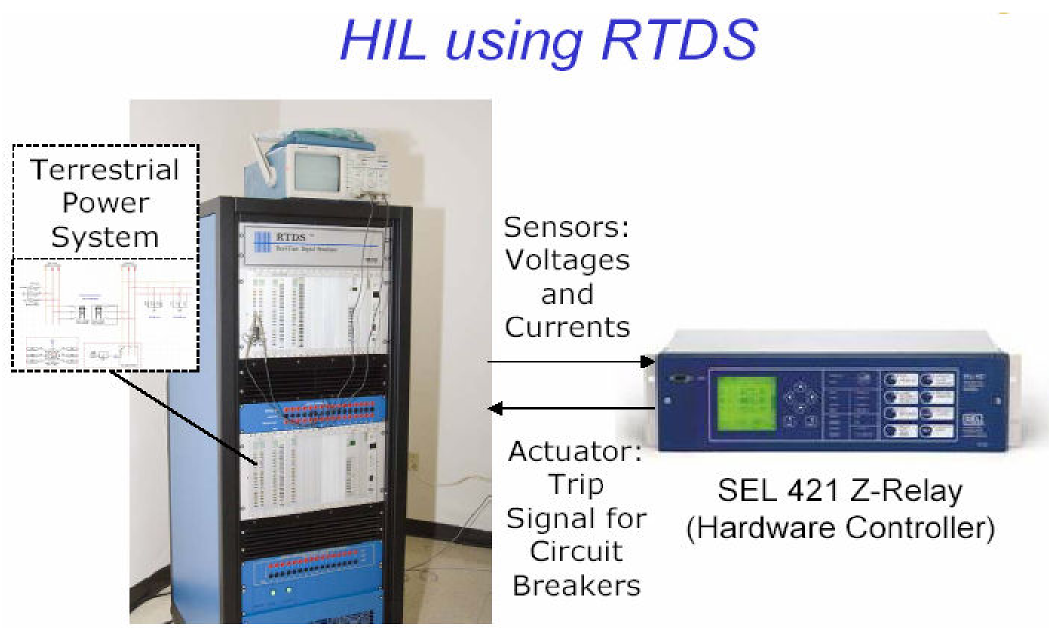

Figure 2: Signal flow between relay and RTDS for HIL setup

Figure 2 shows the data flow for HIL testing with the SEL 421 distance relay using the RTDS. A power system of 14 buses and 3 generators was built in RSCAD. The lower level signals for three phase currents, voltage and ground were given as inputs to SEL relay through the back panel of the RTDS. An output of the SEL relay to open and reclose the breaker for all three phases was given to the RTDS to operate the breaker in the simulated power system. Figure 3 shows the voltages for different lines with single phase fault. A fault was simulated in one of the transmission lines, and operation of relay was observed. This experiment clearly demonstrated the operation of relay using the RTDS simulation and helped students to understand the protection concept.

