Hardware-in-the-Loop Simulation of Distance Relay Using RTDS

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Abstract

Modeling and simulation of different conditions are needed for a better design of future Shipboard Power Systems (SPS). Research work at Mississippi State University (MSU) related to SPS protection aims to develop an adaptive protective controller, which can adapt to different protection schemes depending upon requirements. The first step in this research work is to develop the relay models. The developed relay model will be validated against a commercial relay using hardware-in-the-loop (HIL) simulation. HIL provides an opportunity for understanding the behavior and validating model of the physical device. This paper discusses HIL simulation for Schweitzer Engineering Laboratories (SEL) distance relay using the Real Time Digital Simulator (RTDS).

1. INTRODUCTION

Real time simulation is a commonly used tool for studying power system behavior in response to events. This kind of virtual test could uncover potential problems in advance. Corrective measures could then be taken before implementing the algorithm or logic in the real system. In HIL simulation, some of the components of the virtual power system are replaced with physical devices. HIL technology is one of the methods to understand nonlinear and dynamic behaviors of the system and helps in building and validating a model for physical devices. Authors in [1] presented experimental design for hardware-in-the-loop test and HIL test has been used for testing electric machines in [2]. Different approaches and preliminary design for HIL using National Instruments (NI) devices have been discussed in [3]. Real time digital simulator developments at Western Area Power Administration (WAPA) for testing a protective relay in real time have been presented in [4].

Shipboard Power Systems (SPS) have different characteristics from terrestrial power systems. It is important to investigate how best to adapt conventional protection schemes to SPS [5]. HIL provides a platform to test the performance of protection equipment under different conditions. HIL simulation may also be helpful for the designing the protection system for SPS. Real time assessment for SPS protection has been presented in [6], while the simulation of the electric ship in an efficient way has been discussed in [7].

A Real Time Digital Simulator (RTDS) [5] 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 2 microseconds. RTDS software called RSCAD (http://www.rtds.com/softover.htm) includes a graphical user interface and a detailed model library for power and control system components. Researchers at Mississippi State University (MSU) are working to develop adaptive protective controllers for SPS protection, which can adapt to different protection schemes depending upon requirements. The development of relay models for over-current, distance and differential protection is the first step in this process. To validate the performance of developed models, efforts have been made to develop hardware-in-the-loop simulation platform in VTB-RT, NI and RTDS [8,9]. Issues and challenges faced in using RTDS for HIL simulation of SPS have been discussed in [10]. Modeling of impedance relays using RTDS is presented in [11].

This paper describes the hardware-in-the loop testing of a SEL-421 (manufactured by Schweitzer Engineering Laboratories) high-speed transmission protection relay using a simulated power system. MSU researchers successfully connected the SEL 421 relay to an eight-bus power system modeled on the RTDS. Test results obtained for different types of faults are presented. Modeling of the relay is in progress and the performance of the developed relay model will be validated against the test results obtained from HIL test here.

2. POWER SYSTEM TEST CASE IN RSCAD

An eight-bus power system model consisting of the following components is used to test the relay.

1. 230kV AC Source;
2. A 203kV/230kV (Δ-Y) Transformer;
3. 100 km long ‘Traveling Wave’ type Transmission Lines;
4. A 1200MVA, 15kV Synchronous machine
5. Speed Governor and Turbine
6. Static Exciter
7. Circuit Breakers.
8. CTs and PTs

The test system has two parallel transmission lines between source and load as shown in fig.1.

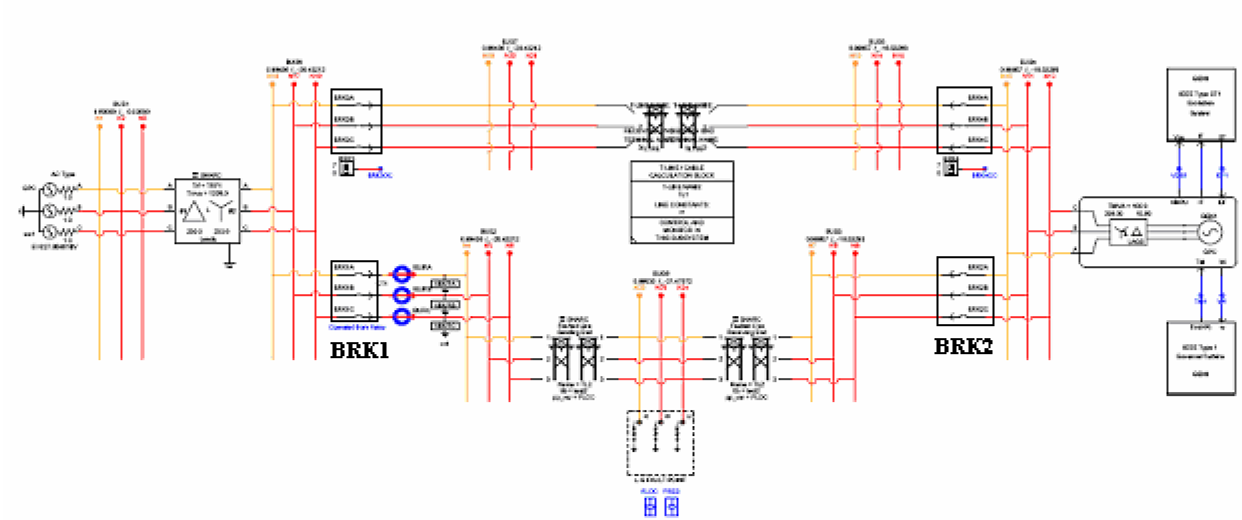

Figure 1. 8-bus power system test case.

Breaker BRK1 is controlled by the physical SEL 421 relay, and breaker BRK2 is controlled by the logic designed in software. The CT and PT were modeled in detail to reflect real system characteristics.

3. SEL –421 DISTANCE RELAY

The SEL-421 is a high-speed transmission line protective relay that includes single-pole tripping, three-pole tripping, reclosing with synchronism check, circuit breaker monitoring, circuit breaker failure protection, and series-compensated line protection logic.

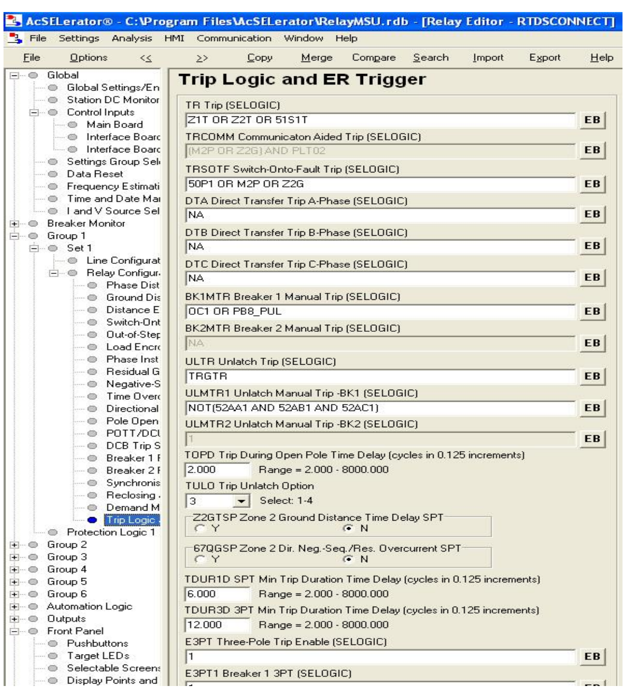

Figure 2. ACSELERATOR settings for SEL 421

Settings for the SEL-421 relay can be set based on power system characteristics using the ACSELERATOR software as shown in fig. 2. [12]

4. HARDWARE SETUP AND CONTROL LOGIC

Fig. 3 shows the interfaced signals between the relay and the RTDS. The relay senses the voltages and currents from the RTDS system, and in case of any fault, it sends out the trip and reclose signals to the simulated circuit breakers in the power system.