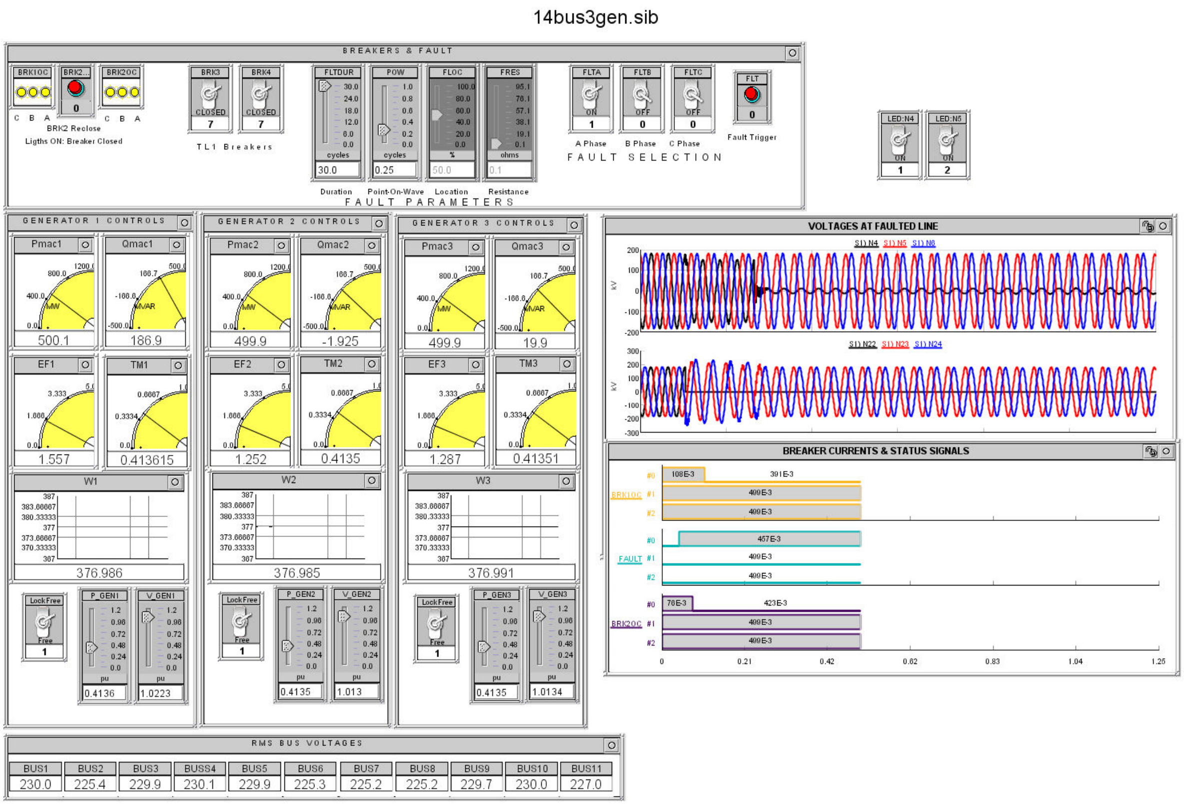

Figure 3: Voltage waveforms with fault on single phase

Figure 4. Setup for closed loop controller testing with RTDS

The hardware setup was also developed utilizing the SEL 351 and SEL 487. Software models were developed for these types of relays to allow simulating multiple relays with one or multiple relays replaced by actual hardware. The Hardware in the Loop (HIL) test provides an opportunity for understanding the behavior and validating the model of physical device. Several tests were performed for HIL and a software model in the loop test. The simulation results of the software model in the loop (SIL) test using the software relay model in RSCAD and the hardware in the loop (HIL) test using the actual relay hardware were compared in order to validate the software relay model in RSCAD.

ii. Interfacing National Instruments and dSPACE controller with RTDS[23, 24]: A detailed software model of an over-current relay was developed using the National Instruments (NI) LabVIEW graphical programming language.

    The performance of the relay model was tested under different fault scenarios with the relay model implemented in NI and dSPACE and the power system model running in real time at RTDS. The results obtained were validated against hardware in the loop (HIL) tests conducted between the relay hardware and power system model in the RTDS. Figure 4 shows the setup for closed loop testing of the designed controller. This setup can be used to verify other control logic developed by researchers at MSU's PERL.

Other than these described research activities, researchers are actively using the RTDS for simulation of DC fault studies[25], an AC/DC system[26] and the research activities related to shipboard power systems[27].

Summary

Helping students visualize the engineering problems related to large complex systems is a pedagogical challenge. By using modeling and simulation tools, engineering faculty can provide educational and research activities that help students get a better feel for real life problems. Several researchers and faculty members have used Real Time Modeling and Simulation (RTMS) as a methodological approach for enhancing power engineering education and research activities. Students can obtain a deeper understanding of concepts and experience behavior of newly designed algorithms or controller actions for a moderately large power system. The RTDS can provide students a hands-on illustrative tool and help them bridge the gap between theory and practical operation of power systems. Several example power system test cases and scenarios have been successfully implemented in both the classroom and research laboraotory and have been summarized here.

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