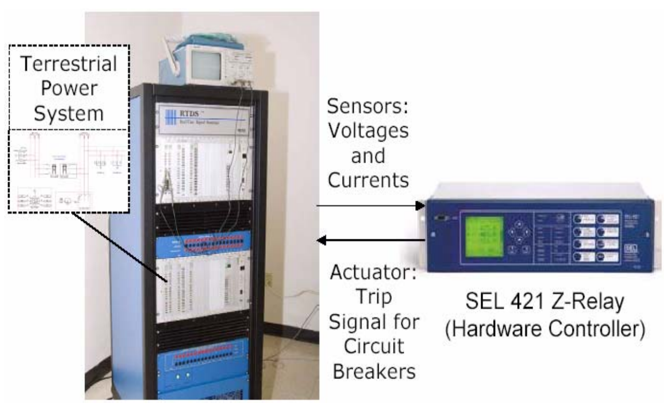

Figure 3. HIL setup using RTDS for SEL 421

Fig. 4 shows how simulated voltage and current signals are sent to D/A converters on the RTDS. The analog signals are then connected to the relay's inputs. SEL relays can be tested with low-level signals or high-level signals. RTDS has the ability to be directly connected to the relay using a low-level signal. An amplifier can be used, if the relay needs to be tested with a high-level signal. In this research, low-level signals were used to interface with the relay. Trip and reclose signals from the relay are interfaced to the

RTDS via digital input ports. Fig. 5 shows how the digital input signals are interfaced in the simulation.

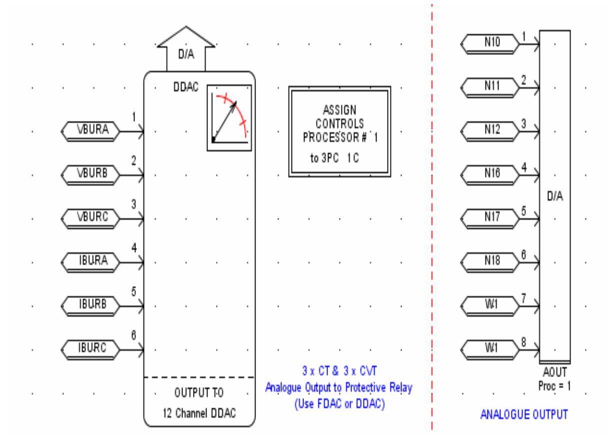

Figure 4. Analog output from power system to relay

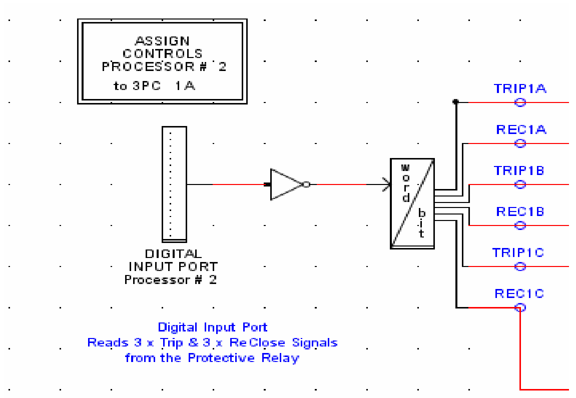

Figure 5. Digital signal from relay to power system

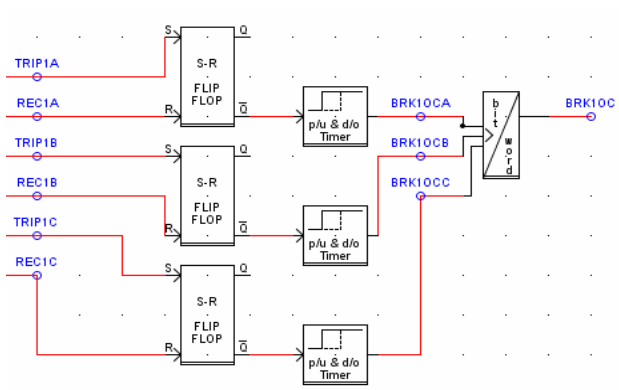

Figure 6. BRK1 control logic

Breaker (BRK1) is directly controlled by the signal received from the physical relay for each phase. Control logic to operate the breaker based on signals from the relay is shown in fig. 6. Figure 7 shows fault control logic to simulate the different types of faults. For a single-phase line to ground fault, BRK1 and BRK 2 should open and reclose once the fault clears automatically for each phase. In the case of a two-phase line to ground fault, all 3 phases of BRK1 and BRK2 should open but should not reclose automatically even after the fault clears.

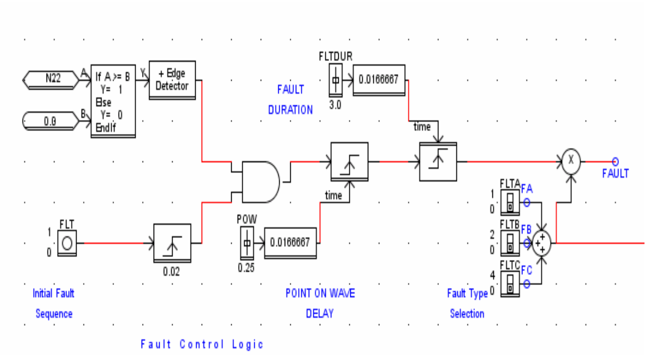

Figure 7. Fault control logic for eight-bus power system

5. SIMULATION RESULTS

Single phase line to ground and two-phase line to ground fault were simulated at a 50% distance on the transmission line in the eight-bus test case. Simulation results obtained for these faults on different phase have been presented here. Simulation results show expected results and successful operation of commercial relay. These results will be used to validate the developed relay model in future research work. Figure 8 shows the voltage, current waveforms and breaker status without any fault. The simulation results show that 'FAULT' signal is equal to 0, which means no fault at this time and the breakers BRK1OC (BRK1) and BRK2OC (BRK2) statuses are equal to 7, which is "111" in the binary form. The first bit of binary form stands for the breaker status for phase C, the second one for phase B and the third one for phase A. "1" means that the breaker is closed, and "0" means open. Therefore, for no fault, all breakers are closed.

Simulation results for single-phase fault on 'phase A' are shown in fig. 9. Current on 'phase A' becomes high when the fault is initiated and becomes zero when the relay operates and the breaker opens. In this case the value of the "FAULT" signal is equal to 1. The breaker BRK1OC would open about 1.7 cycles after the fault, and the breaker BRK2OC would open after approximately two cycles after the fault. Figures 10 and 11 show similar results for a single-phase fault on 'phase B' and 'phase C'. The transient response in case of two-phase line to ground fault is shown in fig. 12. Fault on 'phase A and phase B' to ground was simulated. Relay signals open the breakers and the current becomes zero for all 3 phases. The breakers will not reclose until the manual reclose button is pressed. Simulation results for faults on 'phase A and phase C' to ground and also 'phase B and phase C' to ground were obtained in a similar manner but have not been shown here due to space limitation in paper.

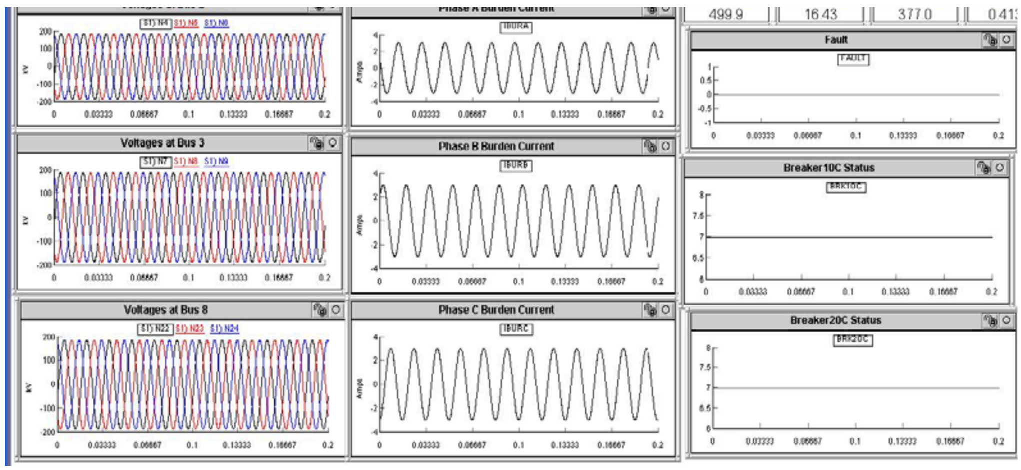

Figure 8. Power system without fault

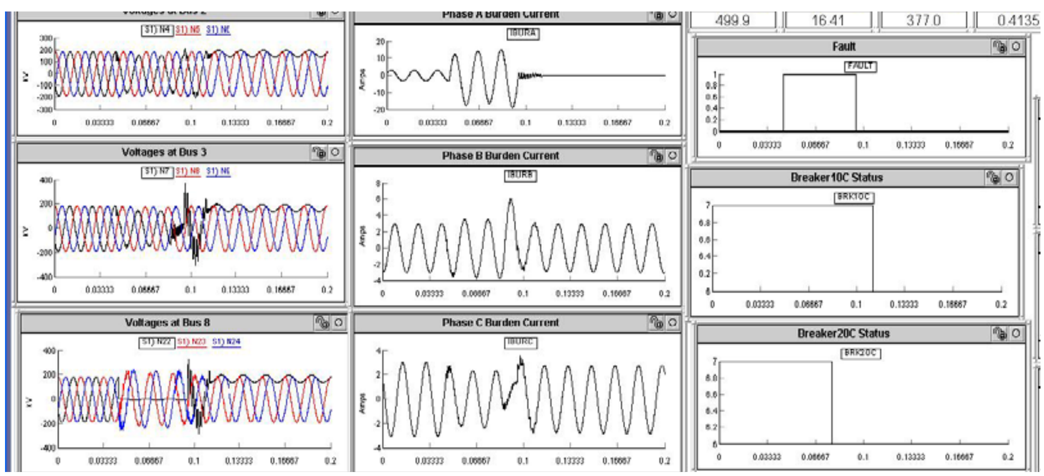

Figure 9. Single-phase fault on phase A

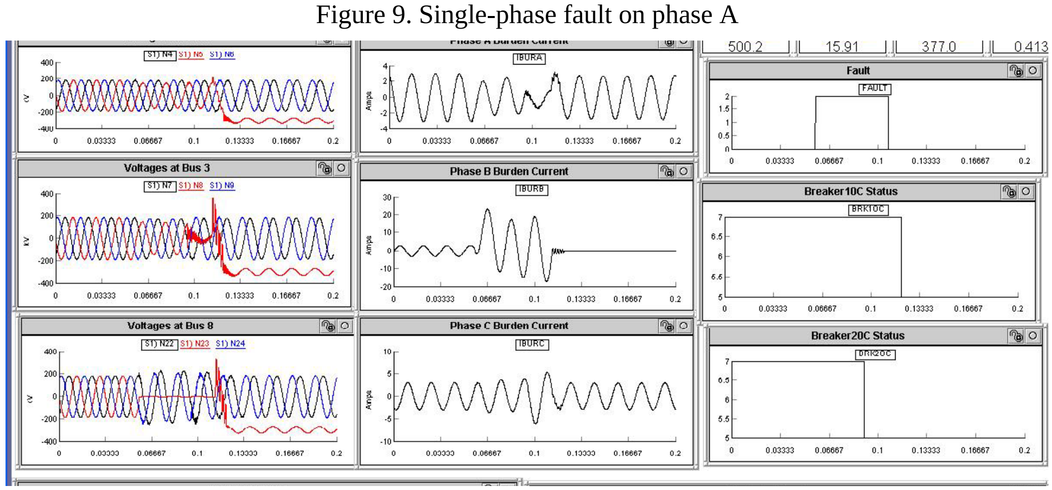

Figure 10. Single-phase fault on phase B

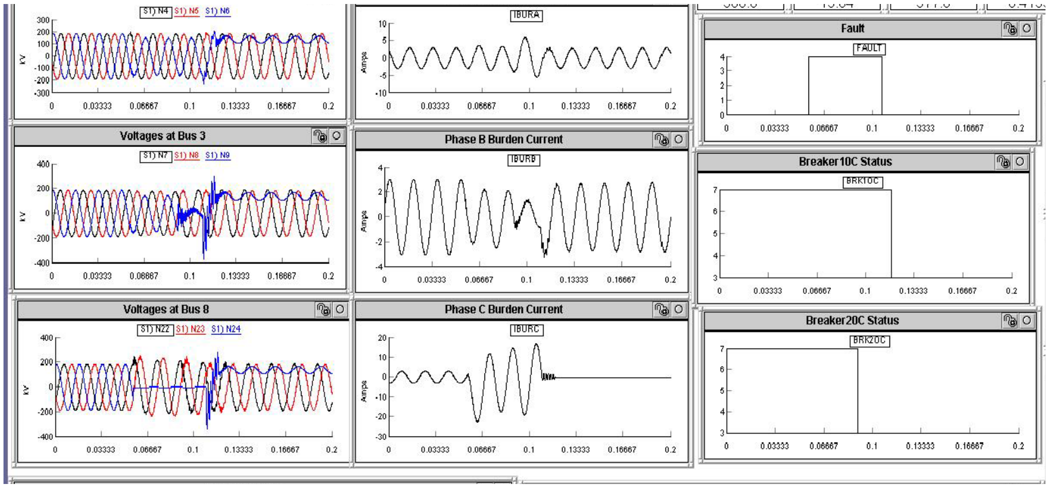

Figure 11. Single-phase fault on phase C

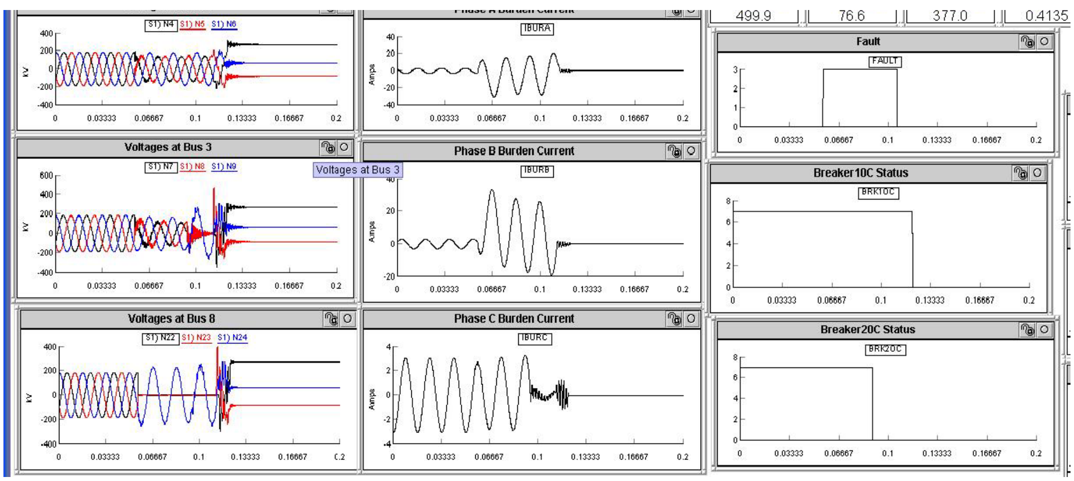

Figure 12. Two-phase fault on phase A and phase B

6. SUMMARY

Hardware-in-the-loop simulation to test a SEL 421 distance relay has been presented in this paper. Hardware setup, control logic and power system test case development have been discussed in detail. Simulation results for single-phase line to ground and two-phase line to ground faults have been presented. Hardware-in-the-loop tests for differential relay and over-current relay using RTDS are part of the current research activities at Mississippi State University (MSU) in an effort to develop an adaptive protective relay for Shipboard Power System (SPS). Modeling of different types of relays is in progress.

7. ACKNOWLEDGEMENT

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Biography

Chenfeng Zhang has been pursuing her master's degree since 2006 in Electrical and Computer Engineering at Mississippi State University (MSU). She received BSEE from Chengdu University of Technology and MSEE from University of Electronic and Science of Technology in China. Her fields of interest include modeling and simulation and protection in power systems.

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Anurag K. Srivastava received his Ph.D. degree from Illinois Institute of Technology (IIT), Chicago, in 2005, M. Tech. from Institute of Technology, India in 1999 and B. Tech. in Electrical Engineering from Harcourt Butler Technological Institute, India in 1997. He is working as Assistant research professor at Mississippi State University since September 2005. Before that, he worked as research assistant and teaching assistant at IIT, Chicago, USA and as Senior Research Associate at Electrical Engineering Department at the Indian Institute of Technology, Kanpur, India as well as Research Fellow at Asian Institute of Technology, Bangkok, Thailand. His research interest includes real time simulation, power system modeling, power system security, power system deregulation and artificial intelligent application in power system. Dr. Srivastava is member of IEEE, IET, Power Engineering Society, Sigma Xi and Eta Kappa Nu. He is recipient of several awards and serves as reviewer for IEEE Transactions, international journals and conferences.

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Rudi Wierckx received B.Sc (EE) 1983 and M.Sc (EE) 1985 degrees from the University of Manitoba. Between 1985 and 1993, he was employed by the Manitoba HVDC Research Center, working on the development of the Real-Time Digital Simulator (RTDS). In 1993 he left the Research Center to form RTDS Technologies Inc. and is currently a director of that company.